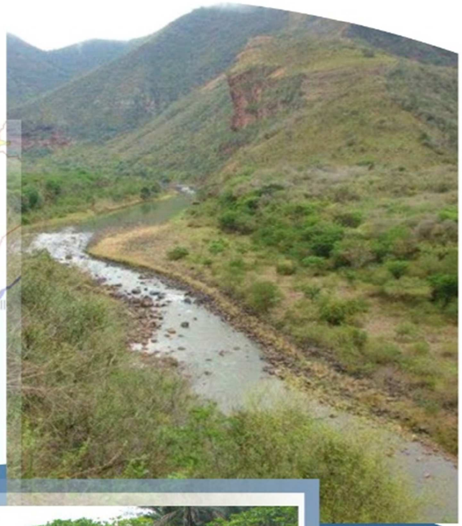
REPORT NO: RDM/WMA11/00/CON/CLA/0714

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 2A:
SUPPORTING INFORMATION ON THE DETERMINATION OF WATER RESOURCE CLASSES - MVOTI (U4) ESTUARY EWR AND ECOLOGICAL CONSEQUENCES OF OPERATIONAL SCENARIOS



DECEMBER 2014

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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 WMA

VOLUME 2A: SUPPORTING INFORMATION ON THE DETERMINATION OF WATER RESOURCE CLASSES – MVOTI (U4) ESTUARY EWR AND ECOLOGICAL CONSEQUENCES OF OPERATIONAL SCENARIOS

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

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6	Report Number: RDM/WMA11/00/CON/CLA/0212	Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: **BHNR**
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10	Report Number: RDM/WMA11/00/CON/CLA/0715	Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: **Implementation Report**
11	Report Number: RDM/WMA11/00/CON/CLA/0815	Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: **Main Report**
12	Report Number: RDM/WMA11/00/CON/CLA/0116	Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: **Closing Report**

DEPARTMENT OF WATER 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 2A: SUPPORTING INFORMATION ON THE DETERMINATION OF WATER RESOURCE CLASSES – MVOTI (U4) ESTUARY EWR AND ECOLOGICAL CONSEQUENCES OF OPERATIONAL SCENARIOS

Approved for RFA by:

……………………………………..	**……………………………………..**
Delana Louw Project Manager	Date

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REPORT SCHEDULE

Version	Date
First draft	December 2014
Final	April 2015

EXECUTIVE SUMMARY

STUDY AREA

The mouth of the Mvoti River is approximately 80 km north of Durban, near the small town of Blythedale. The Mvoti Estuary is classified as a *"River mouth"* type estuary as the marine influence upstream of the inlet is limited for a most of the year. 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°23'31.08"S, 31°20'4.31"E
Upstream boundary:	29°22'12.68"S 31°18'15.83"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

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

PRESENT ECOLOGICAL STATUS

The Mvoti Estuary in its present state is estimated to be 55% similar to natural condition, which translates into a Present Ecological State (PES) of D Category. The PES is mostly attributed to the following factors:

- The high organic load in effluent from the SAPPI Stanger mill just upstream of the estuary head, which contribute to regular low oxygen events (< 4 mg/l);
- Increased nutrient input as a result of poor catchment practises, causing excessive growth of reeds and aquatic invasive plants in intertidal and subtidal habitats;
- Significant loss of habitat in the Estuary Functional Zone as a result of sugarcane farming;
- Changes in sediment structure due to sand mining; and
- The loss of resetting floods which otherwise assist in removing excess vegetation growth from intertidal, subtidal and supratidal areas (important bird habitat).

The highest priority is to address the quality of influent water. Water quality degradation, resulting from the high organic load in the SAPPI discharge and poor catchment management, was found to be the most important non-flow-related factor that influenced the health of the estuary. The regular occurrence of low oxygen events in the estuary reduced invertebrate abundance to 25% of Reference Conditions and prevents the system from functioning as a fish nursery, which in turn reduces food availability to birds. Excess nutrients in the inflowing river water increased plant growth and in so doing contributed to loss of open intertidal, subtidal and riparian habitat. This has had knock-on biological consequences (e.g. loss of sandbanks that were previously important bird habitats).

Another key non-flow related pressure was the loss of riparian area due to sugarcane farming in the Estuary Functional Zone, causing a loss of habitat and 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. 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 (DWA, 2014), apart from functional importance, which was scored by the specialists in the workshop. The Mvoti Estuary is rated as “Important”.

Even though the Mvoti Estuary tends to recruit high numbers of estuarine associated fish in spring and summer, it is of low nursery value as river flow is relatively high (for its size) for most of the year and there are few backwater areas for fish to take refuge in from the main currents. However the Mvoti Estuary is an important movement corridor for eels. This places significance on ecological flow and water quality requirements for the estuary (and the river).

In the 1980s Mvoti Estuary was noted for its high species richness of waterbirds, as well as a high density of waterbirds relative to the length of available shoreline (Ryan *et al.,* 1986). The Mvoti Estuary is classified as a sub-regional Important Bird Area (IBA; Barnes, 1998). Large numbers of terns, up to 10 000 individual birds, have been recorded regularly roosting at the estuary on expansive and exposed islands in the main water channel. Another key waterbird species is the Collared Pratincole, a Red Data species (Barnes, 2000), which has been found breeding on the exposed sandbanks in the river. Other noteworthy Red Data waterbirds recorded at the estuary include African Marsh Harrier, Woolly-necked Stork and Chestnut-banded Plover. Mvoti Estuary has also boasted the regular presence of a large number of vagrant waterbirds over the years, making it a popular spot for bird-watching and bird-watchers. A recent investigation into the current IBA status of the Mvoti Estuary (Theron, 2012), however, reported that the aquatic avifauna of the site has deteriorated sharply since about the mid-2000s and recommended that the site be de-listed as an IBA. Since that time, large numbers of terns no longer roost at the estuary and nor do Collared Pratincoles nest there. The aquatic avifauna of the estuary is now a mere remnant of what it once was and the site is no longer attractive as a bird-watching locality.

The functional importance of Mvoti Estuary is very high for the nearshore marine environment. It is one of five key systems (Mfolozi, Mvoti, uMngeni, uMkhomazi, Mzimkulu) that supply sediment, nutrients and detritus to the coasts. The sediment load from the Mvoti is especially important, as it is habitat forming and plays an important role in maintaining the beaches and nearshore habitat along this coast. The potentially severe impact of dam development on the nearshore marine environment was not assessed as part of this study, but should be evaluated to ensure that all ecological processes and related ecosystem services (e.g. beaches, coastal buffers against storms, the KwaZulu-Natal prawn fishery) are considered.

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 degree of protection (or desired protection) for 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 (based on complementarity)		
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	The remaining estuaries can be allowed to remain in a D category

* Best Attainable State

The PES for the Mvoti Estuary is a D. The Mvoti Estuary is rated as “Important” from a biodiversity perspective and should therefore be in a C Category.

The estuary also forms part of the core set of priority estuaries in need of protection to achieve biodiversity targets defined in the National Estuaries Biodiversity Plan and the National Biodiversity Assessment 2011 (Turpie *et al*., 2013, Van Niekerk and Turpie, 2012).

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

ECOLOGICAL CATEGORIES ASSOCIATED WITH SCENARIOS

The individual Estuary Health Index (EHI) scores, as well as the corresponding ecological category under different scenarios are provided below. The estuary is currently in a D Category. Under Scenario Group A (MV21, 22 and 41) and C (MV42 and 43) the Mvoti Estuary will improve slightly in health, but is expected to remain in a D Category as a result of reduced frequency and duration of mouth closure from Reference. Under Scenario Group B (MV3) the estuary will deteriorate further in health (by about 5%) as a result of an increase in closed mouth conditions. Under Scenario Group D (MV5) the estuary will deteriorate significantly to a D/E Category as a result of even greater mouth closure and a further decline in water quality conditions.

None of the Scenarios Groups A to D achieved the REC for the Mvoti Estuary. Therefore a sensitivity test, Scenario Group E, was conducted. Scenario Group E is based on the freshwater inflow simulated for Scenario Group A (MV 21, MV22 and MV41) in conjunction with the following non-flow related management interventions:

- Improvement of oxygen levels in the estuary, through for example, removal of the high organic content from the SAPPI Stanger effluent;
- Reduce the nutrient input from the catchment by 20% to control growth of reeds and aquatic invasive plants; and
- 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.

Scenario Group E (MV21, 22 and 41 minus Non-flow related impacts) achieved the REC of a C. Therefore, the Present State flows, Scenario Group A (MV 21, 22 and 41) and Scenario Group C (MV42 and MV43) plus management interventions as described above will achieve the REC.

EHI score and corresponding Ecological Categories under the different runoff scenarios

Variable scores	Weight	Scenario Group						
		Present	A (MV 21, 22, 41)	B (MV3)	C (MV42, 43)	D (MV5)	E (MV21, 22, 41 – Non-flow)	Conf
Hydrology	25	53.4	59	42	55	33	59	M
Hydrodynamics	25	95	99	95	99	70	99	H
Water quality	25	58.4	59	54	59	48	65	M
Physical habitat	25	73	73	69	70	53	73	M
Habitat health		**70**	**72**	**65**	**71**	**51**	**74**	
Microalgae	20	80	80	65	80	50	85	M
Macrophytes	20	32	33	33	33	25	50	M
Invertebrates	20	25	25	15	25	10	60	L
Fish	20	55	55	55	55	50	75	M
Birds	20	10	10	10	10	5	45	H
Biotic health		**40**	**41**	**36**	**14**	**28**	**63**	
ESTUARY HEALTH		**55**	**56**	**50**	**56**	**39**	**68**	
ECOLOGICAL STATUS		**D**	**D**	**D**	**D**	**D/E**	**C**	

* Confidence level: M - Medium, H - High

ECOLOGICAL FLOW REQUIREMENTS

From an ecological perspective, it is recommended that the estuary improves to a C REC from its current D Ecological Category. The REC could be achieved either by providing the present day flows with management interventions, or providing the scenarios (Scenario Group A or C) with the same management interventions. **Scenario Group A or C both include the development of a large dam. It should be noted that this scenario recommendations do not take cognisance of the potential detrimental impact further flow reduction (and related sediment fluxes) to the nearshore marine environment will be. It is recommended that these impacts are investigated further if the dam development realises.**

CONFIDENCE

Confidence levels were medium for most of the abiotic components. The biotic components had sufficient data to yield medium to high confidence assessments. The overall confidence of the study was MEDIUM to reflect the confidence in the drivers as the key components

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ACRONYMS AND ABBREVIATIONS

BAS	Best Attainable State
BOD	Biological Oxygen Demand
Conf	Confidence
CSIR	Centre of Scientific and Industrial Research
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphate
DRS	Dissolved Reactive Silicate
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EC	Ecological Category
EHI	Estuarine Health Index
EIS	Estuary Importance Score
EWR	Ecological Water Requirement
H	High
H	High
IBA	Important Bird Area
KZN	KwaZulu Natal
L	Low
M	Medium
MAR	Mean Annual Runoff
MPB	microphytobenthos
MRDP	Mvoti River Development Project
MSL	Mean Sea Level
NBA	National Biodiversity Assessment
NWA	National Water Act (1998)
PES	Present Ecological Status
ppt	Parts per thousand
PSU	Practical Salinity Units
REC	Recommended Ecological Category
RQO	Resource Quality Objectives
SA	South Africa
TPC	Thresholds of potential concern
WMA	Water Management Area
WRYM	Water Resources Yield Model
WWTW	Waste Water Treatment Work

1 INTRODUCTION

1.1 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 (i.e. desired state), recommended Ecological Reserve (i.e. flow allocation to achieve the desired state) and recommended Resource Quality Objectives for a resource on the basis of its present health status and its ecological importance. The approach follows a generic methodology which can be carried out at different levels of effort (e.g. rapid, intermediate or comprehensive). The official method for estuaries (Version 2) is documented in DWA (2008). In 2013, a Version 3 of the method was published as part of a Water Research Commission study (Turpie *et al*., 2012). The study reported upon in this document was initiated in 2012 and Version 2 of the methodology (DWA 2008) is therefore applied, but with consideration of obvious improvements proposed in Version 3 for the evaluation of abiotic processes such as water quality (Turpie *et al*., 2012). Currently, the official suite of “Preliminary Reserve Methods” for estuaries does not include a desktop assessment method. However, a desktop approach for assessing estuary health in data poor environments was recently applied successfully in South Africa’s 2012 **National Biodiversity Assessment** (Van Niekerk and Turpie, 2012). This method has since been refined in a Water Research Commission study (Van Niekerk *et al*., in prep) and was also applied in this Mvoti to Umzimkulu WMA study, where considered appropriate.

This report presented the EcoClassification of the Mvoti Estuary that included a field measurement programme and specialists reports.

The generic steps of the official “Ecological Reserve Method” for estuaries were applied as follows:
Step 1: Initiate study defining the study area, project team and level of study (confirmed in the **inception report** of this study)
Step 2: Delineate the geographical boundaries of the resource units (confirmed in the **delineation report** of this study)
Step 3a: Determine the **Present Ecological Status** (PES) of resource health (water quantity, water quality, habitat and biota) assessed in terms of the degree of similarity to the reference condition (referring to natural, unimpacted characteristics of a water resource, and must represent a stable baseline based on expert judgement in conjunction with local knowledge and historical data). An Estuarine Health Index (EHI) is used to evaluate the current condition of the estuary (Table 1.1).

Table 1.1 Estuarine Health Index scoring system

Variable	Score	Weight	Weighted Score
Hydrology	…	25	…
Hydrodynamics and mouth condition	…	25	…
Water quality	…	25	…
Physical habitat alteration	…	25	…
Habitat health score			**…**
Microalgae	…	20	…
Macrophytes	…	20	…

Variable	Score	Weight	Weighted Score
Invertebrates	…	20	…
Fish	…	20	…
Birds	…	20	…
Biotic health score			**…**
ESTUARY HEALTH SCORE Mean (Habitat health, Biological health)			**…**

In the case of this assessment the EHI scoring of the various variables is based on a review of historical data, as well as data collected during a field monitoring programme in 2013 (refer to Appendices for specialist reports).

The estuarine health score is translated into one of six ecological classes provide below in Table 1.2.

Table 1.2 Translation of EHI scores into ecological classes

EHI Score	PES	General description
91 – 100	A	Unmodified, or approximates natural condition; the natural abiotic template should not be modified. The characteristics of the resource should be determined by unmodifed natural disturbance regimes. There should be no human induced risks to the abiotic and biotic maintenance of the resource. The supply capacity of the resource will not be used
76 – 90	B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged. Only a small risk of modifyng the natural abiotic template and exceeding the resource base should not be allowed. Although the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a very limited number of localities may be slightly higher than expected under natural conditions, the resilience and adaptability of biota must not be compromised. The impact of acute disturbances must be totally mitigated by the presence of sufficient refuge areas.
61 – 75	C	Moderately modified. A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the wellbeing and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least partly be mitigated by the presence of sufficient refuge areas.
41 – 60	D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred. Large risk of modifying the abiotic template and exceeding the resource base may be allowed. Risk to the well-being and survival of intolerant biota depending on (the nature of the disturbance) may be allowed to generally increase substantially with resulting low abundances and frequency of occurrence, and a reduction of resilience and adaptability at a large number of localities. However, the associated increase in the abundance of tolerant species must not be allowed to assume pest proportions. The impact of local and acute disturbances must at least to some extent be mitigated by refuge areas.
21 – 40	E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive
0 – 20	F	Critically modified. Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible

Step 3b: Determine the **Estuary Importance Score (EIS)** that takes account the size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (Table 1.3 and Table 1.4).

Table 1.3 Estuary Importance scoring system

Criterion	Score	Weight	Weighted Score
Estuary Size	…	15	**…**
Zonal Rarity Type	…	10	**…**
Habitat Diversity	…	25	**…**
Biodiversity Importance	…	25	**…**
Functional Importance	…	25	**…**
Weighted Estuary Importance Score			**…**

Table 1.4 Estuarine Importance rating system

EIS	Importance rating
81 – 100	Highly important
61 – 80	Important
0 – 60	Of low to average importance

Step 3c: Set the **Recommended Ecological Category (REC)** which is derived from the PES and EIS (or the protection status allocated to a specific estuary) following the guidelines listed in Table 1.5.

Table 1.5 Guidelines to assign REC based on protection status and importance and PES of an estuary

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 (based on complementarity)		
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	The remaining estuaries can be allowed to remain in a D category

* Best Attainable State

An estuary cannot be allocated an REC below a category “D”. Therefore systems with a PES in categories ‘E’ or ‘F’ needs to be managed towards achieving at least a REC of “D”.

Step 4: **Quantify the ecological consequences of various runoff scenarios** (including proposed operational scenarios) where the predicted future condition of the estuary is assessed under each scenario. As with the determination of the PES, the EHI is used to assess the predicted condition in terms of the degree of similarity to the reference condition.

Step 5: Quantify the (recommended) **Ecological Water Requirements** (EWR) which represent the lowest flow scenario that will maintain the resource in the REC.

Step 6: Estimate (recommended) **Resource Quality Objectives (Ecological Specification)** for the recommended REC, as well as future **monitoring requirements** to improve the confidence of the EWR.

1.2 INTEGRATED STEPS APPLIED IN THIS STUDY

The integrated steps for the National Water Classification System, the Reserve and Resource Quality Objectives (RQOs) are supplied in Table 1.6.

Table 1.6 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 goods, services and attributes
4	**Identification and evaluation of scenarios within the integrated water resource management process.**
5	Develop draft Water Resource Classes and test with stakeholders.
6	Develop draft RQOs and numerical limits.
7	Gazette and implement the class configuration and RQOs.

This report forms ***part*** of the outcomes of Step 4 (highlighted above) within the integrated approach (DWA, 2012). The objective of this task was to provide the scenario analysis, assumptions and results and document the consequences of the scenarios for the various components under Task D4 which are provided as seven report volumes under Report 8 (Table 1.2). All the report volumes apart from 8.7 are supporting information that feeds into Report 8.7. This report will integrate all this information to derive Water Resource Classes for the various scenarios.

Table 1.7 The different report volumes which document the consequences of the scenarios for the various components

8	Operational Scenario and Management Class report volumes
	Report title
8.1	Volume 1: Supporting Information on the Determination of Water Resource Classes – River Ecological Consequences of Operational Scenarios.
8.2	Volume 2: Supporting Information on the Determination of Water Resource Classes - Estuary Ecological Consequences of Operational Scenarios
8.3	Volume 3: Supporting Information on the Determination of Water Resource Classes – Estuary specialist appendices (available electronically only)
8.4	Volume 4: Supporting Information on the Determination of Water Resource Classes - Economic consequences of Operational Scenarios
8.5	Volume 5: Supporting Information on the Determination of Water Resource Classes - EGSA consequences of Operational Scenarios
8.6	Volume 6: Supporting Information on the Determination of Water Resource Classes - Water quality consequences of Operational Scenarios
8.7	Volume 7: Recommended Water Resource Classes.

The purpose of this report is to describe and document the estuary ecological consequences of the operational scenarios by evaluating and determining the impact on the Ecological Category (EC).

Note that as described above, this report (volume 2A) only provides supporting information for Report 8.7.

1.3 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 an 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 we expected the confidence of the study to be medium. 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	Expressed as percentage
Low (L)	Limited data available	<40% certainty
Medium (M)	Reasonable data available	40 – 80% certainty
High (H)	Good data available	> 80% certainty

1.4 ASSUMPTIONS AND LIMITATIONS FOR THIS STUDY

The accuracy and confidence of an Estuarine 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.

1.5 STRUCTURE OF THIS REPORT

The report is structured as follows:

Chapter 1: Introduction
This chapter provides an overview of EWR methods and confidence of the study.

Chapter 2: Background Information
Important background information is summarised and 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 are defined, as well as the zoning and typical abiotic states adopted for this estuary.

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 an estimation of the reference condition. The health state of each component is computed using the Estuary Health Index (EHI).

Chapter 5: Present Ecological Status

This chapter 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 are combined with the EIS for the system to determine the Recommended Ecological Category.

Chapter 7: Consequences of Alternative Scenarios

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

Chapter 8: 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 D: Report Comments

2 BACKGROUND INFORMATION

2.1 HYDROLOGICAL CHARACTERISTICS

The Mvoti catchment is amongst the largest in KwaZulu-Natal (Cooper, 1994). Information in the literature about the catchment area differs with values of 2551 km^2, 2618 km^2, 2701 km^2 and 2736 km^2 given in Begg (1978) and 2728 km^2 in Chunnet *et al.* (1990). Begg (1978) estimates the river length to be between 180 km and 215 km. A river length of 197 km is given by NRIO (1983) while Chunnet *et al.* (1990) approximates 210 km. Mean annual precipitation over the catchment is about 900 mm and varies between 540 and 1380 mm (Chunnet *et al.*, 1990). According to Begg (1978) annual run-off varies between 134 x 10^6 m^3 to 461x 10^6 m^3. NRIO (1983) provides a Mean Annual Runoff (MAR) of 482 x 10^6 m^3 while NRIO (1986) give an estimated MAR of 468 x 10^6 m^3. Chunnet *et al.* (1990) state that the MAR under natural conditions is 420 x 10^6 m^3 at the mouth but that this has been reduced to 314 x 10^6 m^3 as a result of exotic afforestation and dryland sugarcane cultivation. This study estimates a MAR of 372 x 10^6 m^3 and 233 x 10^6 m^3, for the Reference Condition and Present State respectively.

2.2 CATCHMENT CHARACTERISTICS AND LAND-USE

The towns and villages with significant populations are Greytown, Kranskop, Dalton, Stanger and Groutville.

The land in the area surrounding the estuary is used predominantly for growing sugarcane (Chunnet *et al.*, 1990). The floodplain areas are planted with sugarcane. Land on the southern bank of the estuary is leased by the Jex Estates. The sugarcane estates of Gledhow Sugar Co. are on the northern bank. Blythedale Beach is 1.5 km further north (Begg, 1978). Industrial activity in the catchment is limited and nearly all the light industries are concentrated in and around the towns of Greytown, Kranskop, Dalton and Stanger (Chunnet *et al.*, 1990). The heavy industries are based either on agriculture or on forestry and consist of four sugar mills, one paper mill and two wattle extract factories (Chunnet *et al.*, 1990). There are also a few saw mills located in the upper reaches of the catchment. Two of the sugar mills and the paper mill are situated in the lower reaches of the catchment (Chunnet *et al.*, 1990). Considerable use is made of the river water above the national road bridge to supply the SAPPI Stanger mill.

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

- About 43% of the catchment is thicket, with 3% degraded thicket;
- About 13% of the catchment is natural grasslands and 2% planted grasslands, with about 1% classified as degraded grassland;
- Nearly 46% of the catchment is forest plantation (comprising pine, eucalyptus, *Acacia* and clear felled land); and
- Sugarcane is estimated at about 7% of the catchment, while cultivated commercial farming is estimated at 4%, and cultivated temporarily subsistence dryland were estimated at 1%.

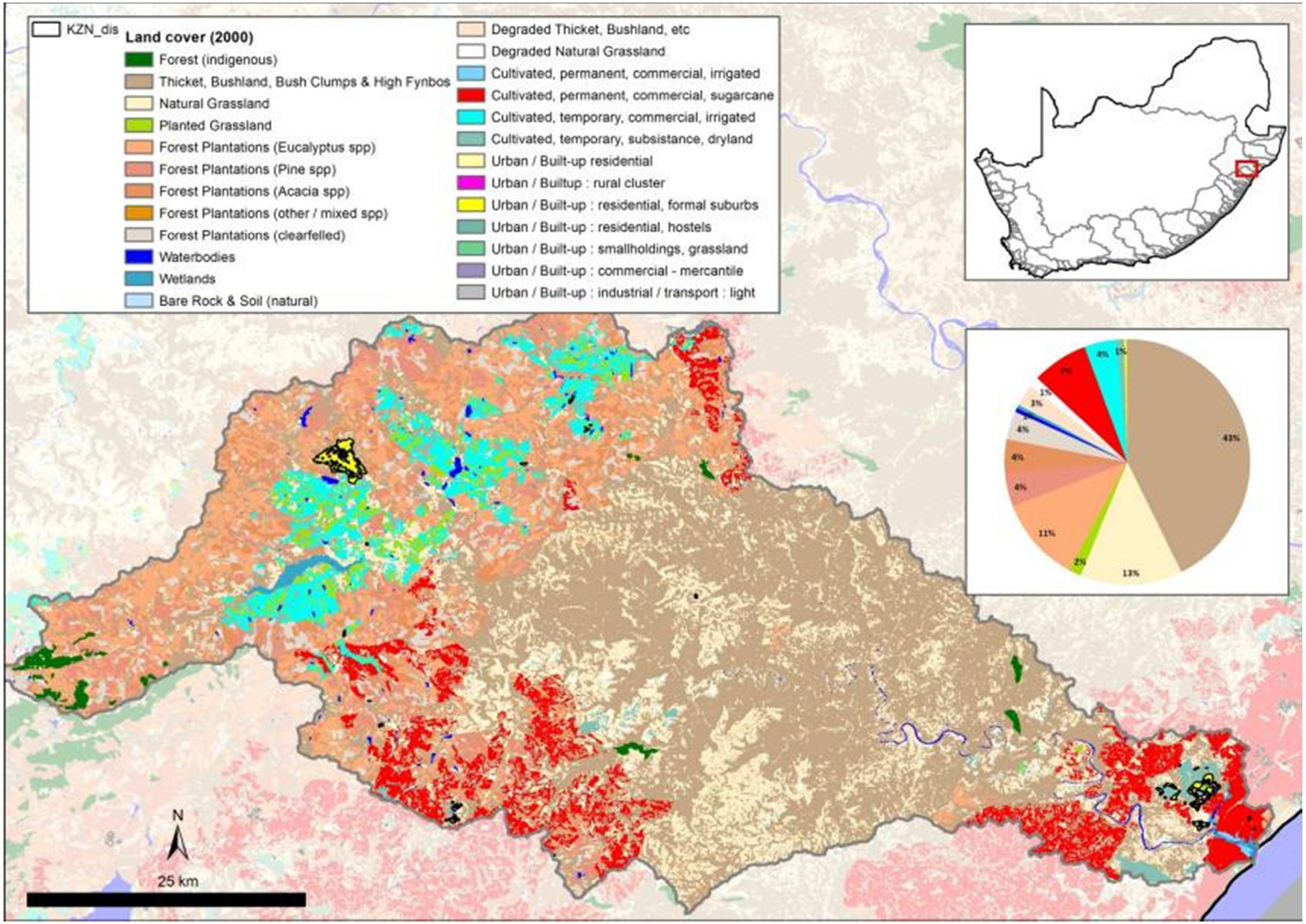


Figure 2.1 Overview of land-use in the Mvoti catchment

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 Mvoti Estuary.

Table 2.1 Pressures related to flow modification

Activity	Present	Description of Impact
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 sugarcane in the floodplain areas.
Stanger Waste Water Treatment Works (WWTW) upstream in river	✓	Municipal wastewater, potentially high nutrients and organic matter
SAPPI Stanger Paper Mill effluent disposal (just above N2 bridge)	✓	Industrial effluent from paper mill (high organic content and possibly toxic substances)
Ushukela Sugar Mill	✓	Industrial effluent (high organic content)
Bridge(s)	✓	The N2 national road crosses the river approximately 3,6 km from the mouth (Figure 1). Just above the national road bridge, a low level bridge also crosses the system.
Artificial breaching	✓	Yes, but breaching level unknown.
Bank stabilisation and destabilisation		
Low-lying developments	✓	Sugarcane fields and possibly the SAPPI pump station.
Migration barrier in river		
Recreational fishing	✓	Limited. Mostly targets the beach.
Commercial/Subsistence fishing (e.g. gillnet fishery)		
Illegal fishing (Poaching)		
Bait collection		
Grazing and trampling of salt mashes		
Translocated or alien fauna and flora	✓	Significant amount of invasive alien plants in Estuary Functional Zone (EFZ).
Recreational disturbance of waterbirds		

3 DELINEATION OF ESTUARY

3.1 GEOGRAPHICAL BOUNDARIES

To avoid confusion about the meaning of the words *estuary*, *estuary mouth* and *river mouth* the following definitions, which are based on common practice, have been applied in the report:

- Mvoti Estuary (also referred to as Mvoti River Estuary): The lower part of the Mvoti River, which is affected by marine influence such as seawater intrusion, influx of marine sediments and/or tidal variation.
- Estuary mouth (also referred to as Mvoti River mouth and Mvoti inlet): The actual mouth of the estuary including the berm and the opening (or inlet) in the berm.

The mouth of the Mvoti River is approximately 80 km north of Durban, near the small town of Blythedale Beach (Figure 3.1). The Mvoti Estuary is classified as a *"River mouth"* type estuary as the marine influence upstream of the inlet is negligible for a large part of the year (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°23'31.08"S, 31°20'4.31"E
Upstream boundary:	29°22'12.68"S 31°18'15.83"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

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

3.2 ZONATION OF THE MVOTI ESTUARY

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

Figure 3.2 Zonation of the Mvoti Estuary

Table 3.1 below lists some of the key features of the Mvoti Estuary zonation that are used to determine the weighting of scores.

Table 3.1 Key features of the Mvoti 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)	-0.3 to -0.5	-0.5 to 0.0	1.0 - 2.0

3.3 TYPICAL ABIOTIC STATES

Based on measured data and available literature, a number of characteristic ‘states’ can be identified for the Mvoti 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 Mvoti Estuary

State	Flow range (m^3/s)	Description
State 1: Closed	< 0.2	The estuary mouth is closed for weeks to months. Zones A, B, and C are well mixed and salinity is about 5 through out the system.
State 2: Tidal, intermitted closed	0.2 - 0.5	The system shows a marine influence due to reduced freshwater inflow and regular breaching. Zones A and B have salinities of about 20 and 5 respectively, while Zone C is fresh,
State 3: Tidal	0.5 - 3	Zones B and C are fresh, with limited saline intrusion into Zone A (salinity ~5).
State 4: Fresh water dominated	> 3	All zones are 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) was 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 10%iles are listed separately to provide a quick comprehensive overview; and

A summary of the typical physical and water quality characteristics of different abiotic states in the Mvoti is provided in Chapter 4. For more detail on the underlying data and assumptions, refer to the Specialist Reports (Volume II).

4 ECOLOGICAL BASELINE AND HEALTH ASSESSMENT

4.1 HYDROLOGY

4.1.1 Baseline description

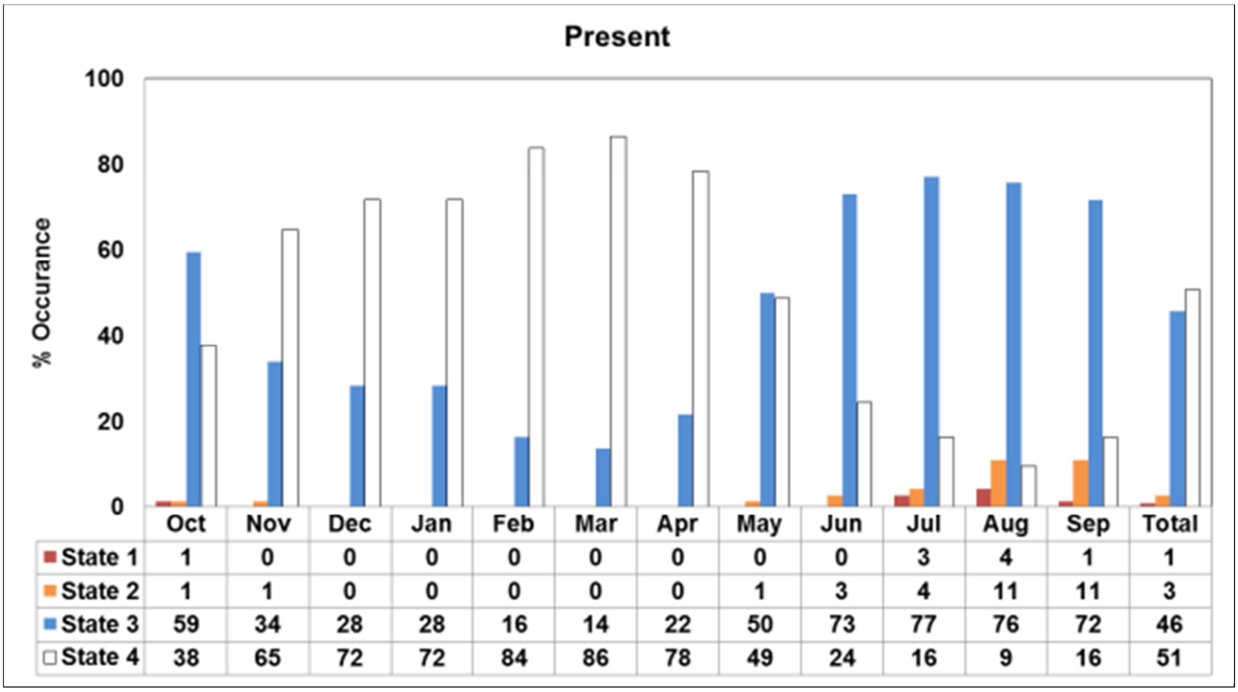
According to the hydrological data provided for this study, the present day MAR into the Mvoti Estuary is 225.49 Million m^3. This is a decrease of 40% compared to the natural MAR of 374.66 Million m^3. The occurrences of flow distributions (mean monthly flows in m^3/s) for the Present State and Reference Condition of the Mvoti Estuary, derived from the 74-year simulated data set, are provided in Table 4.1 and 4.2. A graphic representation of the occurrence of the various abiotic states is presented in Figure 4.1 and 4.2. The full 74-year series of simulated monthly runoff data for the Present State and Reference Condition is provided in Table 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	89.4	47.2	45.2	49.5	86.6	209.7	81.1	53.1	28.7	11.6	28.1	240.4
99	57.7	41.5	41.8	40.3	84.5	133.9	70.9	35.9	25.8	9.2	14.8	82.9
90	7.1	17.2	17.9	23.4	31.6	33.1	18.1	8.5	5.8	3.9	2.9	5.2
80	4.4	8.1	10.2	14.7	23.8	20.6	11.3	6.1	3.7	2.8	1.8	2.4
70	3.3	6.7	7.2	9.7	15.4	13.3	9.2	4.7	2.6	1.6	1.1	1.8
60	2.6	5.0	5.5	6.5	9.9	10.7	7.8	4.2	2.1	1.1	0.9	1.4
50	2.1	4.2	4.6	5.3	8.0	8.1	6.0	2.9	1.7	0.9	0.9	1.0
40	1.5	3.4	3.4	4.4	6.1	6.7	4.7	2.5	1.2	0.9	0.9	0.9
30	1.1	2.7	3.0	3.1	4.7	5.2	3.7	1.9	1.0	0.9	0.8	0.9
20	0.9	1.7	1.9	1.9	3.6	3.5	2.8	1.5	0.9	0.7	0.6	0.7
10	0.9	1.2	1.0	1.3	2.1	2.7	1.7	1.0	0.9	0.6	0.5	0.5
1	0.2	0.6	0.6	0.7	0.7	0.8	0.6	0.6	0.3	0.2	0.2	0.2
0.1	0.2	0.3	0.6	0.7	0.7	0.8	0.6	0.5	0.3	0.2	0.2	0.2

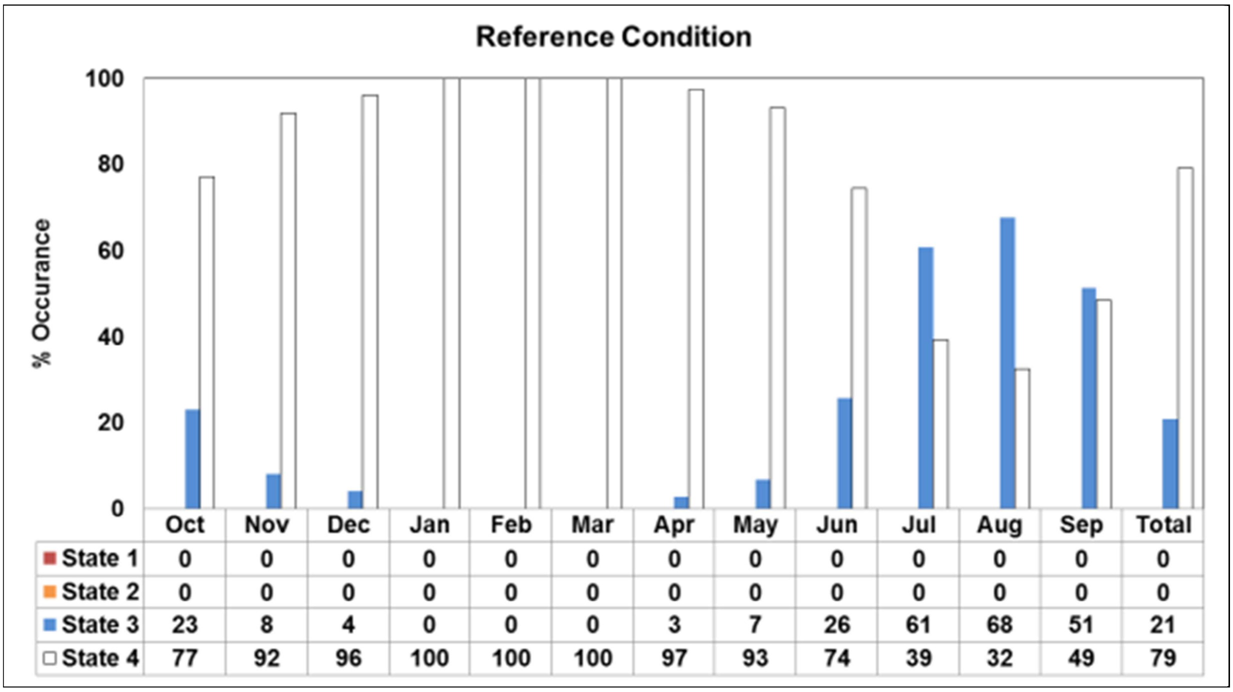
Table 4.2 A summary of the monthly flow (in m^3/s) distribution under the Reference State

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	101.8	57.3	68.2	73.2	114.9	230.3	90.8	70.0	37.1	15.6	40.1	271.1
99	67.3	52.9	64.7	60.4	111.5	152.8	87.6	46.2	33.5	12.3	21.5	99.1
90	11.1	25.4	29.5	41.4	50.4	48.4	26.1	12.0	8.9	6.3	5.8	8.1
80	8.6	14.3	21.9	25.9	37.2	33.3	17.1	9.1	6.3	5.1	4.2	4.6
70	6.1	11.2	13.8	18.4	27.1	21.7	14.5	8.0	5.1	3.9	3.2	3.9
60	5.2	8.7	10.6	13.6	17.6	18.2	12.6	7.4	4.6	2.9	2.7	3.5
50	4.3	7.7	8.7	12.1	14.0	14.0	10.7	5.9	4.1	2.5	2.4	3.0
40	3.5	6.6	8.0	9.3	12.3	12.0	8.9	5.3	3.4	2.3	2.1	2.7
30	3.1	5.5	7.0	7.6	9.9	10.5	7.7	4.6	3.1	2.1	1.9	2.2
20	2.6	4.3	5.2	5.8	8.0	7.8	6.5	4.0	2.6	1.9	1.7	1.7
15	2.2	3.8	4.9	5.4	7.0	6.9	6.1	3.9	2.5	1.7	1.5	1.6
10	2.0	3.3	3.9	4.7	6.3	6.3	5.1	3.5	2.3	1.6	1.4	1.4
1	1.0	1.7	2.0	3.3	3.7	3.5	2.5	2.0	1.5	1.0	0.9	0.9
0.1	0.8	1.1	1.8	3.2	3.4	3.1	2.4	2.0	1.5	1.0	0.8	0.8



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	1	0	0	0	0	0	0	0	0	3	4	1	1
State 2	1	1	0	0	0	0	0	1	3	4	11	11	3
State 3	59	34	28	28	16	14	22	50	73	77	76	72	46
State 4	38	65	72	72	84	86	78	49	24	16	9	16	51

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	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	0	0	0	0	0	0	0	0	0	0	0	0	0
State 3	23	8	4	0	0	0	3	7	26	61	68	51	21
State 4	77	92	96	100	100	100	97	93	74	39	32	49	79

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 Mvoti Estuary for the Present State

Date	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1921	3.2	16.0	27.5	11.9	4.3	3.0	2.2	1.3	1.8	1.6	1.8	1.9
1922	3.1	21.1	10.0	32.0	28.4	12.8	6.7	2.4	0.9	0.7	0.5	0.3
1923	0.2	0.2	0.7	0.9	2.7	2.4	1.4	0.9	0.8	0.5	0.4	1.0
1924	2.2	11.5	17.8	32.1	21.4	218.2	82.3	6.0	2.6	1.6	1.1	1.8
1925	3.4	3.9	3.0	1.3	0.7	2.7	2.7	1.0	0.9	0.9	0.7	1.2
1926	5.0	6.3	5.5	3.8	5.7	55.5	23.6	2.5	0.9	0.8	0.9	0.9
1927	1.1	1.1	1.7	9.9	8.3	5.3	3.8	1.9	0.9	0.6	0.5	0.9
1928	1.0	1.3	0.8	1.4	2.6	16.4	9.8	2.9	2.8	3.9	2.8	2.7
1929	5.3	6.7	4.0	5.1	4.7	8.9	5.6	2.0	0.9	0.7	0.9	1.4
1930	2.5	3.4	3.2	4.1	4.5	3.2	2.3	1.1	0.8	0.7	0.6	0.6
1931	0.8	0.9	1.2	1.7	71.8	49.9	15.5	9.5	7.1	2.8	0.9	0.9
1932	1.1	2.2	3.1	2.9	3.4	3.4	2.5	1.1	0.8	0.9	0.8	0.6
1933	0.7	6.3	11.1	29.4	18.2	9.6	11.6	9.7	6.1	3.0	2.7	2.0
1934	1.1	1.6	28.4	14.5	7.1	6.7	5.1	3.5	24.6	11.8	2.9	1.0
1935	0.9	0.9	0.6	1.3	27.6	34.0	13.8	7.9	7.7	3.9	1.5	0.9
1936	1.7	39.2	15.7	2.5	6.3	6.1	3.3	1.0	0.9	0.7	0.6	0.6
1937	0.9	1.2	14.6	10.1	15.0	7.8	5.6	4.6	2.6	2.9	2.8	1.4
1938	2.2	4.5	9.1	7.0	37.3	21.3	8.7	4.6	2.8	1.6	1.0	2.4
1939	3.3	10.8	12.3	7.9	8.1	5.4	3.6	55.0	29.0	8.3	2.9	1.8
1940	1.8	20.1	45.5	17.6	5.1	3.2	3.9	2.8	1.1	0.8	0.5	0.8
1941	0.9	1.5	0.8	1.5	3.8	12.1	9.2	4.4	2.4	1.3	1.2	1.9
1942	3.8	7.0	40.4	18.3	8.2	8.4	66.6	28.8	7.1	7.2	29.6	15.3
1943	24.7	17.8	9.4	4.6	6.5	14.1	8.1	2.2	1.4	1.2	0.9	3.4
1944	5.8	4.8	1.9	0.7	2.1	21.8	11.3	2.9	1.2	0.9	0.4	0.2
1945	0.9	0.9	0.6	1.5	4.2	4.2	3.1	1.6	0.9	0.5	0.2	0.2
1946	0.9	2.8	3.4	4.4	12.9	12.1	10.6	6.1	3.9	2.9	1.8	1.5
1947	1.9	20.1	14.4	8.4	8.0	20.0	14.0	6.1	2.5	0.9	0.6	0.4
1948	0.9	1.7	1.3	1.6	4.2	5.9	8.2	5.4	2.3	1.0	0.8	0.8
1949	2.4	9.0	18.0	9.7	6.4	9.3	8.3	4.6	2.1	0.9	0.9	0.9
1950	0.9	0.7	3.5	5.2	4.7	3.5	2.7	1.2	0.9	0.6	2.9	5.7
1951	6.3	4.0	4.2	9.9	10.8	7.1	4.7	2.6	1.4	1.0	0.9	0.8
1952	0.6	2.4	7.4	12.6	24.3	10.9	3.6	1.4	0.9	0.5	0.9	1.1
1953	1.5	2.3	3.3	5.1	8.3	7.4	5.9	5.1	4.0	2.0	0.9	2.0
1954	44.6	22.4	5.3	14.9	12.4	8.1	7.2	4.4	2.1	0.9	0.5	0.7
1955	1.6	4.7	5.2	2.1	17.6	22.2	10.0	2.9	1.3	0.9	0.8	1.0
1956	1.5	3.2	39.5	30.5	15.2	9.5	11.2	6.3	2.1	0.9	0.9	18.3
1957	36.0	17.7	6.4	24.4	23.6	9.4	7.9	6.0	2.6	0.9	0.5	1.0
1958	1.3	3.5	7.2	6.2	10.3	6.4	2.8	10.1	8.5	3.2	1.4	1.2
1959	3.0	4.2	3.1	2.0	3.1	4.0	5.5	4.0	1.6	0.9	0.7	0.9
1960	1.3	4.6	21.1	16.1	10.6	8.0	19.9	10.3	3.7	1.8	1.0	1.1
1961	2.0	3.4	3.1	3.7	6.1	6.3	5.0	2.3	0.9	0.6	0.9	0.9
1962	1.2	7.8	6.8	6.6	5.9	11.2	9.4	4.2	2.3	4.1	3.9	1.6
1963	1.3	2.8	1.9	19.5	12.3	3.4	2.5	1.7	0.9	0.9	0.6	0.9
1964	2.3	2.9	2.2	1.5	1.5	0.8	0.6	0.6	1.9	2.9	3.1	3.1
1965	3.1	4.0	3.8	6.1	6.7	3.1	1.2	1.3	1.1	0.9	0.8	0.9
1966	1.0	2.2	3.0	16.7	19.3	43.2	22.0	7.1	3.0	1.1	0.9	0.5
1967	0.9	3.4	3.0	3.2	4.0	4.3	3.7	1.7	0.9	0.4	0.9	1.3
1968	1.6	1.7	2.9	3.1	3.7	34.3	19.2	7.3	4.6	2.0	0.9	0.9
1969	4.1	5.8	5.0	3.1	2.2	1.1	0.8	0.9	1.0	0.9	0.9	2.8
1970	12.2	8.6	4.7	5.3	8.0	7.6	6.9	17.5	9.8	3.9	4.2	4.1
1971	3.7	3.2	5.6	5.3	24.1	13.3	5.6	4.0	3.5	2.2	1.1	0.8
1972	0.9	1.8	1.8	2.9	33.6	17.8	8.6	4.7	1.7	0.9	1.1	7.4
1973	7.5	6.3	4.5	28.4	27.0	13.6	8.2	5.3	3.6	1.8	0.9	0.6
1974	0.2	0.9	1.8	9.6	25.9	11.5	4.5	2.6	1.1	0.8	0.5	5.6
1975	5.9	5.2	9.6	50.5	52.0	102.7	42.7	8.4	3.7	1.3	1.0	1.0
1976	3.2	5.3	3.3	4.8	17.3	13.3	7.5	2.9	1.1	0.8	0.8	1.5
1977	3.8	5.1	3.8	5.7	8.0	13.4	9.5	4.3	1.6	0.9	0.9	1.4
1978	4.9	7.7	6.9	5.8	8.2	6.7	4.0	2.0	1.0	0.9	0.9	0.9
1979	1.4	1.4	0.8	0.7	0.7	0.8	0.6	0.5	0.3	0.2	0.2	5.7
1980	5.6	7.0	4.8	4.5	5.9	3.5	1.3	1.5	1.9	1.1	1.7	3.3
1981	3.4	6.8	4.0	2.6	3.3	7.6	6.7	3.1	1.2	0.8	0.4	0.4
1982	2.7	4.5	3.0	1.6	0.9	0.8	0.8	0.9	0.7	0.7	0.9	1.0
1983	1.0	7.5	7.7	36.5	60.0	27.7	15.5	8.5	4.0	3.3	3.7	2.4
1984	2.7	3.3	1.9	3.9	83.6	31.0	3.3	0.9	0.5	0.3	0.2	0.2
1985	18.8	10.7	5.9	13.1	8.0	5.9	6.1	3.0	1.2	0.9	0.7	0.6
1986	1.1	2.0	6.7	21.1	18.7	23.4	11.9	4.7	5.0	3.8	3.6	257.8
1987	93.0	12.9	8.5	5.0	86.8	76.3	22.4	3.7	2.6	2.1	2.1	1.8
1988	2.1	4.3	10.7	7.0	33.0	14.5	3.4	1.9	1.4	0.9	0.7	0.5
1989	0.9	47.8	19.8	3.0	2.1	5.2	7.1	4.3	1.7	0.9	1.3	1.7
1990	2.6	2.9	5.6	9.1	25.1	27.1	10.7	2.3	1.1	0.9	0.9	1.1
1991	3.6	4.5	2.2	0.8	1.2	1.1	0.8	0.8	0.3	0.2	0.2	0.3
1992	0.7	1.3	0.9	0.7	1.3	2.7	2.7	1.5	0.9	0.6	0.8	1.2
1993	9.0	6.9	5.2	6.2	4.9	4.3	4.0	1.6	0.9	0.9	9.4	5.6
1994	2.2	1.7	0.8	0.7	0.7	1.6	3.9	4.7	5.2	3.9	1.9	1.0
Average	5.3	6.7	7.8	9.1	14.6	16.5	9.4	4.9	3.0	1.7	1.7	5.5
Min	0.2	0.2	0.6	0.7	0.7	0.8	0.6	0.5	0.3	0.2	0.2	0.2
Max	93.0	47.8	45.5	50.5	86.8	218.2	82.3	55.0	29.0	11.8	29.6	257.8

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

Date	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1921	5.6	29.1	46.3	19.3	7.0	6.3	5.6	4.0	4.6	4.1	4.3	4.3
1922	6.1	30.3	17.5	54.4	43.7	17.8	9.8	4.7	2.4	1.7	1.4	1.1
1923	0.8	1.0	2.1	4.0	6.8	6.3	4.9	3.2	2.3	1.5	1.3	3.0
1924	4.7	23.2	31.9	54.4	34.7	239.0	91.2	8.8	4.7	3.5	2.9	3.9
1925	6.0	6.9	6.5	4.6	3.8	6.8	6.8	3.6	3.0	2.7	1.9	3.5
1926	9.4	11.0	10.6	8.7	12.3	77.6	32.4	4.8	2.5	1.8	2.5	2.7
1927	3.1	3.2	5.1	19.0	15.2	9.8	8.0	4.9	2.9	1.7	1.5	2.2
1928	3.2	3.5	3.2	6.3	7.6	32.9	18.4	5.8	5.5	7.1	5.6	5.4
1929	8.7	11.2	8.3	11.8	9.7	19.2	11.8	4.9	2.8	1.9	2.2	3.6
1930	5.2	6.8	7.2	9.2	9.9	7.5	6.2	3.8	2.2	1.9	1.8	1.6
1931	2.0	2.8	4.2	5.4	107.8	69.1	20.8	13.7	10.3	5.0	2.6	2.2
1932	3.1	5.1	8.0	7.5	8.2	7.8	6.5	3.7	2.2	2.1	2.1	1.6
1933	1.7	11.2	21.6	54.8	27.8	14.1	16.6	13.2	8.6	5.3	5.0	4.2
1934	3.1	4.5	52.8	25.1	10.6	11.1	9.0	6.7	32.0	16.0	5.1	2.7
1935	2.0	2.1	2.0	4.5	48.1	51.1	20.2	12.2	10.9	6.3	3.4	2.5
1936	3.9	51.0	22.4	6.3	15.1	11.7	6.9	3.4	2.1	1.8	1.6	1.4
1937	2.2	3.2	23.1	17.7	29.5	14.3	10.2	8.1	5.2	5.6	5.5	3.6
1938	4.7	7.8	15.2	13.0	63.6	33.8	12.6	7.3	5.1	3.6	2.9	4.9
1939	6.1	18.4	25.6	14.8	15.4	11.9	7.5	72.7	37.5	10.9	4.9	3.9
1940	4.1	28.4	68.6	27.0	8.1	6.5	7.7	5.9	3.3	1.9	1.4	1.8
1941	2.6	3.8	3.2	4.8	12.5	27.6	17.0	7.9	5.1	3.3	3.2	4.2
1942	6.8	12.4	63.0	28.3	13.6	13.6	86.3	36.5	9.7	10.2	42.2	21.1
1943	37.7	25.8	13.7	8.1	11.7	19.8	12.1	4.6	3.4	3.0	2.3	7.3
1944	9.0	7.7	4.7	3.4	6.0	37.3	19.5	5.9	3.4	1.9	1.2	0.9
1945	1.8	1.9	1.8	4.7	9.2	9.4	7.5	4.4	2.6	1.5	1.0	1.0
1946	2.1	5.6	7.5	9.6	26.6	21.6	15.7	9.3	6.8	5.7	4.1	3.7
1947	4.2	29.8	24.6	14.7	13.0	35.0	21.3	9.0	4.7	2.3	1.5	1.2
1948	2.4	4.3	4.5	5.4	9.7	12.0	14.2	9.1	4.7	2.8	1.9	1.8
1949	4.4	15.2	30.6	17.1	11.3	16.3	13.6	8.0	4.6	2.6	2.8	2.8
1950	2.1	2.1	8.6	13.5	10.7	7.7	6.5	3.9	2.4	1.6	5.9	9.7
1951	10.3	7.1	8.1	18.3	20.6	12.6	8.6	5.5	3.7	2.7	2.4	1.8
1952	1.7	5.4	14.3	22.1	42.0	18.3	6.9	3.9	2.4	1.6	2.1	3.2
1953	3.6	5.0	7.1	10.9	17.8	13.3	10.2	8.9	7.2	4.4	2.7	4.2
1954	53.2	30.0	9.4	27.8	20.8	13.0	11.3	7.4	4.4	2.5	1.5	1.6
1955	3.4	8.0	9.2	5.2	27.1	33.0	15.9	5.9	3.6	2.3	2.0	2.9
1956	3.6	6.9	63.3	52.0	22.2	13.9	16.6	9.5	4.2	2.6	2.5	28.4
1957	52.1	24.6	9.8	32.7	36.8	14.9	12.8	9.5	4.8	2.3	1.4	2.3
1958	3.0	6.1	12.7	13.5	27.7	13.4	5.7	17.0	13.0	5.6	3.4	3.3
1959	5.6	7.5	7.0	6.1	7.9	8.6	10.3	7.6	4.1	2.2	1.8	2.2
1960	3.5	8.8	41.1	28.9	17.0	14.1	28.2	14.5	6.1	3.8	2.4	2.9
1961	4.2	6.5	7.2	12.5	12.7	11.1	9.3	5.3	2.8	1.6	2.3	2.7
1962	3.2	13.1	12.8	13.5	10.7	21.4	15.7	7.2	4.7	7.1	6.8	3.7
1963	3.4	6.0	5.1	41.4	22.4	6.5	5.8	4.4	3.2	2.4	1.8	2.1
1964	4.9	6.0	5.9	5.5	5.4	3.6	2.4	2.0	4.7	6.2	6.2	6.1
1965	6.0	7.7	8.3	14.7	13.7	6.9	4.3	4.0	3.5	2.3	2.0	2.2
1966	2.7	5.0	7.0	36.5	37.7	58.5	29.4	10.0	5.2	3.0	2.1	1.4
1967	2.4	6.8	7.0	7.7	8.7	8.8	8.1	4.7	2.5	1.5	2.0	3.2
1968	3.4	3.8	7.0	8.0	9.0	61.7	30.1	10.2	7.1	4.1	2.6	2.7
1969	8.6	9.7	9.0	7.3	6.4	4.6	3.1	2.8	3.1	2.3	2.4	6.3
1970	19.3	13.8	10.1	11.4	13.3	12.1	11.2	24.4	14.1	6.6	7.1	7.0
1971	6.4	6.0	10.6	10.3	33.7	23.5	11.1	7.3	6.3	4.5	3.0	1.8
1972	1.9	4.3	4.9	7.7	65.4	29.2	13.4	7.9	3.9	2.1	3.2	13.5
1973	11.5	9.5	8.0	55.2	43.3	19.9	12.0	8.2	6.2	4.1	2.6	1.6
1974	1.0	2.7	5.3	21.1	46.9	19.3	7.9	5.4	3.3	1.9	1.4	11.6
1975	9.9	9.0	22.7	74.6	71.4	120.9	51.0	11.5	6.0	3.1	2.3	2.5
1976	6.2	9.4	7.1	11.4	27.0	25.7	13.4	5.5	3.1	1.8	1.8	3.5
1977	6.6	8.7	8.1	13.6	14.5	19.9	14.8	7.7	4.0	2.3	2.1	3.7
1978	9.3	12.5	15.4	12.4	14.9	11.4	7.7	4.9	3.3	2.4	2.7	3.1
1979	3.5	3.5	3.3	3.8	4.1	3.1	2.6	2.0	1.5	1.0	0.9	10.1
1980	8.6	11.0	8.9	9.2	12.3	7.6	4.3	4.1	4.2	3.0	3.8	5.9
1981	5.7	11.6	8.2	6.4	7.8	17.1	12.8	6.1	3.3	1.9	1.3	1.2
1982	5.4	8.3	6.9	5.4	4.2	3.9	4.2	3.1	2.2	2.0	2.7	2.5
1983	3.1	15.0	15.3	54.6	74.1	36.6	20.8	11.6	6.3	5.7	6.0	4.4
1984	5.2	6.6	5.2	10.5	115.3	41.8	6.1	2.6	1.5	1.1	0.8	0.8
1985	25.6	15.7	16.4	25.2	14.3	10.6	10.4	5.8	3.3	2.3	1.8	1.6
1986	3.1	4.8	13.0	41.2	35.3	35.9	17.4	7.4	7.7	6.2	6.5	290.2
1987	105.6	18.1	12.6	8.9	110.1	94.5	28.5	6.3	5.0	4.5	4.6	4.1
1988	4.4	8.0	23.0	13.9	51.3	21.9	6.3	4.4	3.9	2.8	1.9	1.5
1989	2.5	57.8	26.8	7.3	6.3	11.8	12.5	7.7	4.1	2.2	3.4	3.9
1990	5.1	5.5	11.7	25.1	42.3	35.9	14.5	4.6	3.1	2.4	2.0	2.9
1991	6.7	8.1	5.6	4.1	6.6	5.5	4.2	2.7	1.5	1.0	0.9	1.1
1992	1.8	3.5	3.7	3.2	6.2	9.9	7.5	4.2	2.6	1.6	1.8	3.0
1993	15.7	11.7	10.5	13.3	10.4	10.2	8.5	4.4	2.5	2.5	13.8	8.4
1994	4.0	3.8	3.4	3.3	3.3	5.6	8.9	8.9	9.0	6.8	4.1	2.6
Average	8.3	11.0	14.4	17.5	24.5	24.7	14.5	8.2	5.4	3.5	3.5	8.0
Min	0.8	1.0	1.8	3.2	3.3	3.1	2.4	2.0	1.5	1.0	0.8	0.8
Max	105.6	57.8	68.6	74.6	115.3	239.0	91.2	72.7	37.5	16.0	42.2	290.2

4.1.2 Low flows

Winter inflows never decrease below 0.5 m^3/s under the Reference Conditions, thereby maintaining open mouth conditions and preventing the ingress of salinity into the upper reaches. Under the Reference Condition monthly flow exceeded 3.0 m^3/s for nearly 80% of the time (Table 4.5), while under the Present State river inflow only exceeds 1 m^3/s for about 80% of the time.

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

Percentile	Monthly flow (m^3/s)		% Remaining
	Natural	Present	
30%ile	3.8	1.4	35.2
20%ile	2.9	0.9	32.5
10%ile	2.1	0.8	38.5
% Similarity in low flows			**35.4**

Confidence: High

4.1.3 Flood regime

To provide an indication of the change in the flood regime from the Reference Condition to the Present State the ten highest simulated monthly flow volumes were compared for the 74-year period (summarised Table 4.6). The analysis of the simulated monthly flow data indicate that under Reference Conditions floods were about 20% higher than at present, depending on the size class.

Table 4.6 Summary of the ten highest simulated monthly volumes to the Mvoti Estuary under Reference Condition and Present State

Date	Monthly Volume ($x10^6$ m^3/month)		% Remaining
	Natural	Present	
Sep 1987	752.2	668.3	88.8
Mar 1925	640.0	584.3	91.3
Mar 1976	323.7	275.2	85.0
Oct 1987	282.8	249.0	88.0
Feb 1985	281.5	204.2	72.5
Feb 1932	263.1	175.2	66.6
Mar 1988	253.0	204.2	80.7
Apr 1925	236.3	213.3	90.2
Apr 1943	223.7	172.7	77.2
Mar 1927	207.9	148.6	71.5
% Similarity in floods			**81.2**

Confidence: Medium

4.1.4 Hydrological health

Table 4.7 provides a summary of the hydrological health of the Mvoti Estuary.

Table 4.7 Calculation of the hydrological health score, giving examples in italics

Variable	Summary of change	Score	Conf[1]
a.% Similarity in period of low flows	A significant reduction in low flows from reference condition	35	H
b.% Similarity in mean annual frequency of floods	The simulated monthly flow data indicate that under Reference Conditions floods were about 20% higher than at present, depending on the size class.	81	M
Hydrology score		**53.4**	

1 Confidence level: L - Low, M - Medium, H - High

4.2 PHYSICAL HABITAT

4.2.1 Baseline description

Sedimentary deposits and processes in the Mvoti Estuary are predominantly fluvial in nature and the system is classified as a river-dominated estuary (Cooper, 1994). The greatest geomorphological impacts in the channel and sand berm at the mouth are caused by extreme river floods. Sedimentary processes show significant changes in response to river inflow variation. Within the normal range of discharge variation the channel varies in dimension and morphology but no major long-term build-up of sediment is evident in the floodplain or channel. Minor floods deposit muddy overbank deposits. During such floods, the channel depth and gradient is increased by mouth breaching and channel shortening, but the high wave energy along this coast rapidly leads to a more constricted mouth post flood event. Superimposed on these short-term changes is a cyclic pattern driven by major floods which cause lateral channel erosion and overbank deposition. Post-flood recovery involves progressive channel confinement and stabilisation as flow reverts to a single or braided channel and the floodplain is re-vegetated.

Under the Reference Condition there would have been less sediments coming from the catchment. Poor land-use practises are at present leading to more sediment, especially finer fractions, entering the system. The reduction in major floods and loss of minor resetting events would have resulted in a slowdown of the natural erosion-deposition cycle, leading to the estuary being more in a shallow constricted phase of the cycle as a result of the loss of resetting events.

Sand mining in the floodplain in the river reach just above the estuary is reducing historical depositional areas and removing some of the medium sand fractions from the system.

4.2.2 Physical habitat health

Table 4.8 provides a summary of the physical habitat health of the Mvoti Estuary. About 70% of the impact on the physical habitat was thought to be non-flow related.

Table 4.8 Calculation of the physical habitat score and adjusted score (net of non-flow impacts)

Variable		Score	Motivation	Conf
1. Resemblance of intertidal sediment structure and distribution to Reference condition				
1a	% Similarity in intertidal area exposed	70	Sedimentation processes are similar to Reference conditions, but there is some loss of intertidal habitat due deposition and infilling of the intertidal habitat. During State 1 and 2 there is also less exposed intertidal habitat at low tide due to increased mouth closure and greater mouth restriction.	M
1b	% Similarity in sand fraction	80	Information is lacking on changes in % similarity in sand fraction relative to total sand and mud, but the score of 80 is based on an	M

Variable		Score	Motivation	Conf
	relative to total sand and mud		increase in clay and silt fractions experienced in similar systems, especially in Zone B and C. Sand mining will also be changing grains size distribution in the system..	
2. Resemblance of <u>subtidal sediment</u> structure and distribution to Reference condition				
2	% Similarity in subtidal components: depth, bed or channel morphology	70	There has been some infilling of sub-tidal areas as a result of the decrease/loss in resetting floods and increase sediment yield from the catchment. Under the Reference Conditions floods would have scoured the system to mean sea level before the natural deposition cycle caused infilling, Under the Present State resetting events have been significantly reduced and infilling is maintaining the more constricted equilibrium state. There is also a loss of the meandering nature of the estuary channels which would have lead to bank instability and the loss and reformation of islands. There are also indications that the bridges are causing localise changes in bathymetry..	M
Physical habitat score		**73**		**M**
Adjusted score		**92**		
No-flow related influence:				
1	Percentage of overall change in <u>intertidal and supratidal habitat</u> caused by **anthropogenic** activity as opposed to modifications to water flow into estuary	70	Poor agricultural practises and developments in the catchment are causing degradation and changes in sedimentation- this is especially relevant. This is of set to some extend by sand mining	M
2	Percentage of overall change in subt<u>idal habitat</u> caused by **anthropogenic** modifications (e.g. bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary	70	Poor agricultural practises and developments in the catchment are causing degradation and changes in sedimentation.	M

[1] $Score\ = \frac{(1a.x\ 0.5+1b.x\ 0.5)\ \ +2.)}{2}$

4.3 HYDRODYNAMICS

4.3.1 Baseline description

Table 4.9 provides a summary of the hydrodynamics characteristics associated with the typical abiotic states occurring in the Mvoti Estuary.

Table 4.9 Summary of the abiotic states, and associated hydrodynamic characteristics

Parameter	State 1: Closed	State 2: Tidal, intermitted closed	State 3: Tidal	State 4: Fresh water dominated
Flow range ($m^{3/}s$)	<0.2	0.2 – 0.5	0.5 – 2	>2
Mouth condition	Closed	Closed < 7 days	Open	Open
Water level (m to MSL)	1.5 – 2.0 (can reach ~3 m MSL but artificially breached)	1.5	1.5	1.5, but can increase significantly during floods to 3 m MSL
Inundation	Yes, back flooding during closed state	N/A	N/A	Yes, during floods
Tidal range	0	0.3	0.5-0.7	1.0 m, but suppressed during floods

Parameter	State 1: Closed	State 2: Tidal, intermitted closed	State 3: Tidal	State 4: Fresh water dominated
Dominant circulation process	Wind	Tides	Tides and river	River
Retention	Months	1 - 2 weeks	< week	< 1 day

4.3.2 Hydrodynamic health

Table 4.10 provides a summary of the hydrodynamic health of the Mvoti Estuary.

Table 4.10 Calculation of the hydrodynamics score

Variable	Summary of change	Score	Conf
Hydrodynamics and mouth conditions score	Mouth closure occurs for about 1% of the time under the Present State, while the estuary was permanently open under the Reference Condition. Artificial breaching at low levels is disguising the actual frequency at which this is occurring as the system is artificially breached as soon as the mouth becomes constricted. Note: Mouth closure is scored conservatively following an exponential curve (DWA, 2009).	95	H
Hydrodynamic score		**95**	**H**

4.4 WATER QUALITY

4.4.1 Baseline description

A summary of the water quality characteristics for the various states, in each of the three zones is presented in Table 4.11. This summary was derived from available information on the estuary as presented in the Abiotic Specialist Report. These were derived from limited water quality data available on the system (see Abiotic specialist report), as well as expert opinion and experience gained from specialists at the EWR workshop. 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).

Table 4.11 Summary of water quality characteristics of different abiotic states in the Mvoti 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: Tidal, intermitted closed			State 3: Tidal			State 4: Fresh water dominated		
Salinity	5	5	5	20	5	0	5	0	0	0	0	0
Temperature (°C)	Summer			Summer			Summer			Summer		
	25-30 °C			25-30 °C			25-30 °C			25-30 °C		
	Winter			Winter			Winter			Winter		
	<20 °C			<20 °C			<20 °C			<20 °C		
pH	7-8			7-8			7-8			7-8		
DO[1] (mgl/l)	Reference			Reference			Reference			Reference		
	8	8	8	8	8	8	8	8	8	8	8	8
	Present and Future			Present and Future			Present and Future			Present and Future		
	1	1	1	2	2	3	2	2	4	2	2	4
Turbidity (NTU)	Reference			Reference			Reference			Reference		
	10	10	10	10	10	10	10	10	10	100	100	100
	Present and Future			Present and Future			Present and Future			Present and Future		
	10	10	10	10	20	20	20	30	30	400	400	400
DIN[2] (µg/l)	Reference			Reference			Reference			Reference		
	50	50	50	50	50	50	0	50	50	100	100	100
	Present and Future			Present and Future			Present and F ture			Present and Future		
	300	300	300	200	300	500	300	00	500	800	800	800
DIP[3] (µg/l)	Reference			Reference			Reference			Refe ence		
	10	10	10	10	10	10	10	10	10	10	10	10
	Present and Future			Present and Future			Present and uture			Present and Future		
	15	15	15	15	15	15	15	15	15	30	30	30
DRS[4] (µg/l)	7000	7000	7000	6000	7000	8000	700	8 00	8000	8000	8000	8000

1 Dissolved Oxygen 2 Dissolved Inorganic Nitrogen 3 Dissolved Inorganic Phosphate 4 Dissolved Reactive Silicate

A summary of the water quality characteristics under the various flow scenarios are provided for each zone in Table 4.12.

Table 4.12 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 decrease in the baseflows to the system (i.e. an increase in the occurrence of monthly flows below 3 m^3/s)	Lower	2	3
		Middle	2	3
		Upper	1	1
DIN (µg/ℓ)	Due to increased nutrient input from anthropogenic sources in the catchment (including WWTWs and industrial effluent) concentrations in the estuary increased under Present state (and future scenarios) compared with reference.	Lower	90	551
		Middle	90	645
		Upper	90	651
DIP (µg/ℓ)	Due to increased nutrient input from anthropogenic sources in the catchment (including WWTWs and industrial effluent) concentrations in the estuary increased under Present state (and future scenarios) compared with reference.	Lower	10	23
		Middle	10	23
		Upper	10	23
Turbidity (NTU)	Urban development and industrial effluent introduced high suspended solid loading into the estuary (High flows river runoff and low flow input from downstream industries	Lower	81	212
		Middle	81	217
		Upper	81	217
DO (µg/ℓ)	Organic loading into the estuary from anthropogenic sources (e.g. industrial effluent) resulted in lower oxygen levels in the estuary, especially during low flow periods	Lower	8	2
		Middle	8	2
		Upper	8	4
Toxic substances	Urban development in the catchment (e.g. Stanger) as well as industries just upstream of the estuary has been known to introduce toxic substances into the estuary similarity to reference as 60% for present and all future scenarios.	60% similarity between Reference and Present		

4.4.2 Water quality health

The similarity in each parameter (e.g. dissolved oxygen) 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. A:Lower = 0.50; B: Middle = 0.20; C: 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 4.13).

Table 4.13 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 flows	80	H
2	**General water quality in estuary**			
a	DIN and DIP concentrations	⇧ due to nutrient enrichment from catchment activities, WWTW and industrial discharges	44	M/L
b	Turbidity (transparency)	⇧ due to suspended solid loading from catchment (high flows) and industries (low flows)	55	M/L
c	Dissolved oxygen (mg/l)	⇩due to organic loading from industries (especially low flows)	48	M/L
d	Toxic substances	⇧ industrial inputs	60	L
Water quality health score[1]			**58.4**	**M**
% of impact non-flow related			**90**	**H**
Adjusted score			**96**	

1 $Score = (0.6 * S + 0.4 * (min\,(a\,to\,d)))$

4.5 MICROALGAE

4.5.1 Overview

i) Main grouping and baseline description

The importance of the microalgae in the ecology of an estuary is that they provide the main source of food for fish and most of the microfauna. This food source occurs both in the water column and on the sediment surface. Some components of the diatom community that make up a variable proportion of the total diatom population can migrate into the sediment for a proportion of the day and night. This implies that these organisms can withstand periods when the surface of the sediment is not under water. This is important in the tidal portions of the estuary that can often be observed as a green/brown mat on the surface of estuary margins during low tide.

Being relatively large by comparison with other microalgal groups, diatoms are sometimes the most important group in an estuary even though they may not be numerically dominant. They have relatively large cells and can be present in the water column or on the bottom. Under very low flow conditions the diatom community is mostly on the sediment surface but under disturbed or high flow conditions they become suspended in the water column.

The flagellate components of the microalgal community are able to maintain themselves in the water column using their flagellae and they are usually numerically dominant when counts are made. They are made up of both autotrophic and heterotrophic organisms, the latter being consumers rather than photosynthetically productive. Despite this, they are still components that are ingested and are therefore part of the food available to larger consumers and especially fish.

The cyanophytes (blue-green microalgae) are a group of non-flagellated photosynthetic bacteria that can make up a large component of both the planktonic and benthic microalgal community. They can be important in that under certain conditions (including anaerobic) because they can utilise gasses such as hydrogen sulphide in order to grow. Some species are able to fix nitrogen and can become important under conditions where the water column is oligotrophic. Certain species of cyanophytes can produce toxins which are able to be harmful if present in high concentration.

The green microalgae are a very diverse group that can be present in estuary waters in fairly high proportions. They are included mostly in the flagellated group and because of the flagellum they are able to maintain their presence within the water column rather than sink to the sediment surface as do the diatoms.

ii) Description of factors influencing microalgae

The factors influencing the different microalgal groups are summarised in Table 4.14. Based on these considerations, the expected influence of the different abiotic states on microalgae is described in Table 4.15.

Table 4.14 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various groupings

Variable	Grouping	
	Phytoplankton	**Microphytobenthos (MPB)**
Open water area	Proportional reduction with loss of open water area (form 37ha to16 ha).	Proportional reduction with loss of open water area (43% remaining).
Salinity	Very little effect when > 5 PSU. When < 5 PSU[1] there can be a few freshwater species present.	Very little salinity effect with estuary MPB.
Mouth condition	Mouth open - Biomass maximum at ~15 PSU. Vertical salinity gradient.	Mouth open - 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 in high retention states.	MPB biomass elevated in high retention states.
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.
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 4.15 Summary of Microalgae responses to different abiotic states

State	Response
State 1 closed (1%)	Very little adverse response if only closed for very short periods
State 2 Intermittently closed (1 - 2 weeks)	Very little adverse response if only closed for short periods
State 3 Tidal (< 7 days)	Productivity and biomass would be maximal under these conditions.
State 4 Freshwater (<1 day)	90% of the phytoplankton and 80% of the MPB would be lost during floods, but the recovery would be quick

iii) Reference condition

Relative change from Reference to Present State are summarised in Table 4.16.

Table 4.16 Summary of relative changes from Reference Condition to Present state

Key drivers	Change
Open water area	57% reduction in area
Closed mouth conditions	5% reduction (with artificial opening)
Nutrient increases	70% increase in biomass
Toxic substances	Possible 5% reduction
Total Change	**16%**

4.5.2 Microalgae health

Health scores are summarised in Table 4.17. About 90% of the impact on microalgae was thought to be non-flow related.

Table 4.17 Microalgae component health score

Variable	Summary of change	Score	Conf
1. Species richness	20% decrease in species richness	80	H
2. Abundance	20% increase in abundance	80	M
3. Community composition	20% change in community composition	80	M
Biotic component health score		**80**	
% of impact non-flow related		**90**	**M**
Adjusted score		**98**	

4.6 MACROPHYTES

4.6.1 Overview

i) Main grouping and baseline description

Mvoti Estuary has a wide riparian area that supports four of the nine macrophyte habitats as described in Table 4.18 and Figure 4.3. Reeds and sedges, particularly common reed (*Phragmites australis)*, dominate the floodplain. Swamp forest, represented by lagoon hibiscus (*Hibiscus tiliaceus)* and freshwater mangrove (*Barringtonia racemosa)* cover the second largest area. A healthy stand of *B. racemosa,* with seedlings present, was situated below the Jex Estate south of the mouth. *Juncus effusus* and *Schoenoplectus scirpoides* surrounded freshwater pools located north of the mouth. Hygrophilous grasses, mainly antelope grass (*Echinocloa pyramidalis*), fringed the water channel before the reed habitat. Although not mapped dune vegetation

(*Commelina africana, Gazania rigens, Ipomoea pes-capre* and *Scaevola plumieri)* was present along the extensive sand and mudflats. Coastal dune forest occurred on a slope to the north of the estuary, close to the reeds and sedges and freshwater pools. Species present were Black Milkwood (*Mimusops caffra*), Coastal Silveroak (*Brachylaena discolour)*, Dune Myrtle (*Eugenia capensis*), Wild banana (*Strelitzia nicolai)*, and White Milkwood (*Sideroxylon inerme*).

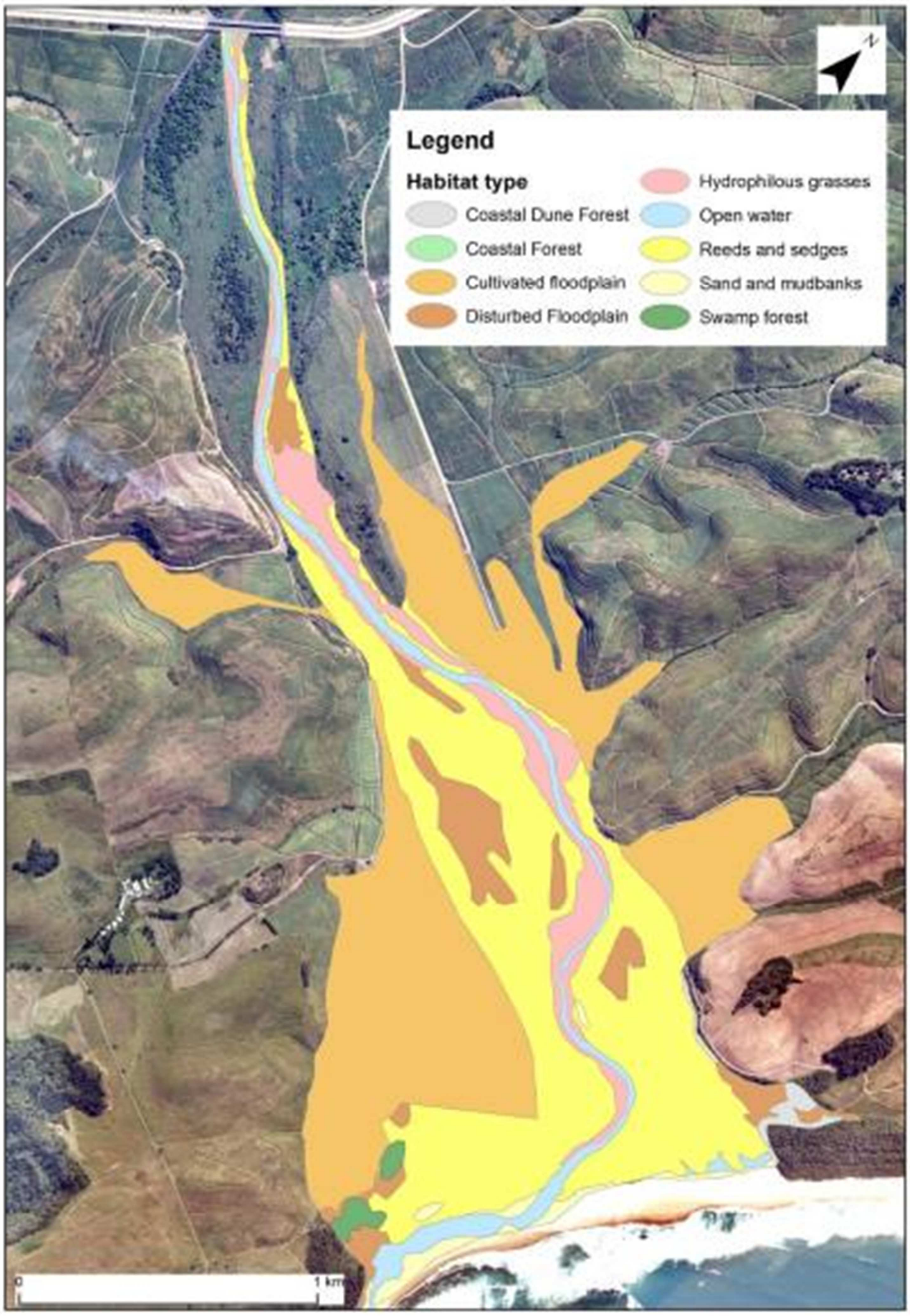


Figure 4.3 Distribution of macrophyte habitats in 2013

A similar species composition was present on the slope below the Jex Estate on the south bank at the mouth. However, this patch was invaded by coastal beefwood (*Casuarina equisetifolia*) and prickly pear trees (*Opuntia ficus-indica*).

Invasive species were prevalent in the estuary, most occurring as bush clumps within the monospecific *Phragmites* spp. stands in the lower reaches. Abundant species were Brazilian Pepper tree (*Schinus terebinthifolius)*, Castor Oil tree (*R. communis*) Peanut butter bush (*Senna didymobotrya),* Spanish Gold (*Sesbania punicea)* and Lantana (*Lantana camara)*.

Invasive shrubs and climbers as well as aquatic invaders such as water hyacinth (*Eichhornia crassipes*) and blue Egyptian water lilies (*Nymphaea nouchali* var. *caerulea)* were also present in these pools.

Table 4.18 Macrophyte habitats and functional groups recorded in the estuary (spp. examples in italics)

Habitat type	Defining features, typical/dominant species	Area (ha) 2013
Open surface water area	Serves as a possible habitat for phytoplankton.	16
Intertidal sand and mudflats	Intertidal zone consists of sand/mud banks that are regularly flooded by freshwater inflows. This habitat provides a possible area for microphytobenthos to inhabit.	5
Swamp forest	Stands of freshwater mangrove, *Barringtonia racemosa,* and coastal hibiscus, *Hibiscus tiliaceus*, present at the south bank of the mouth.	2
Reeds and sedges	Stands of *Phragmites australis* and *Phragmites mauritianus* were abundant. *Schoenoplectus scirpoides* present surrounding the freshwater pools north of the estuary.	87
Floodplain	Little natural floodplain still remains at Mvoti Estuary. Grasses, particularly *Echinochloa pyramidalis, Stenotaphrum secundatum* and *Sporobolus virginicus,* fringe the water channel and are backed by reeds and sedges. Coastal forest (*Brachylaena discolor*) occurs on both banks near the mouth, but most of the area does not occur within the EFZ.	51

ii) Description of factors influencing macrophytes

Table 4.19 provides a summary of the effect of abiotic drivers on the various macrophyte groups, while Table 4.20 list the responses to the abiotic states.

Table 4.19 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on macrophyte habitats

Variable	Grouping	
	Reeds and sedges	Swamp forest
Mouth condition	Present open mouth conditions will enable the further proliferation of reeds and sedges due to low water level.	Present open mouth conditions maintain salinities suitable for *B. racemosa*. Even during closed conditions the salinities remain in a low enough range to not affect the *B. racemosa* stand.
Retention times of water masses	The mouth is kept permanently open due to high flows and artificial breaching thus retention time is minimal. This prevents the establishment of submerged macrophytes and macroalgae.	
Flow velocities (e.g. tidal velocities or river inflow velocities)	High river inflow prevents the establishment of submerged macrophytes and macroalgae.	
Total volume and/or estimated volume of different salinity ranges	No strong longitudinal salinity gradient present along the estuary therefore reeds and sedges uniformly distributed.	
Floods	There has been some reduction in floods and re-resetting events that would result in a more stable system allowing macrophyte encroachment. Under natural conditions floods would flush out excess nutrients and sediment from the estuary and prevent reed encroachment.	
Salinity	Low salinity encourages the growth of reeds, sedges and swamp forest.	
Turbidity	High turbidity as a result of high flows and catchment disturbance prevents the establishment of submerged macrophytes.	

Variable	Grouping	
	Reeds and sedges	**Swamp forest**
Dissolved oxygen	This would not influence the macrophytes.	
Nutrients	High nutrients levels encourage the proliferation of *Phragmites* spp. and other macrophytes. Invasive aquatics such as water hyacinth occur in response to high nutrients.	
Sediment characteristics (including sedimentation)	Sedimentation increases the available habitat for the establishment of reeds and sedges.	Accumulation of sediments in the *B. racemosa* stand could smother seedlings thus causing a decline in the population.
Other biotic components	Little natural floodplain remains due to extensive sugarcane cultivation. Infilling and draining of wetlands for planting of sugarcane was evident in the lower reaches of the estuary. Invasive species are abundant replacing indigenous vegetation.	

Table 4.20 Summary of Macrophyte responses to different abiotic states

State	Response
State 1: Closed	Inundation of swamp forest habitat may be detrimental but only after months. Potential for growth of submerged macrophytes and macroalgae due to reduced water velocity.
State 2: Tidal, intermitted closed	High water level could prevent reeds and sedges growing into the main water channel.
State 3: Tidal	Ideal conditions for the proliferation of reeds and sedges due to favourable water level.
State 4: Fresh water dominated	Large floods would remove reed and sedge habitat. High water velocity would prevent the growth of submerged macrophytes and macroalgae.

iii) Reference condition

The loss of natural floodplain due to cultivation, the extent of invasive species and the presence of hygrophilous grasses has resulted in a low similarity in community composition compared to natural conditions. Changes in the macrophyte habitats were assessed from historical aerial photographs. The distribution of different estuary habitats was mapped from rectified 1937 aerial images from National Geo-spatial Information (previous Chief Directorate: Surveys and Mapping). The present distribution and area cover of habitats was mapped from 2009 aerial images with updates provided from the ESRI™ World Imagery basemap of 2013. Table 4.21 provides a comparison of the areas covered by macrophytes. As the estuary had already been transformed in 1937 due to sugarcane cultivation, the areas obtained from the 1937 aerial imagery were adjusted to reflect the natural conditions of the estuary.

Almost the entire (71.9%) floodplain of Mvoti Estuary was under sugarcane cultivation in 1937 (Table 4.21). In 2013 this area had declined to 45% resulting in the expansion of reed habitat. Reed and sedge habitat has almost quadrupled since 1937 where it only fringed the water channel. The dune vegetation present at the sandbar at the mouth was not visible in earlier aerial photography and thus was not mapped. Swamp forest could not be mapped from the 1937 aerial photograph, but it is assumed that it would have naturally occurred in the estuary.

Over time the river channel has narrowed abandoning a large area immediately north of the bend in the estuary (Table 4.21). This area has become overgrown by hygrophilous grasses dominated by antelope grass, *Echinochloa pyramidalis.* According to Begg (1976) the owner of the sugar estate, Mr Jex, planted this fodder grass to stabilise the banks of the estuary. It is therefore unlikely that this habitat would have been present under natural conditions. Sand and mudflats have also been overgrown with reeds.

The water channel of the estuary is dynamic and changes over time may be as a result of the aerial photographs being taken in different seasons. Reed habitat would also vary as channel changes and flooding events would flush out the reeds. Under natural conditions swamp forest would likely have occurred behind the reeds fringing the open water, particularly in the lower reaches.

Table 4.21 Comparison of macrophyte habitats area (ha) at Mvoti Estuary

Macrophyte habitat	Area		
	Natural	1937	2013
Open water	27	27	16
Cultivation	0	184	116
Sand and mudbanks	22	22	6
Reeds and sedges	40	23	87
Swamp forest	5	0	2
Natural floodplain	191	29	0
Hygrophilous grasses	0	0	51
Alien vegetation	0	0	7
TOTAL	**285**	**285**	**285**

4.6.2 Macrophyte health

Table 4.22 and Table 4.23 were used to inform the changes in the macrophyte habitats over time. Alien plants were added as a subgroup as they occupy a large area and thus have substantially affected the natural estuarine vegetation. Area covered by reeds and sedges and hygrophilous grasses was adjusted to add alien vegetation area as they were the most invaded. There has been a major increase in hygrophilous grass and reed and sedge areas where a dynamic floodplain would have existed previously. Sand and mud banks have been vegetated with grasses and reeds thus altering the community composition. The loss of natural floodplain due to cultivation, the extent of invasive species and the presence of hygrophilous grasses has resulted in a low similarity in community composition compared to natural conditions.

Table 4.22 Summary of relative changes from Reference Condition to Present state

Key drivers	Change
⇧ nutrients from catchment activities, WWTW and industrial discharges	⇧ Growth of all macrophytes, in particular reed, sedge and grass expansion. ⇧ invasive aquatics
⇧ in State 1 and 2 (closed mouth conditions)	⇧ Growth of all macrophytes due to nutrient retention and low water velocity conditions
⇩ flow 1 $m^3 s^{-1}$ for 80% time and ⇩ floods	⇧ reeds, sedges, hygrophilous grasses, now a more stable estuary with sediment deposition and infilling of intertidal habitats
⇧ catchment and floodplain disturbance	⇧ invasive species

Table 4.23 Area (ha) covered by macrophyte habitats and calculation of the similarity in community composition.

Macrophyte habitat	Natural area cover	2013 area cover	Minimum
Floodplain	191	0	0
Reeds & sedges	40	87	40
Swamp forest	5	2	2
Alien plants	0	7	0
Hygrophilous grasses	0	51	0
Cultivated floodplain	0	115	0
% similarity			**32%**

Changes in species richness, abundance and community composition from natural to present conditions was used to determine the macrophyte health score (Table 4.24). Mvoti Estuary has been completely transformed by sugarcane cultivation within the dynamic floodplain, resulting in a macrophyte community composition minimum health score of 32.

Table 4.24 Macrophyte component health score

Variable	Summary of change	Score	Conf
1. Species richness	Large monospecific stands of reeds and sedges cause low diversity. Invasive species potentially displaced some species. Species have been lost because of disturbance of the floodplain.	60	H
2. Abundance	Extensive sugarcane cultivation in the floodplain has reduced macrophyte habitat. There has been an increase in reeds, sedges, hygrophilous grasses and floating invasive aquatics as a result of nutrient input. The system is less dynamic, emergent macrophytes now colonise stabilised sand and mudbanks which are removed by large floods.	52	H
3. Community composition	Natural floodplain is now cultivated with sugarcane. Sand and mud flats have been colonized by reeds, sedges and grasses.	32	H
Biotic component health score		**32**	
% of impact non-flow related		**60**	
Adjusted score		**72.8**	

4.7 INVERTEBRATES

4.7.1 Overview

i) Description of factors influencing invertebrates

Each invertebrate species associated with estuaries utilises and depends on a particular suite of biotic and abiotic parameters, which determines their abundance and distribution. In order to predict a response in the invertebrate community structure to changes in these parameters, the estuarine invertebrate macrofauna need to be understood according to their relative dependence on these parameters.

ii) Baseline description

Benthic sampling of intermittently open and river mouth type estuaries in KwaZulu Natal (KZN) covering virtually every such system (MER, unpublished) in KZN from the Mahlongwa at the southern end of the eThekwini municipal area to the Nhlabane north of Richards Bay indicates that over an extended period a maximum of 30-40 benthic macroinvertebrate species may be encountered in any one system. These include resident species as well as others having a marine phase in the life cycle. In terms of abundance the major groups are the polychaete worms, whose life cycles and dispersal abilities are virtually unknown, and the peracarid groups of crustaceans. Larger anomuran crustaceans and bivalves are uncommon. Chironomid fly larvae are the only insects that occur in any numbers but are typically associated with low salinities. This latter group may also occur with oligochaete worms.

Development of an estuarine type zooplankton would depend to a large degree on water retention in the estuary, which is not a feature of general conditions in the Mvoti.

Five taxa were recorded in total (Table 4.25), consisting of four at the two upper sites and three at the two lower sites in August 2013. The very short list included a total of 19 leeches, eight polychaetes *Ceratonereis keiskama,* one tubificid oligochaete and one bivalve *Brachidontes virgiliae.* Oligochaetes were common at the upper site, decreasing downstream but the benthos was totally dominated by chironomid midge larvae which were between five and 80 times more abundant than the next most common taxon at any one site. The community crashed further in February 2014 when only three taxa were recorded consisting of a single tentatively identified polychaete, a single tubificid oligochaete and the rest oligochaetes. The previously dominant chironomid larvae were not recorded.

Placing the generalisations of invertebrates in KZN systems in the context of the Mvoti Estuary it is highly significant that only two taxa occurred in any numbers, *viz.* chironomid fly larvae and oligochaete worms, neither of which could be identified to species level.

Table 4.25 Benthic macroinvertebrates found within the Mvoti estuary during 2013 - 2014

	August 2013				February 2014			
	1	2	3	4	1	2	3	4
ANNELIDA								
Polychaeta								
Ceratonereis keiskama		89						
Cirratulidae					9			
Hirudinea	18		133	9				
Oligochaeta	98	222	977	3863	9	1465	1758	213
Tubificidae			9				9	
MOLLUSCA								
Bivalvia								
Brachidontes virgiliae				9				
INSECTA								
Diptera								
Chironomidae incl pupae	5728	20513	11455	11011				
Mean total individuals.m^2	**5843**	**20824**	**12574**	**14892**	**18**	**1465**	**1767**	**213**
No of taxa at each site	**3**	**3**	**4**	**4**	**2**	**1**	**2**	**1**

The invertebrates respond to the states within the Mvoti are summarised in Table 4.26 below.

Table 4.26 Summary of Invertebrate responses to different abiotic states

State	Response
State 1: Closed	Closure is likely to provide some retention and stability as well as water depth which is likely to encourage an increase in abundance of the species present in the system which are freshwater tolerant.
State 2: Tidal, intermitted closed	Closure is likely to provide some retention and stability as well as water depth which is likely to encourage an increase in abundance of the species present in the system which are freshwater tolerant.
State 3: Tidal	This state may allow for the inclusion in the zooplankton and macroinvertebrate community of estuarine and marine species if salinities are in the upper part of the predicted range (i.e. 15 – 20 ppt[1]).
State 4: Fresh water dominated	The invertebrate population is unlikely to remain within the system during periods of strong outflow. The predominantly freshwater conditions which would prevail would eliminate the estuarine

1 Parts per thousand

iii) Reference condition

Reference conditions would have featured a hugely different dissolved oxygen regime and the absence of any possible toxic pollutants (Table 4.27). Floods and consistent river flows would have maintained the system in states three and four; under present conditions there have been some changes, as shown by the appearance of states one and two, but the temporal dominance of states three and four implies that there would be little biological response.

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

Key drivers	Change
⇧ nutrients and other pollutants from catchment activities, WWTW and industrial discharges	Encourages macrophyte and microphyte growth increasing Biological Oxygen Demand (BOD) and influencing water quality to the extent that it affects zooplankton and benthic macro invertebrate populations.
⇧ in State 1 and 2 (constricted or closed mouth conditions)	Increased retention with accumulation of contaminants and concomitant declines in water quality reducing biomass and excluding sensitive species.
⇩ flow 1 m^3/s for 80% time and ⇩ floods	Net accumulation of sediments in the system, shallowing and loss of habitat for epifauna and infaunal invertebrates. Loss of intertidal habitat results in a loss of intertidal invertebrates.
⇧ catchment and floodplain disturbance	Loss of habitat and declines in abundance and biomass and potential for run-off from adjacent land to influence the estuary negatively. No riparian or fringing vegetation to slow flows and remove contaminants.

4.7.2 Invertebrate health

Health scores for the invertebrate component are provided in Table 4.28. About 95% 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	The Mvoti estuary would never have been a system with a very rich estuarine biota due to strong outflows and freshwater conditions but some species would have been expected in zone A and zone B at times. It is important to acknowledge that the loss of habitat due to cultivation and manipulation of the EFZ and less flow and poor water quality may have resulted in the exclusion of some sensitive species.	25	M
2. Abundance	A loss of habitat diversity and reduction in surface area - intertidal sandbanks, water column and the prevailing low dissolved oxygen levels over long time periods will have resulted in a depression the populations from reference. Although retention during state 1 & 2 may have offset this by allowing more time for these communities to develop the poor water quality works against this making it unlikely.	30	M
3. Community composition	The dominance and proliferation of oligochaetes, chironomids and other tolerant species suggests that the conditions in the system have favoured some species over others.	30	M
Biotic component health score		**25**	
% of impact non-flow related		**95**	**M**
Adjusted score		**74**	

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.

Category	Description
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 Mvoti estuary have been sampled on several occasions in the last 20 years and a fairly wide range of species (48) has been recorded. Two of these, the guppy *Poecilia reticulata* and the common carp *Cyprinus carpio*, are alien. Indigenous species include representatives from all functional estuarine use groups and the main trophic categories. In general however, and compared with most other KwaZulu-Natal open estuaries, a low number of species occurs in the Mvoti at any one time. Notable also is the fact that very few of these species occur with any regular frequency of occurrence. These include predominantly estuarine dependent marine and freshwater species. The estuarine round herring. *Gilchristella aestuaria* is the noted exception, the only estuarine resident species that has occurred in over 40% of the documented fish surveys. The fish fauna is highly dominated by detritivores, particularly young juvenile mullet and Mozambique tilapia *Oreochromis mossambicus*. Zooplanktivores occur in low abundances as in the case with zoobenthivores. Piscivores are even more uncommon.

Overall, estuarine dependent marine and freshwater fishes dominate the fish assemblage in terms of frequency of occurrence and relative abundance. Although estuarine residents occur with a high frequency of occurrence, they do so as different species and in low abundance. Their populations in the Mvoti are neither stable, nor persistent. A notable feature of the estuary's sampled ichthyofauna is the presence of catadromous Anguillid eels. The relatively high frequency of occurrence of eels in the Mvoti indicates that the river is important for this group of fishes. The permanently open estuary and consistent flow of fresh water into the sea are therefore important as a migration conduit.

To a large extent then, the low species diversity on the estuary is natural and reflective of the system's reference condition, and is the result of the naturally poor nursery habitat in the estuary because of its perched nature and ever-flowing fresh water outflow.

ii) Description of factors influencing microalgae

The main flow related factors influencing fish in the Mvoti 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 rowspan="2">Variable</th><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="5">Estuarine fish habitat is naturally limited in the estuary. It undergoes natural fluctuations strongly affected by the long term hydrological cycle:</td></tr>
<tr><td rowspan="2">Floods</td><td colspan="4">Floods open and scour the system of sediments and marginal vegetation. They leave a wide, braided channel with sloping banks. A matrix of intertidal and subtidal habitat, with a complexity of current flows, provides habitat for estuarine and estuarine dependent species.</td></tr>
<tr><td colspan="3">Increased habitat supports higher numbers of estuarine associated fish species and higher abundances of these fishes.</td><td>Reduced habitat quality for most freshwater species results in lower species richness and abundance of these fishes.</td></tr>
<tr><td rowspan="2">Prolonged low flow periods</td><td colspan="4">Prolonged absence of large floods allows bank vegetation to encroach into the shallow channel and the estuary is effectively canalised by dense stands of reeds. This reduces habitat complexity of open waters (subtidal and intertidal sand banks and flats). This is exacerbated by poor water quality (high nutrient loads) that stimulate growth of emergent vegetation, and floating mats of alien vegetation under present day conditions.</td></tr>
<tr><td colspan="3">Reduced habitat for most estuarine associated species causes loss of species from the system, and loss of fish abundances.</td><td>Increase in vegetated habitats results in increases in freshwater species richness as well as abundances.</td></tr>
<tr><td colspan="5">The estuary's tidal prism is small and mouth condition is affected primarily by river flow. Mouth closure occurs infrequently under present day and reference conditions. Moderately reduced flows result in a constrained mouth which increases retention time in the estuary and results in a greater area of backfill, and therefore volume of estuarine water.</td></tr>
<tr><td>Mouth closure</td><td>Most resident species proliferate under closed mouth conditions. Under present day nutrient loads and organic inputs water quality under mouth closure will result in kills of estuarine residents.</td><td colspan="2">Recruitment of marine spawning fishes is reduced by prolonged mouth closure but short periods of closure may benefit fishes (more so the estuarine dependent than marine species) that are already in the system. Numbers of species and abundance therefore declines with prolonged mouth closure. Under present day nutrient loads an organic inputs water quality under prolonged mouth closed conditions will result in fish kills and a severely reduced estuarine dependent ichthyofauna.</td><td>Increase in abundance of selected salinity tolerant species, most notably O. mossambicus. Under present day nutrient loads and organic inputs water quality under mouth closed conditions will result in fish kills and a severely reduced freshwater ichthyofauna. Select tolerant species are likely to persist.</td></tr>
<tr><td>Mouth constraint</td><td>Resident species proliferate but present day nutrient loads and organic</td><td colspan="2">Recruitment is not limited by a constrained mouth. Even infrequent closure is unlikely to affect the species compliment that presently uses the estuary markedly. Mouth constraint</td><td>Increase in abundance of selected salinity tolerant species, most notably O. mossambicus. Under</td></tr>
</table>

Variable	Grouping			
	Estuarine resident	Estuarine dependent marine	Marine	Freshwater
	inputs result in pollution impacts to estuarine resident species.	rather benefits estuarine associated fishes in the estuary. Estuarine residents and estuarine dependent fishes especially increase under conditions of higher estuarine volume, greater water retention time and increased zooplankton and benthic productivity. Numbers of species and abundance therefore increase. However, present day nutrient loads and organic inputs and increased retention has water quality and habitat impacts (stimulated vegetation growth) that cause declines in estuarine associated fishes in the long term.		present day nutrient loads an organic inputs water quality impacts occur but two tolerant species are likely to persist, *O. mossambicus* and sharptooth catfish, *Clarias gariepinus*.

Table 4.31 Summary of fish responses to different abiotic states

State	Response
State 1: Closed	Higher water levels and increased estuary volume result in greater water column productivity and benefit species that current predominate in the estuary. Some freshwater species will be affected by higher salinities and precluded from the lower, middle and even upper reaches of the estuary. Under current condition of nutrient inputs, prolonged mouth closure will result in very poor water quality conditions, low oxygen concentrations which will be detrimental and likely result in fish kills.
State 2: Tidal, intermitted closed	Higher water levels and increased estuary volume result in greater water column productivity and benefit estuarine residents, as well as marine species that current predominate in the estuary. Some freshwater species will be affected by higher salinities and be precluded from the lower and middle reaches of the estuary. Overall however, this state is likely to result in the greatest diversity of fishes in the estuary.
State 3: Tidal	Most estuarine associated fishes will be limited to using the lower reaches of the estuary, even though physical habitat is probably poorest in this reach (due to shallow at the mouth and high current flows with little refugia). The highest productivity is likely to occur in middle reaches, where fewer species will occur, but in higher abundance and in larger sizes.
State 4: Fresh water dominated	Lowest diversity of fishes. Few estuarine dependent fishes due to lack of habitat and food resources. Only those with a preference for vegetated habitats will prevail as these areas provide refuge from high freshwater flows. Mullet species are also likely to be limited to fewer taxa in occur in reduced abundances. Freshwater species will prevail and occur in vegetated habitats.

iii) Reference condition

Under reference conditions, the Mvoti estuary occurred predominantly in a fresh water dominated state. Tidal intrusion occurred over the low flow months from late autumn to early spring. The estuarine channel was maintained by periodic flood events that prevented over encroachment of reeds and bank vegetation into the naturally shallow system. Water quality was good, with markedly lower nutrient and organic loads delivered to the system from the catchment. Flow complexity was caused by tidal back-up and a braided channel, which created depth variability and lee backwaters behind sandbars.

A well-developed estuarine plume occurred in the nearshore coastal waters off the systems mouth. These waters were used by estuarine dependent fishes but probably more significantly provided cues for catadromous fishes to enter the estuary. Freshwater mullet, *Myxus capensis*, would have occurred in the estuary but Anguillid would have passed through the lower reaches as glass eels and elvers to access freshwater habitats higher in the catchment. The Mvoti was probably an important catchment for these eels. The best nursery areas would have occurred in the lower and middle reaches of the estuary for most species, although a selected few species would have preferentially used the upper reaches of the estuary and even accessed lower coastal reaches of the river. These would have included the mullets *M. capensis* and *Mugil cephalus* as well as the moony *Monodactylus argenteus*. Estuarine residents occurred in small populations, as did a few freshwater species, including, most abundantly, *O. mossambicus*.

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
Salinity gradient	Under reference state a higher frequency of open fresh conditions (State 4) occurred. Present state sees a marked increase in tidal conditions (State 3) which sees some salinity gradient develop. This, together with mouth constraint (Sate 2) and even period mouth closure (State 1) actually improves conditions for estuarine resident and estuarine dependent marine fishes, assuming habitat and water quality remain supportive of these fishes.
Flood period	Lower frequency and magnitude flood events results in quicker and greater encroachment of bank vegetation into the shallow estuarine channel between floods. This reduces habitat area for estuarine and estuarine dependent fishes and reduces the already limited nursery function of the estuary.
Water quality	Nutrient and organic loads to the estuary are much higher than under reference conditions. This stimulates vegetation encroachment from the banks and also results in the establishment of alien floating forms which severely reduces and degrades estuarine nursery habitat. Oxygen concentrations under present day conditions are limiting to the fish fauna as a result of water pollution. Poor water quality contributes to the occurrence of alien freshwater species in the estuary.

4.8.2 Fish health

The Present Ecological State of the Mvoti fish assemblage is described and scored in Table 4.33 below. About 70% 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		80	M
2. Abundance		55	M
3. Community composition		655	M
Biotic component health score		**55**	
% of impact non-flow related		**70**	
Adjusted score		**87**	

4.9 BIRDS

4.9.1 Overview

i) Main groupings and baseline description

In the 1980s, Mvoti Estuary was noted for its high species richness of waterbirds, as well as a relatively high density of waterbirds relative to the length of shoreline. The Mvoti Estuary is classified as a sub-regional Important Bird Area (IBA; Barnes, 1998). Large numbers of terns, up to 10 000 individual birds, have been recorded regularly roosting at the estuary on expansive and exposed islands in the main water channel.

Another key waterbird species is the Collared Pratincole, a Red Data species (Barnes, 2000), which has been found breeding on the exposed sandbanks in the river. Other noteworthy Red Data waterbirds recorded at the estuary include African Marsh Harrier, Woolly-necked Stork and Chestnut-banded Plover. Mvoti Estuary has also boasted the regular presence of a large number of vagrant waterbirds over the years, making it a popular spot for bird-watching and 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 Mvoti 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 Mvoti 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 Mvoti 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. Mvoti Estuary is characterised by extensive encroachment by aquatic vegetation.

Main foraging guilds	Defining features and typical/dominant species
Carnivorous and scavenging gulls	Gulls, primarily the Kelp and Grey-headed gulls along the KwaZulu-Natal 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 below lists the effects of various abiotic and biotic factors on the different waterbird feeding guilds present at Mvoti 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).

Variable	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 (as well as breeding pratincoles)
Abundance of zooplankton	Indirectly, through influence on fish		Assumed positive for some omnivorous species	
Benthic invertebrate	Indirectly, through influence on fish			Primary food source for invertebrate-feeding waders

Variable	Grouping			
	Swimming and large wading piscivores	Aerial piscivores	Swimming herbivorous waterfowl	Small wading invertebrate feeders
abundance				
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, and nesting pratincoles.
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, but a large-scale flood is currently required for this system to ‘re-set’ itself and remove the current high levels of encroaching vegetation and siltation.

iii) Reference condition

The primary reasons for the recent diminution in avifaunal value stem from a chronic deterioration in the aquatic habitats present at the estuary between at least the 1980s (and likely earlier dating back to the reference condition). The main damage to the estuarine functioning is associated with extensive sugar-cane planting in the catchment and floodplain (including floodplain drainage), siltation, sand-winning, water abstraction and other flow-related factors, water pollution including eutrophication, the spread of both alien and indigenous (reedbeds) aquatic vegetation, human disturbance and changes to the physical configuration of the estuary (Table 4.37). Loss of the exposed sandbanks in the main channel to encroaching vegetation was identified as a major contributor to the loss of the roosting terns and breeding pratincoles.

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

Key drivers	Change
Sugar-cane planting in floodplain (including drainage) and catchment	Direct loss of estuarine habitat. Increased siltation and turbidity of estuary. Directly effects visual predatory piscivores.
Sand winning upstream of estuary	Decrease in water quality, i.e. increased turbidity. 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	Eutrophication promotes encroachment of macrophytes in the estuary, a major problem at Mvoti Estuary.
Macrophyte encroachment at cost of exposed sandflats in main river channel	One of the most major threats to avifaunal habitats at Mvoti Estuary.
Human disturbance at the mouth	Negatively impacts roosting terns and gulls.

Key drivers	Change
TOTAL CHANGE	**90%**

4.9.2 Bird health

A recent investigation into the current IBA status of the Mvoti Estuary (Theron, 2013) reported that the waterbird avifauna of the site has deteriorated sharply since about the mid-2000s and recommended that the site be de-listed as an IBA. Since that time, large numbers of terns no longer roost at the estuary and nor do Collared Pratincoles nest there.

The waterbird information synthesised in this report clearly confirms a dramatic decrease in both species richness and the abundance of waterbirds at Mvoti Estuary between the 1980s and today. Most notable have been the desertion of the site by large numbers of roosting terns (mainly Palaearctic migrant terns) and by breeding Collared Pratincoles. The site has deteriorated from being one of significant avifaunal importance, as evidenced by its listing as an Important Bird Area, and great popularity with bird-watchers, to a site no longer worthy of IBA status and now rarely visited by bird-watchers.

At this stage, there seems little chance of any reversal of this deterioration.

The Present Ecological State of the Mvoti bird assemblage is described and scored in Table 4.38 below. About 60% 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	Many key species no longer present at the estuary or now only rare visitors, e.g. Collared Pratincole.	10	H
2. Abundance	Massive overall decrease in waterbird numbers, including loss of major tern roost which once numbers up to 10 000 birds.	10	H
3. Community composition	Loss of many rarer species (e.g. Collared Pratincole) and important Palaearctic migrants (e.g. many of the terns), with remnant waterbird population now mainly comprising hardy generalists, e.g. Blacksmith Lapwing and Egyptian and Spur-winged geese.	10	H
Biotic component health score		**10**	**H**
% of impact non-flow related		**60**	**H**
Adjusted score		**64**	

5 PRESENT ECOLOGICAL STATUS

5.1 OVERALL ESTUARINE HEALTH INDEX SCORE

The EHI scores allocated to the various abiotic and biotic health parameters for the Mvoti Estuary and the overall PES for the system are calculated from the overall EHI score (Table 5.1). The EHI score for the Mvoti Estuary in its present state was estimated to be 55 (i.e. 55% similar to natural condition), which translates into a D (summarised in Table 5.1). The Mvoti Estuary is presently in a D Category, which is mostly attributed to the following factors:

- The high organic load in the SAPPI Stanger effluent which contributes to regular low oxygen events (< 4 mg/l);
- Increase nutrient input as a result of 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 sugarcane farming;
- Change in sediment structure due to sand mining; and
- The loss of resetting floods which assists in removing excessive vegetation growth form intertidal and supratidal areas (important bird habitat).

Table 5.1 Estuarine Health Score for the Mvoti Estuary

Variable	Estuarine health score		
	Overall	Excluding flow related pressures	Conf
Hydrology	53.4	53	M
Hydrodynamics and mouth condition	95	95	H
Water quality	58.4	58.4	M
Physical habitat alteration	73	92	M
Habitat health score	**70**	**75**	
Microalgae	80	98	
Macrophytes	32	73	H
Invertebrates	25	96	M
Fish	55	87	M
Birds	10	64	H
Biotic health score	**40**	**88**	
ESTUARY HEALTH SCORE	**55**	**81**	
PRESENT ECOLOGICAL STATUS (PES)	**D**	**B**	
OVERALL CONFIDENCE	**M**	**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 81, 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 C, 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 organic load in the SAPPI discharge and poor catchments practises was found to be the most important factor that influenced the health of the system. The regular occurrence of low oxygen events in the estuary reduced invertebrate abundance to 55% of Reference Conditions and prevents the system from functioning as a fish nursery, in turn reducing food availability to birds. The excess nutrients in the inflow water increased plant growth and loss of open intertidal and riparian habitat (e.g. sand and mudbank that use to be important bird habitats).

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

6 THE RECOMMENDED ECOLOGICAL CATEGORY

6.1 CONSERVATION IMPORTANCE

The EIS takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (Table 6.1). 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 (DWA 2014), apart from functional importance, which is scored by the specialists in the workshop (Table 6.1). The Estuary Importance scores for five components and the importance rating is presented in Tables 6.2 and 6.3, respectively.

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

Functionality	Score
a. Estuary: Input of detritus and nutrients generated in estuary	20
b. Nursery function for marine-living fish	30
c. Movement corridor for river invertebrates and fish breeding in sea	80
d. Migratory stopover for coastal birds	80
e. Catchment detritus, nutrients and sediments to sea	100
f. Coastal connectivity (way point) for fish	20
Functional importance score - Max (a to f)	**100**

Even though the Mvoti Estuary tends to recruit high numbers of estuarine associated fish in spring and summer, it is of low nursery value as the river flow is high for most of the year, and there are few backwater areas for fish to take refuge in from the main currents. However the Mvoti Estuary is an important movement corridor for eels (CITES listed species). This places significance on ecological flow and water quality requirements for the estuary (and the river).

In the 1980s Mvoti Estuary was noted for its high species richness of waterbirds, as well as a relatively high density of waterbirds relative to the length of available shoreline (Ryan *et al.,* 1986). The Mvoti Estuary is classified as a sub-regional IBA (Barnes, 1998). Large numbers of terns, up to 10 000 individual birds, have been recorded regularly roosting at the estuary on expansive and exposed islands in the main water channel. Another key waterbird species is the Collared Pratincole, a Red Data species (Barnes, 2000), which has been found breeding on the exposed sandbanks in the river. Other noteworthy Red Data waterbirds recorded at the estuary include African Marsh Harrier, Woolly-necked Stork and Chestnut-banded Plover. Mvoti Estuary has also boasted the regular presence of a large number of vagrant waterbirds over the years, making it a popular spot for bird-watching and bird-watchers. A recent investigation into the current IBA status of the Mvoti Estuary (Theron, 2012), however, reported that the waterbird avifauna of the site has deteriorated sharply since about the mid-2000s and recommended that the site be de-listed as an IBA. Since that time, large numbers of terns no longer roost at the estuary and nor do Collared Pratincoles nest there. The aquatic avifauna of the estuary is now a mere remnant of what it once was and the site is no longer attractive as a bird-watching locality.

The functional importance of Mvoti Estuary is very high for the nearshore marine environment. It is one of five key systems (Mfolozi, Mvoti, uMngeni, uMkhomazi, Umzimkulu) that supply sediment, nutrients and detritus to the coasts. The sediment load from the Mvoti is especially important as it is habitat forming and plays an important role in

maintaining the beaches and near shore habitats along this coast. The impact of further dam development on the nearshore marine environment was not assessed as part of this study, but should be assessed to ensure that all ecological processes and related ecosystem services (e.g. beaches, coastal buffers against storms, nearshore and prawn fishery) are addressed.

The EIS for the Mvoti Estuary, is therefore estimated to be 69 (Table 6.2), i.e., the estuary is rated as "Important" (Table 6.3).

Table 6.2 EIS for the Mvoti Estuary

Criterion	Weight	Score
Estuary Size	15	60
Zonal Rarity Type	10	70
Habitat Diversity	25	30
Biodiversity Importance	25	80.5
Functional Importance	25	100
Weighted Estuary Importance Score		**69**

Table 6.3 Estuarine importance scores (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 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 degree of protection, or desired protection, for a particular estuary (Table 6.5).

Table 6.5 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.

The PES for the Mvoti Estuary is a D. The Mvoti 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, which formed part of the National Biodiversity Assessment (NBA) 2011 (Turpie *et al*., 2013, Van Niekerk and Turpie, 2012). The NBA 2011 (Van Niekerk and Turpie, 2012) recommends that the minimum Category for the Mvoti be a D, that the system be a granted full no-take protection, and that 75% of the estuary margin be undeveloped (Table 6.6).

Table 6.6 National Estuary Biodiversity Plan requirements

Estuary Requirements	Mvoti
Current health category	**D**
National and/or Regional Priority set	**SA**
Recommended extent of protection	**Full**
Recommended extent of undeveloped margin	**75%**
Provisional estimate of Recommended Ecological Category	**D**

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

7 CONSEQUENCES OF ALTERNATIVE SCENARIOS

7.1 DESCRIPTION OF SCENARIOS

The proposed scenarios for the Mvoti system are summarised in Table 7.1 and each scenario and its associated variables are described in the sub-sections that follow. Detailed scenario descriptions are provided in Report RDM/WMA11/00/CON/CLA/0414.

7.1.1 Present Day

The Water Resources Yield Model (WRYM) from the original DWA Mvoti River Dam Feasibility Study was updated with the latest information available to produce the best possible estimate of present day flow. Information from the DWS All Towns Strategies and the Water Reconciliation Strategy Study for the KwaZulu-Natal Coastal Metropolitan Areas was used to define the urban and industrial water requirements and return flows to present day levels (2007).

Table 7.1 Summary of the Mvoti Scenarios

Scenario	Scenario Variables				
	Update water demands	Ultimate development demands and return flows (2040)	EWR	MRDP[1]	Imvutshane Dam
MV1	Yes	No	No	No	No
MV21	Yes	No	REC tot[2]	No	No
MV22	Yes	No	REC low[3]	No	No
MV3	Yes	Yes	No	Yes	Yes
MV41	Yes	Yes	REC tot[2]	Yes	Yes
MV42	Yes	Yes	REC low[3]	Yes	Yes
MV43	Yes	Yes	REC low+[4]	Yes	Yes

1 Mvoti River Development Project (Isithundu Dam). 2 Recommended Ecological Category (Total Flows)
3 Recommended Ecological Category (Low Flows).
4 Recommended Ecological Category (Total Flows for January, February, March and Low Flows for remaining months).

7.1.2 Scenario MV21 and MV22: Present Day and REC EWR

For these scenarios, both the total flow EWRs set to achieve the REC (MV21) and the low flow EWRs set to achieve the REC (MV22) will be included in the model and the modelled flows at the EWR sites will be assessed for present day conditions.

The purpose is to determine to what degree both the two EWR flow scenarios (MV21 and MV22) with the tributary inflows will achieve the REC and whether curtailments in the upstream water use are required under present day conditions bearing in mind that there is currently minimal storage regulation in the Mvoti River System, with the only noticeable dam being Lake Merthley in the upper reaches of the catchment (supports Greytown).

7.1.3 Scenario MV3: Ultimate Development, Mvoti River Development Project and Imvutshane Dam

This scenario will include estimates of increased water use and return flows for the domestic sector (Greytown and Kwadukuza) due to population growth and improved service delivery for the ultimate development scenario. Estimated increased domestic use will be sourced from the DWA's All Towns Strategies.

This scenario will also include the implementation of the MRDP (Isithundu Dam (102 m^3 gross storage)) and the Imvutshane Dam (located on a tributary of Hlimbitwa River just above the Mvoti and Hlimbitwa confluence), which is currently being planned by Umgeni Water to augment supply to Mapumulo and Maqumbi.

The modelled flows at the EWR sites with the described developments are included.

7.1.4 Scenario MV41, MV42 and MV43: Ultimate Development, REC EWR and Mvoti River Development Project

These scenarios are based on Scenario MV3 where the flows at the EWR sites will be assessed for the following EWR flows:

- Total flow EWRs set to achieve the REC (**MV41**).
- Low flow EWRs set to achieve the REC (**MV42**).
- Total Flows for January, February, March and Low Flows remaining months set to achieve the REC (**MV43**).

The purpose of these scenarios is to determine to what degree the total flow, low flow and the in between flow EWRs together with the dam spills and tributary inflows from the dam will achieve the REC. The 'cost' of releasing an EWR from the future Isithundu Dam (and possibly Imvutshane Dam) can also be determined as an impact on the current socio-economics.

7.1.5 Scenario M5: Extreme Development, with Welverdiend Dam and its Excess FY included as an abstraction

This scenario is based on Scenario MV3 where the following aspects are included:

- No EWRs.
- Scenario MV5 includes an additional storage dam (Welverdiend) with a Full Supply Capacity of 250 million m^3 and a demand equal to the excess yield of the dam (75.3 million m^3/a) was abstracted from the dam.

These changes had quite a significant impact on the low flows of the estuary. The purpose of this scenario is to test the significant impact on the low flows against the Mvoti Estuary Condition.

The above mentioned water resource development scenarios were then grouped into four groups (Group A to D) based on how the simulated runoff scenarios would affect the Mvoti Estuary.

Table 7.2 Summary of flow scenarios

Scenarios		Description	MAR ($X10^6$ m^3)	% Remaining
Reference		Natural Flow	374.66	100
Present		Present	225.49	60
Group A	S21	Present, with total EWRs.	232.51	62
	S22	Present, with low flow EWRs.	231.05	62
Group B	S3	Ultimate Development Demands and Return Flows (2040), include Imvutshane Dam.	187.78	50
Group A	S41	Ultimate development demands and return flows (2040), include Imvutshane Dam , with total EWRs.	217.02	58
Group C	S42	Ultimate development demands and return flows (2040), include Imvutshane Dam , with low flow EWRs.	209.15	56
	S43	Ultimate development demands and return flows (2040), include Imvutshane Dam with total EWRs for January to March.	211.13	56

Scenarios		Description	MAR ($X10^6$ m^3)	% Remaining
Group D	S 5	Extreme Development, with Welverdiend Dam and its Excess FY included as an abstraction.	106.99	29
Group E	S21	Similar to Scenario Group A, MV21 (Present, with total EWRs), minus organics in SAPPI effluent, 25% reduction in nutrient input and flood plain restoration in the Estuary Functional Zone.	232.51	62

7.2 VARIABILITY IN RIVER INFLOW

The occurrences of the flow distributions (monthly flows in m^3/s) under the future Scenarios of the Mvoti Estuary, derived from a 74-year simulated data set are provided in Table 7.3 to 7.6. The full sets 74-year series of simulated monthly runoff data for the future Scenarios are provided in Table 7.7 to 7.10.

Table 7.3 Summary of the monthly flow (in m^3/s) distribution under Scenario Group A (and E)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	89.6	47.3	45.3	49.7	86.8	210.0	81.3	53.2	28.8	11.7	28.2	240.5
99	57.8	41.6	42.0	40.5	84.7	134.1	71.1	36.0	25.9	9.3	14.9	83.0
90	7.2	17.3	18.1	23.5	31.8	33.3	18.3	8.6	5.9	4.0	3.0	5.2
80	4.5	8.2	10.4	14.8	24.0	20.7	11.4	6.2	3.8	3.1	2.4	2.6
70	3.4	6.8	7.3	9.9	15.6	13.5	9.4	4.8	3.0	2.2	1.7	2.2
60	2.7	5.1	5.6	6.6	10.1	10.8	7.9	4.4	2.7	1.6	1.4	1.8
50	2.2	4.3	4.6	5.4	8.1	8.2	6.1	3.0	2.2	1.2	1.2	1.6
40	1.7	3.4	3.5	4.5	6.3	6.8	4.8	2.6	1.8	1.1	0.9	1.4
30	1.5	2.8	3.1	3.2	4.8	5.3	3.8	2.3	1.6	0.9	0.8	1.0
20	1.3	1.7	1.9	1.9	3.7	3.5	2.8	1.9	1.2	0.8	0.6	0.7
10	0.9	1.3	1.3	1.4	2.1	2.8	1.9	1.7	0.9	0.6	0.5	0.5
1	0.3	0.6	0.6	0.9	1.2	1.2	0.8	0.6	0.5	0.3	0.3	0.3
0.1	0.3	0.4	0.6	0.8	0.9	0.9	0.7	0.6	0.5	0.3	0.3	0.3

Table 7.4 Summary of the monthly flow (in m^3/s) distribution under Scenario Group B

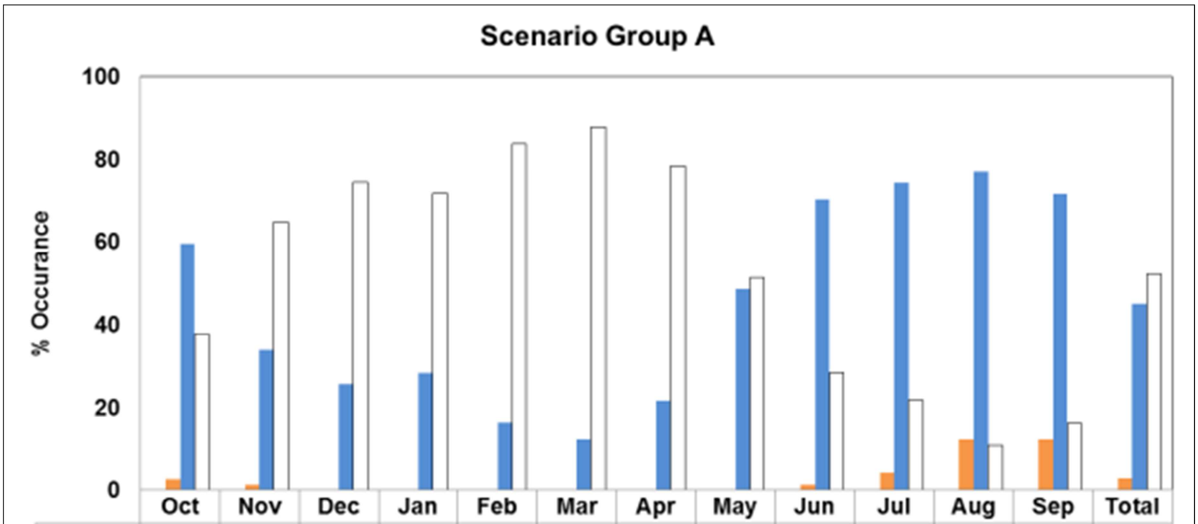
%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	88.2	41.5	44.2	48.1	85.7	208.9	80.0	52.2	27.6	10.4	27.0	239.5
99	55.6	37.8	40.8	35.9	83.6	133.0	69.8	34.8	24.8	8.1	13.6	80.6
90	5.5	16.1	15.1	21.6	28.5	29.9	17.0	7.3	4.6	2.5	1.7	3.0
80	2.6	5.8	8.6	12.5	21.5	19.2	10.2	4.9	2.6	1.6	1.1	1.2
70	1.9	4.3	4.8	7.0	14.1	12.2	7.9	3.5	1.5	1.0	0.7	1.1
60	1.4	2.9	3.7	4.8	7.1	8.4	6.2	3.0	1.2	0.7	0.5	0.8
50	1.2	2.3	2.8	3.5	6.2	6.5	4.6	1.8	1.0	0.5	0.4	0.7
40	1.0	1.9	1.7	2.3	4.6	5.2	3.4	1.3	0.6	0.4	0.4	0.5
30	0.7	1.2	1.3	1.3	2.5	3.7	2.4	1.0	0.5	0.3	0.3	0.4
20	0.5	1.1	1.0	0.9	1.4	2.1	1.4	0.7	0.4	0.3	0.3	0.3
10	0.4	0.7	0.7	0.8	0.8	1.0	0.8	0.4	0.3	0.3	0.3	0.3
1	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3
0.1	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table 7.5 Summary of the monthly flow (in m^3/s) distribution under Scenario Group C

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	88.7	41.2	44.8	48.8	86.4	209.7	80.7	52.9	28.3	11.1	27.8	239.5
99	54.9	37.8	40.4	36.7	83.8	133.7	70.6	35.5	25.5	8.8	14.7	80.5
90	5.4	15.5	15.9	22.5	28.8	30.9	17.7	8.1	5.3	3.6	3.1	3.4
80	3.2	5.9	9.1	13.3	22.6	19.3	10.9	5.7	3.6	3.2	2.4	2.7
70	2.8	4.6	5.6	7.5	14.9	12.9	8.8	4.3	3.0	2.2	1.7	2.2
60	2.4	3.2	4.0	5.4	7.8	9.2	7.0	3.8	2.6	1.6	1.3	1.8
50	2.0	2.8	3.3	4.1	7.1	7.5	5.3	2.8	2.1	1.2	1.2	1.4
40	1.5	2.2	2.2	2.7	4.7	5.9	4.1	2.4	1.6	1.1	0.9	1.2
30	1.2	1.7	1.8	2.0	2.8	4.1	3.1	2.0	1.4	0.9	0.8	0.8
20	0.9	1.5	1.5	1.5	2.0	2.5	2.3	1.7	1.1	0.8	0.7	0.7
10	0.7	1.1	1.1	1.2	1.6	2.0	1.7	1.4	0.9	0.6	0.6	0.6
1	0.4	0.6	0.6	0.8	0.9	1.0	0.9	0.7	0.6	0.4	0.4	0.4
0.1	0.4	0.5	0.6	0.8	0.9	1.0	0.8	0.7	0.6	0.4	0.4	0.4

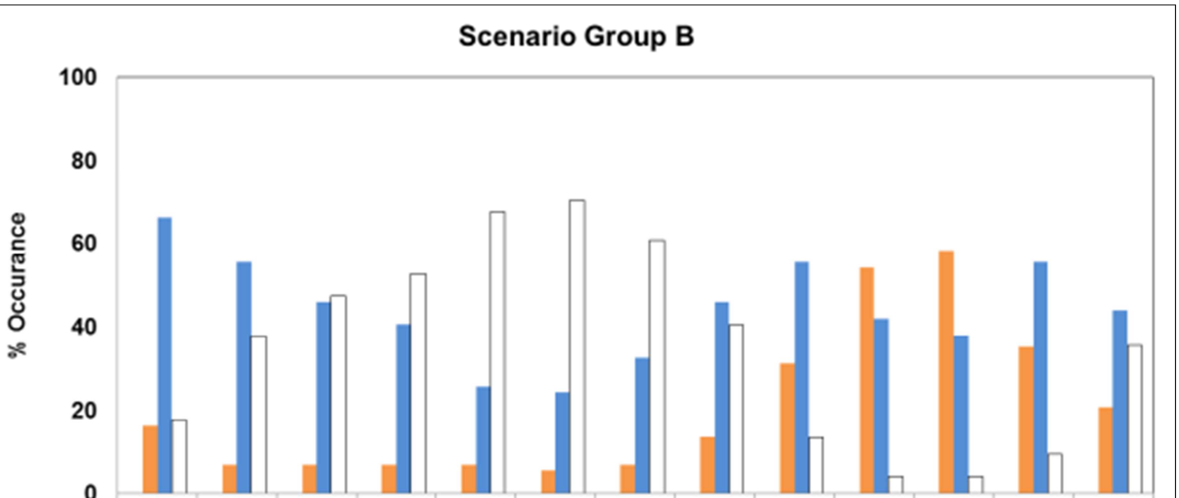
Table 7.6 Summary of the monthly flow (in m^3/s) distribution under Scenario Group D

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	85.0	26.7	40.7	43.1	83.7	208.1	77.2	49.7	25.2	7.6	24.5	237.8
99	47.7	24.4	28.9	33.0	75.3	131.5	67.4	32.1	22.5	5.3	9.6	77.3
90	0.8	7.0	5.7	11.2	20.8	19.9	10.1	4.6	2.0	0.4	0.4	0.5
80	0.5	0.7	1.4	1.2	7.3	9.7	6.1	2.1	0.4	0.3	0.3	0.4
70	0.4	0.5	0.4	0.5	4.0	5.5	3.6	0.5	0.3	0.3	0.3	0.3
60	0.4	0.4	0.4	0.4	1.1	2.4	1.5	0.4	0.3	0.3	0.3	0.3
50	0.3	0.4	0.4	0.4	0.4	1.4	0.5	0.3	0.3	0.3	0.3	0.3
40	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
30	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3
20	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
10	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.1	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2



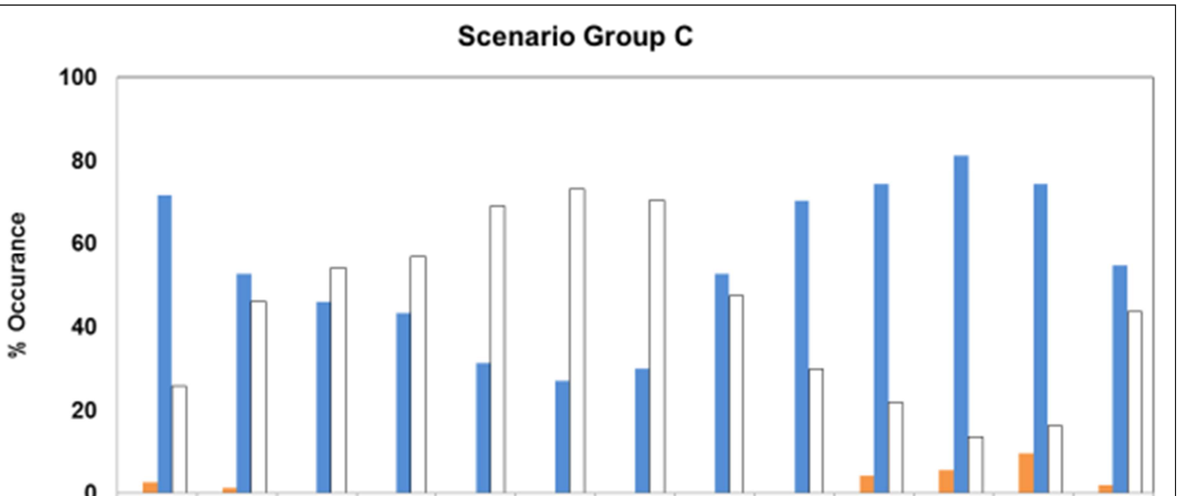
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	3	1	0	0	0	0	0	0	1	4	12	12	3
State 3	59	34	26	28	16	12	22	49	70	74	77	72	45
State 4	38	65	74	72	84	88	78	51	28	22	11	16	52

Figure 7.1 Graphic presentation of the occurrence of the various abiotic states under the Scenario Group A (and E)



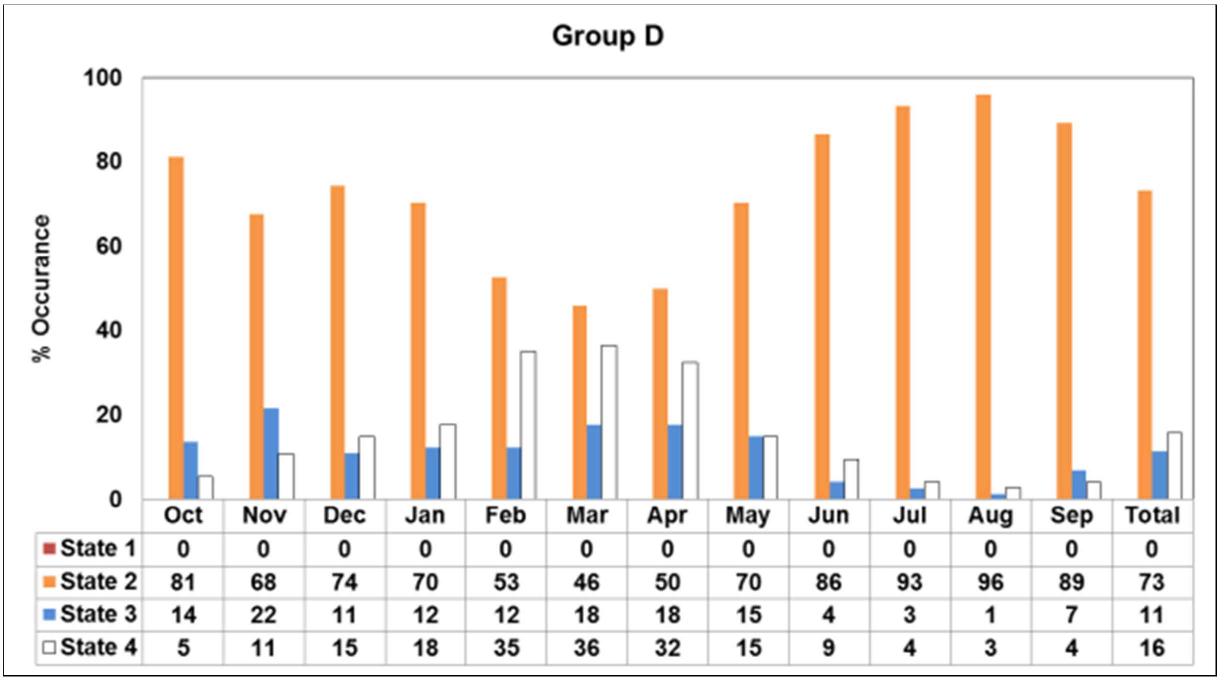
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	16	7	7	7	7	5	7	14	31	54	58	35	21
State 3	66	55	46	41	26	24	32	46	55	42	38	55	44
State 4	18	38	47	53	68	70	61	41	14	4	4	9	35

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



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	3	1	0	0	0	0	0	0	0	4	5	9	2
State 3	72	53	46	43	31	27	30	53	70	74	81	74	55
State 4	26	46	54	57	69	73	70	47	30	22	14	16	44

Figure 7.3 Graphic presentation of the occurrence of the various abiotic states under Scenario Group C



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	81	68	74	70	53	46	50	70	86	93	96	89	73
State 3	14	22	11	12	12	18	18	15	4	3	1	7	11
State 4	5	11	15	18	35	36	32	15	9	4	3	4	16

Figure 7.4 Graphic presentation of the occurrence of the various abiotic states under Scenario Group D

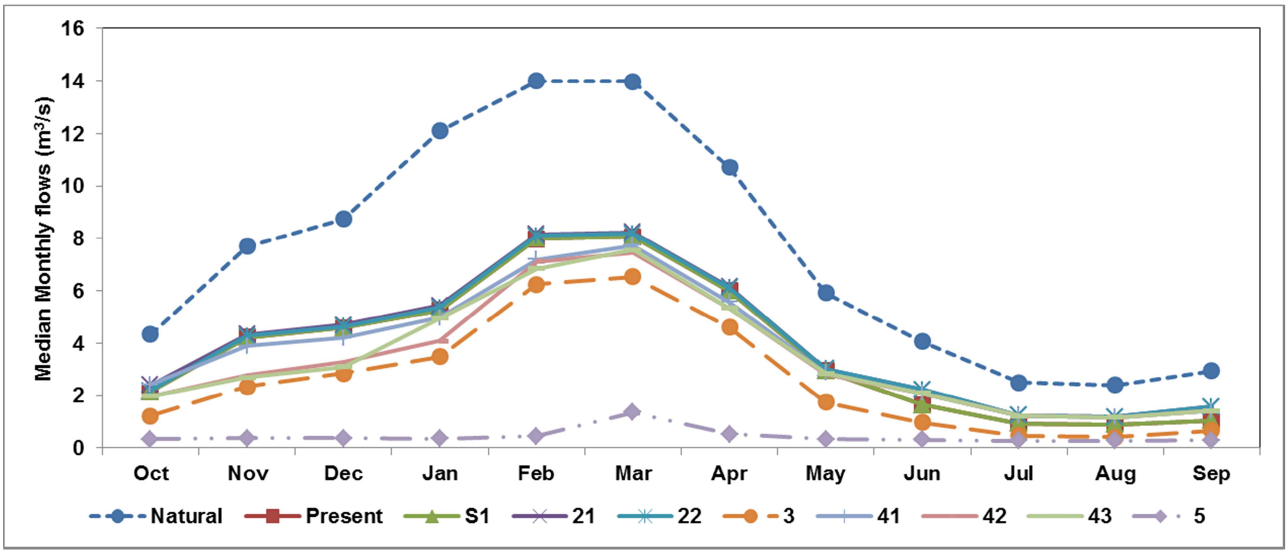


Figure 7.5 Graphic presentation of the simulated median monthly under various flow scenarios

Table 7.7 Simulated monthly flows (in m^3/s) to the Mvoti Estuary for Scenario Group (A and E)

Date	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1921	3.3	16.1	27.7	12.1	4.3	3.0	2.3	1.9	2.5	2.2	2.4	2.5
1922	3.2	21.3	10.1	32.1	28.6	12.9	6.8	2.5	1.2	0.7	0.5	0.3
1923	0.3	0.4	0.7	1.3	2.7	2.5	1.7	1.3	0.9	0.5	0.4	1.6
1924	2.3	11.6	17.9	32.3	21.6	218.4	82.5	6.2	2.8	2.1	1.7	2.1
1925	3.4	3.9	3.1	1.4	1.4	2.8	2.8	1.7	1.3	1.3	0.7	1.8
1926	5.1	6.4	5.6	3.8	5.8	55.7	23.8	2.6	1.3	0.8	1.3	1.4
1927	1.4	1.3	1.8	10.0	8.4	5.3	3.9	2.3	1.2	0.6	0.5	0.9
1928	1.5	1.3	1.3	1.6	2.7	16.5	10.0	3.0	3.2	4.1	3.0	2.8
1929	5.4	6.8	4.1	5.2	4.8	9.0	5.8	2.5	1.3	0.7	0.9	1.9
1930	2.6	3.4	3.2	4.1	4.6	3.2	2.3	1.7	0.8	0.7	0.6	0.6
1931	0.8	1.3	1.4	1.7	72.0	50.1	15.7	9.7	7.2	3.1	1.4	1.0
1932	1.4	2.2	3.2	2.9	3.5	3.4	2.6	1.8	0.8	0.9	0.9	0.6
1933	0.7	6.4	11.2	29.6	18.4	9.7	11.7	9.9	6.2	3.2	2.8	2.5
1934	1.5	1.7	28.6	14.7	7.1	6.7	5.2	3.6	24.7	11.9	3.0	1.4
1935	1.0	0.9	0.6	1.4	27.8	34.2	14.0	8.0	7.8	4.0	2.0	1.3
1936	1.8	39.3	15.8	2.6	6.4	6.2	3.4	1.7	0.9	0.7	0.6	0.6
1937	1.0	1.3	14.7	10.2	15.2	7.9	5.7	4.7	3.1	3.2	3.0	2.0
1938	2.3	4.5	9.2	7.1	37.5	21.5	8.8	4.7	3.0	2.1	1.6	2.6
1939	3.4	10.9	12.5	8.0	8.2	5.6	3.7	55.1	29.2	8.4	3.0	2.4
1940	1.9	20.2	45.7	17.7	5.1	3.3	4.0	2.9	1.7	0.8	0.5	0.8
1941	1.3	1.6	1.3	1.5	3.9	12.3	9.4	4.6	3.0	1.9	1.8	2.4
1942	3.8	7.1	40.6	18.4	8.3	8.5	66.8	29.0	7.2	7.3	29.7	15.4
1943	24.8	17.9	9.5	4.7	6.6	14.3	8.2	2.2	1.8	1.7	1.1	3.5
1944	5.9	4.9	1.9	1.2	2.1	21.9	11.5	3.0	1.8	0.9	0.4	0.3
1945	0.9	1.0	0.7	1.6	4.2	4.3	3.2	2.1	1.1	0.6	0.3	0.3
1946	1.0	2.8	3.5	4.4	13.0	12.3	10.7	6.2	4.1	3.2	2.4	2.0
1947	2.0	20.2	14.6	8.6	8.1	20.2	14.2	6.3	2.8	1.2	0.6	0.4
1948	1.1	1.8	1.4	1.6	4.2	6.0	8.3	5.5	2.7	1.5	0.8	0.8
1949	2.4	9.1	18.1	9.8	6.5	9.4	8.5	4.7	2.7	1.3	1.4	1.3
1950	0.9	0.7	3.5	5.4	4.8	3.6	2.8	1.9	1.0	0.6	3.0	5.8
1951	6.4	4.0	4.3	10.1	10.9	7.2	4.8	2.7	2.0	1.4	1.2	0.8
1952	0.7	2.5	7.5	12.7	24.5	11.1	3.7	1.9	1.1	0.5	0.9	1.6
1953	1.7	2.4	3.4	5.2	8.5	7.5	6.0	5.3	4.1	2.7	1.4	2.4
1954	44.7	22.5	5.3	15.0	12.6	8.2	7.4	4.5	2.7	1.3	0.6	0.7
1955	1.6	4.8	5.3	2.1	17.7	22.4	10.1	3.0	1.8	1.0	0.9	1.5
1956	1.7	3.3	39.7	30.7	15.4	9.6	11.3	6.4	2.3	1.4	1.2	18.3
1957	36.1	17.9	6.5	24.5	23.8	9.5	8.0	6.2	2.9	1.2	0.5	1.3
1958	1.4	3.5	7.3	6.3	10.5	6.6	2.8	10.3	8.6	3.3	2.0	1.8
1959	3.1	4.2	3.2	2.0	3.1	4.1	5.6	4.1	2.2	1.0	0.7	0.9
1960	1.7	4.7	21.2	16.3	10.7	8.2	20.1	10.4	3.8	2.3	1.3	1.6
1961	2.1	3.4	3.1	3.8	6.2	6.4	5.1	2.5	1.3	0.6	1.1	1.4
1962	1.4	7.9	6.9	6.7	5.9	11.3	9.5	4.3	2.7	4.2	3.9	2.1
1963	1.6	2.9	1.9	19.7	12.4	3.5	2.6	2.2	1.5	1.1	0.6	0.9
1964	2.3	3.0	2.2	1.6	1.5	1.4	0.7	0.6	2.6	3.2	3.2	3.2
1965	3.2	4.1	3.8	6.2	6.8	3.2	1.6	1.9	1.7	1.0	0.9	1.0
1966	1.3	2.2	3.1	16.9	19.5	43.4	22.1	7.2	3.2	1.7	1.0	0.5
1967	1.2	3.5	3.0	3.2	4.0	4.3	3.8	2.3	1.0	0.5	0.9	1.7
1968	1.6	1.7	3.0	3.2	3.8	34.5	19.4	7.4	4.7	2.4	1.4	1.4
1969	4.2	5.8	5.0	3.2	2.3	1.7	1.0	1.1	1.4	1.0	1.1	2.9
1970	12.3	8.7	4.8	5.4	8.0	7.7	7.0	17.6	9.9	4.0	4.3	4.2
1971	3.8	3.2	5.6	5.3	24.3	13.5	5.7	4.1	3.6	2.5	1.6	0.8
1972	0.9	1.8	1.9	3.0	33.9	18.0	8.8	4.9	2.3	1.0	1.7	7.5
1973	7.6	6.4	4.5	28.6	27.2	13.8	8.3	5.4	3.7	2.5	1.3	0.6
1974	0.3	1.2	1.8	9.8	26.1	11.7	4.6	2.7	1.7	0.8	0.5	5.7
1975	6.0	5.3	9.8	50.7	52.3	103.0	42.9	8.6	3.8	1.9	1.3	1.4
1976	3.3	5.3	3.3	4.9	17.4	13.5	7.6	3.0	1.7	0.8	0.8	1.9
1977	3.8	5.1	3.9	5.8	8.1	13.5	9.6	4.4	2.3	1.1	1.0	2.0
1978	5.0	7.8	7.0	5.9	8.3	6.8	4.1	2.4	1.6	1.1	1.3	1.5
1979	1.6	1.4	1.3	1.3	1.4	0.9	0.8	0.6	0.5	0.3	0.3	5.8
1980	5.7	7.1	4.9	4.6	6.0	3.5	1.7	1.9	2.1	1.6	2.1	3.4
1981	3.4	6.9	4.1	2.6	3.4	7.8	6.9	3.2	1.7	0.8	0.4	0.4
1982	2.7	4.5	3.0	1.6	1.4	1.5	1.6	1.1	0.7	0.8	1.3	1.1
1983	1.4	7.6	7.8	36.7	60.2	27.8	15.7	8.7	4.1	3.5	3.8	2.6
1984	2.7	3.4	1.9	3.9	83.9	31.2	3.4	1.2	0.5	0.3	0.3	0.3
1985	18.9	10.8	6.0	13.3	8.1	5.9	6.2	3.0	1.8	1.1	0.7	0.6
1986	1.5	2.1	6.8	21.2	18.9	23.6	12.1	4.8	5.2	3.9	3.7	258.0
1987	93.1	13.0	8.5	5.1	87.1	76.4	22.6	3.8	3.0	2.7	2.6	2.3
1988	2.2	4.4	10.8	7.1	33.2	14.6	3.4	2.2	2.1	1.4	0.8	0.5
1989	1.1	47.9	19.9	3.1	2.1	5.3	7.2	4.4	2.3	1.0	1.9	2.2
1990	2.7	2.9	5.7	9.3	25.3	27.3	10.8	2.4	1.7	1.2	0.9	1.6
1991	3.7	4.6	2.2	1.4	1.7	1.8	1.5	0.9	0.5	0.3	0.3	0.3
1992	0.7	1.4	1.3	1.0	1.6	2.8	2.8	2.0	1.2	0.6	0.8	1.6
1993	9.1	7.0	5.3	6.3	4.9	4.5	4.1	2.3	1.1	1.2	9.4	5.7
1994	2.2	1.7	1.3	0.8	0.8	1.8	4.0	4.8	5.3	4.0	2.3	1.4
Averag	5.4	6.8	7.9	9.3	14.8	16.7	9.6	5.1	3.3	2.0	1.9	5.7
Min	0.3	0.4	0.6	0.8	0.8	0.9	0.7	0.6	0.5	0.3	0.3	0.3
Max	93.1	47.9	45.7	50.7	87.1	218.4	82.5	55.1	29.2	11.9	29.7	258.0

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

Date	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1921	2.1	14.9	26.5	10.8	3.1	1.9	1.0	0.7	1.0	0.9	1.1	1.1
1922	1.6	18.5	8.8	30.9	27.4	11.7	5.6	1.2	0.4	0.3	0.3	0.3
1923	0.3	0.3	0.3	0.7	1.1	1.0	0.8	0.5	0.4	0.3	0.3	0.6
1924	1.1	6.9	10.3	24.9	20.3	217.3	81.1	4.9	1.4	0.9	0.7	1.3
1925	2.0	2.2	1.4	0.7	0.3	0.9	1.0	0.5	0.5	0.5	0.3	0.6
1926	2.7	3.2	2.8	2.6	4.6	54.5	22.4	1.4	0.4	0.3	0.4	0.5
1927	0.7	0.7	0.9	4.9	5.8	4.2	2.7	1.0	0.3	0.3	0.3	0.3
1928	0.6	0.8	0.4	0.8	0.8	9.2	7.9	1.7	1.7	2.8	1.7	1.6
1929	4.2	5.6	2.8	4.0	3.6	7.7	4.5	0.9	0.3	0.3	0.3	0.9
1930	1.3	1.7	1.3	1.6	2.5	2.0	1.1	0.4	0.3	0.3	0.3	0.3
1931	0.3	0.5	0.7	0.8	62.1	48.9	14.4	8.5	5.9	1.7	0.5	0.4
1932	0.6	1.1	1.1	0.8	1.5	2.2	1.4	0.5	0.3	0.3	0.3	0.3
1933	0.3	3.6	6.3	27.3	17.1	8.5	10.5	8.6	4.9	1.9	1.6	1.2
1934	0.7	0.9	26.0	13.4	5.9	5.6	4.0	2.4	23.6	10.7	1.7	0.8
1935	0.5	0.4	0.3	1.0	20.7	33.0	12.6	6.8	6.5	2.8	0.8	0.5
1936	1.1	36.3	14.5	1.4	5.3	5.0	2.1	0.4	0.3	0.4	0.4	0.3
1937	0.4	0.7	10.7	6.4	12.2	6.6	4.6	3.4	1.5	1.8	1.7	0.8
1938	1.2	2.7	8.0	5.9	36.2	20.2	7.5	3.5	1.6	0.9	0.6	1.2
1939	1.7	9.2	11.2	6.7	6.9	4.3	2.4	54.1	27.9	7.1	1.7	1.1
1940	1.0	18.3	44.5	16.4	3.9	2.1	2.8	1.6	0.5	0.3	0.3	0.4
1941	0.6	1.0	0.6	0.9	1.4	4.9	8.1	3.3	1.3	0.7	0.7	1.1
1942	2.0	5.0	39.4	17.1	7.1	7.3	65.6	27.7	6.0	6.1	28.5	14.1
1943	23.7	16.7	8.3	3.4	5.4	13.1	6.9	1.1	0.8	0.7	0.5	2.0
1944	3.6	2.9	1.0	0.4	0.9	19.4	10.2	1.7	0.7	0.3	0.3	0.3
1945	0.5	0.6	0.3	0.8	2.0	1.7	1.1	0.9	0.5	0.3	0.3	0.3
1946	0.4	1.2	1.6	1.9	6.5	6.1	9.0	4.9	2.9	1.8	1.1	1.0
1947	1.1	17.7	13.4	7.3	6.9	19.0	12.9	4.9	1.3	0.4	0.3	0.3
1948	0.5	1.1	0.8	0.8	1.6	2.5	4.6	4.2	1.2	0.7	0.4	0.4
1949	1.4	6.0	15.3	8.6	5.3	8.2	7.2	3.4	1.1	0.4	0.4	0.4
1950	0.3	0.3	1.7	2.1	1.4	2.4	1.6	0.6	0.3	0.3	1.3	2.9
1951	4.5	2.8	3.2	8.8	9.6	6.0	3.5	1.4	0.8	0.6	0.5	0.3
1952	0.3	1.1	3.9	9.4	23.3	9.8	2.5	0.8	0.3	0.3	0.3	0.6
1953	0.9	1.2	1.7	2.5	4.2	6.3	4.7	4.0	2.9	1.1	0.5	1.2
1954	42.2	21.3	4.1	13.9	11.3	7.0	6.1	3.3	1.2	0.5	0.3	0.3
1955	1.0	2.8	2.9	0.9	14.2	21.1	8.8	1.7	0.6	0.3	0.3	0.7
1956	1.0	1.5	35.0	29.3	14.1	8.4	10.1	5.1	1.1	0.5	0.4	15.4
1957	34.9	16.6	5.3	23.4	22.6	8.3	6.9	4.9	1.4	0.5	0.3	0.6
1958	1.0	1.9	4.1	3.4	9.3	5.2	1.6	9.1	7.4	2.0	0.7	0.8
1959	1.6	2.3	1.9	0.8	2.0	2.9	4.4	2.8	0.9	0.5	0.3	0.4
1960	0.8	2.5	16.5	15.0	9.5	6.9	18.9	9.1	2.6	1.1	0.6	0.7
1961	1.3	1.8	1.3	1.1	4.9	5.2	3.9	1.2	0.3	0.3	0.4	0.5
1962	0.8	4.5	3.5	5.4	4.7	10.1	8.2	3.0	1.3	2.8	2.7	1.0
1963	0.8	1.3	0.9	17.6	11.1	2.3	1.4	1.0	0.4	0.3	0.3	0.3
1964	1.2	1.5	1.0	0.8	0.6	0.3	0.3	0.3	1.1	1.5	1.6	1.6
1965	1.7	2.2	1.7	2.9	2.7	1.2	0.7	0.6	0.6	0.5	0.3	0.4
1966	0.6	1.1	1.3	10.4	18.2	42.1	20.8	5.9	1.8	0.5	0.3	0.3
1967	0.5	1.7	1.2	1.3	1.8	2.4	2.6	1.0	0.3	0.3	0.4	0.9
1968	1.1	1.2	1.4	1.1	1.1	30.0	18.1	6.2	3.4	1.2	0.5	0.5
1969	2.3	3.5	3.8	2.0	1.1	0.6	0.3	0.3	0.6	0.5	0.4	1.1
1970	6.6	6.8	3.6	4.2	6.9	6.5	5.8	16.4	8.6	2.8	3.1	3.0
1971	2.6	2.1	4.5	4.2	23.1	12.2	4.4	2.9	2.3	1.3	0.8	0.4
1972	0.4	1.1	1.0	1.2	29.0	16.7	7.5	3.5	1.0	0.3	0.5	4.8
1973	6.0	5.2	3.3	27.4	25.9	12.5	7.1	4.2	2.5	1.0	0.3	0.3
1974	0.3	0.4	0.9	5.2	23.1	10.4	3.4	1.4	0.6	0.3	0.3	3.0
1975	3.3	4.0	8.5	49.4	50.9	101.7	41.6	7.3	2.6	0.8	0.6	0.7
1976	1.6	2.8	1.4	3.7	16.2	12.2	6.3	1.8	0.5	0.3	0.3	1.0
1977	2.2	2.9	1.8	3.5	6.9	12.3	8.3	3.1	1.0	0.4	0.4	0.8
1978	2.6	4.7	5.7	4.7	7.1	5.5	2.9	0.9	0.3	0.3	0.3	0.5
1979	0.9	0.9	0.6	0.4	0.3	0.3	0.2	0.2	0.3	0.3	0.3	4.1
1980	3.6	4.5	2.7	2.2	3.1	1.6	0.7	1.1	1.3	0.9	1.2	2.0
1981	2.1	4.4	2.1	1.0	1.4	3.8	2.9	1.2	0.7	0.4	0.3	0.3
1982	1.3	2.4	1.3	0.8	0.4	0.3	0.3	0.3	0.3	0.3	0.5	0.6
1983	0.6	4.2	3.9	27.0	59.0	26.6	14.5	7.3	2.9	2.2	2.6	1.5
1984	1.4	2.1	0.9	2.6	82.7	29.8	2.1	0.3	0.3	0.3	0.3	0.2
1985	12.8	7.4	4.8	11.9	6.8	4.8	5.0	1.8	0.6	0.4	0.3	0.3
1986	0.6	1.1	3.8	17.1	17.6	22.4	10.7	3.6	4.0	2.6	2.6	257.1
1987	91.8	11.8	7.3	3.9	86.0	75.2	21.2	2.6	1.5	1.1	1.1	1.1
1988	1.2	2.2	9.5	5.9	32.0	13.3	2.2	1.0	0.5	0.3	0.3	0.3
1989	0.5	41.9	18.6	1.9	1.0	4.1	5.9	3.1	1.0	0.4	0.8	1.1
1990	1.5	1.6	3.2	6.9	24.0	26.1	9.5	1.2	0.6	0.5	0.4	0.7
1991	1.9	2.5	1.0	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3
1992	0.4	0.9	0.6	0.3	0.5	0.9	0.9	0.6	0.4	0.3	0.4	0.8
1993	5.9	4.3	2.7	2.8	1.6	1.1	0.8	0.3	0.3	0.5	8.1	4.3
1994	1.3	1.1	0.4	0.3	0.2	0.8	1.7	2.4	2.8	2.1	1.2	0.7
Averag	4.2	5.1	6.1	7.4	12.9	15.0	8.2	3.9	2.2	1.1	1.2	4.8
Min	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Max	91.8	41.9	44.5	49.4	86.0	217.3	81.1	54.1	27.9	10.7	28.5	257.1

Table 7.9 Simulated monthly flows (in m^3/s) to the Mvoti Estuary for Scenario Group C

Date	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1921	2.8	15.6	27.2	11.5	3.8	2.5	1.9	1.6	2.5	2.3	2.4	2.5
1922	2.7	15.2	9.5	31.7	28.1	12.4	6.3	2.3	1.0	0.7	0.6	0.4
1923	0.4	0.5	0.6	1.2	1.7	1.9	1.6	1.3	0.9	0.6	0.5	1.4
1924	2.1	6.5	10.1	29.1	21.1	218.1	81.9	5.6	2.8	2.0	1.6	2.1
1925	2.8	2.5	1.7	1.2	1.0	2.0	2.2	1.4	1.3	1.3	0.7	1.8
1926	3.1	3.5	3.0	2.2	4.5	55.2	23.2	2.4	1.0	0.8	1.2	1.2
1927	1.1	1.1	1.3	4.7	7.7	4.8	3.4	2.0	1.1	0.7	0.6	0.8
1928	1.2	1.2	0.9	1.4	1.7	9.4	9.4	2.9	3.3	3.6	3.1	2.8
1929	3.9	4.6	3.5	4.7	4.2	8.5	5.2	2.0	1.1	0.8	1.0	1.8
1930	2.3	2.2	2.0	2.2	2.2	2.5	2.1	1.5	0.8	0.8	0.7	0.6
1931	0.7	0.8	1.1	1.4	63.6	49.6	15.1	9.2	6.6	3.2	1.4	0.8
1932	1.1	1.5	2.2	1.8	1.9	2.2	2.1	1.5	0.8	0.9	0.9	0.6
1933	0.6	3.7	6.3	29.1	17.8	9.2	11.2	9.4	5.6	3.4	2.9	2.5
1934	1.2	1.2	25.0	14.2	6.6	6.2	4.6	3.1	24.3	11.4	3.0	1.3
1935	0.8	0.7	0.6	1.4	22.1	33.8	13.4	7.6	7.3	3.6	1.9	1.1
1936	1.7	36.5	15.2	2.0	6.0	5.7	2.8	1.3	0.8	0.8	0.7	0.6
1937	0.8	1.1	10.7	7.4	14.7	7.3	5.3	4.2	3.1	3.3	3.1	1.9
1938	2.1	2.9	6.0	6.5	37.0	21.0	8.2	4.2	3.0	2.0	1.6	2.7
1939	2.8	7.1	12.0	7.4	7.6	5.0	3.1	54.8	28.7	7.8	2.9	2.2
1940	1.7	18.0	45.3	17.2	4.6	2.7	3.5	2.8	1.5	0.8	0.6	0.7
1941	1.0	1.4	1.0	1.5	2.8	5.4	8.8	4.0	3.0	1.8	1.7	2.4
1942	3.0	4.6	38.6	17.9	7.8	7.9	66.4	28.4	6.7	6.8	29.2	14.8
1943	24.4	17.4	9.0	4.1	6.1	13.8	7.6	2.2	1.6	1.7	1.1	3.1
1944	4.5	3.3	1.5	0.9	1.7	19.0	10.9	2.8	1.7	0.8	0.5	0.4
1945	0.7	0.9	0.6	1.4	2.3	2.5	2.3	2.0	1.1	0.6	0.4	0.4
1946	0.7	1.8	2.0	2.3	6.7	9.2	10.2	5.7	3.8	3.3	2.3	1.9
1947	1.9	16.4	14.1	8.0	7.6	19.7	13.6	5.7	2.8	1.1	0.6	0.5
1948	0.9	1.4	1.2	1.2	2.2	3.3	6.1	4.9	2.8	1.5	0.8	0.7
1949	2.0	6.0	16.3	9.3	6.0	8.9	7.9	4.2	2.6	1.3	1.4	1.2
1950	0.7	0.6	2.3	3.0	2.4	2.2	2.2	1.6	0.9	0.6	3.0	3.5
1951	4.1	3.0	3.8	9.6	10.4	6.7	4.2	2.6	1.8	1.4	1.2	0.7
1952	0.6	1.7	4.0	10.3	24.0	10.5	3.1	1.6	1.0	0.6	1.0	1.5
1953	1.5	1.7	1.8	2.9	5.5	7.0	5.4	4.8	3.8	2.7	1.4	2.4
1954	40.9	22.0	4.8	14.6	12.1	7.7	6.8	4.0	2.6	1.3	0.6	0.6
1955	1.4	3.1	3.1	1.5	15.7	21.9	9.6	2.9	1.8	1.1	0.9	1.3
1956	1.5	2.3	34.8	30.1	14.9	9.1	10.9	5.8	2.3	1.3	1.2	15.1
1957	35.6	17.3	5.9	24.1	23.3	9.0	7.6	5.6	2.9	1.2	0.6	1.0
1958	1.3	2.0	4.0	5.3	10.0	6.0	2.3	9.8	8.1	3.2	1.9	1.6
1959	2.6	2.7	1.8	1.6	1.9	3.6	5.1	3.6	2.1	1.1	0.7	0.8
1960	1.4	3.1	17.1	15.7	10.2	7.6	19.6	9.9	3.6	2.2	1.3	1.4
1961	2.0	2.2	2.0	2.9	3.6	5.9	4.6	2.4	1.1	0.7	1.1	1.2
1962	1.2	4.6	4.3	6.2	5.4	10.9	9.0	3.7	2.7	3.8	3.4	2.0
1963	1.4	1.9	1.4	17.1	11.8	2.9	2.1	1.9	1.4	1.1	0.7	0.7
1964	2.2	2.0	1.6	1.3	1.2	1.1	0.8	0.6	2.6	3.4	3.2	3.0
1965	2.7	2.7	2.3	3.6	3.3	2.0	1.2	1.6	1.7	1.0	0.9	0.8
1966	1.0	1.6	1.8	8.6	17.5	42.9	21.6	6.6	3.0	1.6	0.9	0.5
1967	0.8	2.2	2.0	1.9	2.1	2.9	3.2	2.0	1.0	0.6	0.9	1.6
1968	1.5	1.5	1.8	2.0	2.0	31.0	18.8	6.9	4.1	2.3	1.3	1.2
1969	3.2	3.9	3.7	2.6	1.7	1.2	1.0	1.0	1.3	1.1	1.1	2.7
1970	6.5	7.2	4.2	4.9	7.5	7.2	6.5	17.2	9.3	3.7	3.7	3.7
1971	3.3	2.7	5.2	4.8	23.8	12.9	5.1	3.6	3.7	2.6	1.6	0.7
1972	0.7	1.3	1.5	1.9	29.1	17.4	8.2	4.3	2.0	0.9	1.6	5.5
1973	5.7	5.8	4.0	28.1	26.7	13.2	7.8	4.9	3.5	2.4	1.3	0.6
1974	0.4	0.8	1.4	5.8	23.9	11.1	4.1	2.6	1.5	0.8	0.6	3.2
1975	4.0	4.8	9.3	50.2	51.7	102.5	42.4	8.0	3.6	1.8	1.1	1.1
1976	2.8	3.2	1.9	3.9	17.0	13.0	7.0	2.7	1.3	0.7	0.8	1.8
1977	3.1	3.4	2.3	4.1	7.6	13.0	9.1	3.8	2.1	1.1	1.0	2.0
1978	3.4	4.9	6.0	5.4	7.8	6.2	3.5	2.1	1.5	1.1	1.3	1.4
1979	1.4	1.3	1.1	1.0	1.0	1.0	0.9	0.7	0.6	0.4	0.4	5.4
1980	4.5	4.9	3.1	2.6	3.4	2.5	1.5	1.9	2.3	1.6	2.2	3.3
1981	2.7	4.1	2.4	1.7	1.9	4.1	4.1	2.8	1.5	0.8	0.5	0.5
1982	2.4	2.9	1.8	1.4	1.1	1.2	1.1	1.1	0.8	0.8	1.3	1.0
1983	1.1	4.1	4.6	27.4	59.8	27.3	15.2	8.1	3.7	3.5	3.6	2.7
1984	2.4	2.2	1.5	2.5	82.7	30.6	2.8	0.9	0.6	0.4	0.4	0.4
1985	12.9	10.3	5.5	12.7	7.5	5.5	5.7	2.8	1.6	1.1	0.7	0.6
1986	1.1	1.5	3.7	18.7	18.3	23.1	11.5	4.3	4.7	3.8	3.3	257.2
1987	92.5	12.5	8.0	4.6	86.7	76.0	21.9	3.3	3.0	2.8	2.6	2.3
1988	2.0	2.7	7.3	6.6	32.8	14.0	2.9	1.9	2.1	1.4	0.9	0.6
1989	0.9	41.5	19.4	2.5	1.6	4.7	6.7	3.8	2.1	1.0	1.8	2.2
1990	2.3	2.0	3.5	6.9	24.8	26.8	10.2	2.3	1.4	1.2	0.9	1.4
1991	2.9	2.9	1.7	1.0	1.2	1.3	1.1	1.0	0.6	0.4	0.4	0.4
1992	0.6	1.2	1.1	0.7	1.3	2.4	2.2	1.8	1.1	0.6	0.8	1.4
1993	6.0	4.6	3.4	3.6	2.4	2.5	2.5	1.7	1.0	1.2	9.3	5.5
1994	1.9	1.5	0.9	0.8	0.9	1.5	2.9	4.3	4.5	3.7	2.4	1.2
Averag	4.7	5.4	6.5	8.0	13.5	15.7	9.0	4.8	3.2	1.9	1.9	5.5
Min	0.4	0.5	0.6	0.7	0.9	1.0	0.8	0.6	0.6	0.4	0.4	0.4
Max	92.5	41.5	45.3	50.2	86.7	218.1	81.9	54.8	28.7	11.4	29.2	257.2

Table 7.10 Simulated monthly flows (in m^3/s) to the Mvoti Estuary for Scenario Group D

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1921	0.3	12.0	24.0	7.8	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1922	0.4	0.9	5.8	28.8	24.8	8.9	2.7	0.3	0.3	0.3	0.3	0.3
1923	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1924	0.3	1.1	1.6	0.7	3.4	216.6	78.3	2.2	0.4	0.3	0.3	0.4
1925	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1926	0.3	0.4	0.3	0.3	0.3	20.0	19.5	0.3	0.3	0.3	0.3	0.3
1927	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1928	0.3	0.3	0.3	0.3	0.3	1.9	0.8	0.3	0.3	0.4	0.4	0.4
1929	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1930	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1931	0.3	0.3	0.3	0.3	4.9	28.4	11.7	6.1	3.1	0.3	0.3	0.3
1932	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1933	0.3	0.4	0.5	0.5	7.1	5.9	8.1	6.1	2.2	0.4	0.4	0.4
1934	0.3	0.3	14.5	10.6	3.2	2.9	1.1	0.3	21.5	7.9	0.4	0.3
1935	0.3	0.3	0.3	0.3	3.6	30.7	9.7	4.5	3.8	0.4	0.3	0.3
1936	0.3	27.0	11.6	0.3	0.9	2.1	0.3	0.3	0.3	0.3	0.3	0.3
1937	0.3	0.3	2.8	1.2	0.5	1.3	2.0	0.6	0.3	0.4	0.4	0.3
1938	0.3	0.4	0.4	0.3	33.1	17.7	4.7	1.0	0.4	0.3	0.3	0.3
1939	0.4	0.7	5.5	3.8	3.9	1.6	0.3	51.6	25.5	4.3	0.3	0.3
1940	0.3	10.4	42.0	13.4	1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1941	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.3
1942	0.4	0.5	13.6	14.2	4.5	4.9	63.4	24.9	3.3	3.7	26.1	11.3
1943	21.3	14.2	5.4	0.5	2.9	10.6	4.1	0.3	0.3	0.3	0.3	0.5
1944	0.8	0.5	0.3	0.3	0.3	1.5	6.2	0.3	0.3	0.3	0.3	0.3
1945	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1946	0.3	0.3	0.3	0.3	0.4	0.5	0.6	0.5	0.4	0.3	0.3	0.3
1947	0.3	0.9	0.6	0.4	0.4	9.0	10.3	2.1	0.3	0.3	0.3	0.3
1948	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.4	0.4	0.3	0.3	0.3
1949	0.4	0.9	1.8	0.6	0.4	0.4	1.9	0.8	0.3	0.3	0.3	0.3
1950	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5
1951	0.5	0.4	0.4	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
1952	0.3	0.3	0.3	0.6	1.8	1.4	0.3	0.3	0.3	0.3	0.3	0.3
1953	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
1954	21.5	18.8	1.3	11.5	8.5	4.6	3.5	0.5	0.3	0.3	0.3	0.3
1955	0.3	0.4	0.4	0.3	1.1	14.1	6.0	0.3	0.3	0.3	0.3	0.3
1956	0.3	0.3	18.0	26.5	11.6	5.8	7.7	2.3	0.3	0.3	0.3	5.8
1957	32.4	13.9	2.6	21.2	20.2	5.5	4.5	2.1	0.3	0.3	0.3	0.3
1958	0.3	0.4	0.4	0.4	0.3	0.3	0.3	2.1	4.5	0.3	0.3	0.3
1959	0.4	0.4	0.3	0.3	0.3	0.4	0.5	0.4	0.3	0.3	0.3	0.3
1960	0.3	0.4	1.0	1.7	6.6	4.3	16.7	6.3	0.4	0.3	0.3	0.3
1961	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1962	0.3	0.4	0.4	0.5	0.5	1.0	0.6	0.4	0.4	0.6	0.5	0.3
1963	0.3	0.3	0.3	0.4	5.9	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1964	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4
1965	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1966	0.3	0.3	0.3	0.5	0.5	3.5	9.6	3.0	0.3	0.3	0.3	0.3
1967	0.3	0.4	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
1968	0.3	0.3	0.3	0.3	0.3	1.8	0.9	3.4	0.6	0.3	0.3	0.3
1969	0.4	0.6	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1970	0.5	0.6	0.4	0.4	0.5	0.5	0.4	5.9	5.8	0.4	0.4	0.5
1971	0.5	0.4	0.4	1.2	21.0	9.4	1.6	0.4	0.4	0.4	0.3	0.3
1972	0.3	0.3	0.3	0.3	8.9	14.0	4.7	0.7	0.3	0.3	0.3	1.4
1973	1.0	0.7	0.4	23.2	23.5	9.8	4.3	1.5	0.3	0.3	0.3	0.3
1974	0.3	0.3	0.3	0.4	6.1	7.5	0.8	0.3	0.3	0.3	0.3	0.4
1975	0.6	0.5	0.4	44.3	48.5	100.0	39.2	4.6	0.4	0.3	0.3	0.3
1976	0.4	0.4	0.4	0.3	2.8	9.5	3.5	0.3	0.3	0.3	0.3	0.4
1977	0.5	0.5	0.4	0.4	0.4	0.4	5.4	0.3	0.3	0.3	0.3	0.3
1978	0.4	0.6	0.4	0.4	0.3	2.4	0.3	0.3	0.3	0.3	0.3	0.3
1979	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3	1.3
1980	0.8	0.5	0.4	0.4	0.5	0.4	0.3	0.4	0.4	0.3	0.4	0.5
1981	0.5	0.5	0.4	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
1982	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1983	0.3	0.4	0.5	3.7	7.7	2.5	2.9	4.6	0.4	0.5	0.7	0.4
1984	0.4	0.4	0.3	0.4	71.8	26.9	0.3	0.3	0.3	0.3	0.3	0.2
1985	3.0	1.4	0.4	6.8	4.1	2.2	2.3	0.3	0.3	0.3	0.3	0.3
1986	0.3	0.3	0.4	1.0	13.1	19.9	7.9	1.1	1.5	0.5	0.4	255.7
1987	89.2	9.4	4.7	1.0	84.6	73.3	18.3	0.3	0.3	0.3	0.3	0.3
1988	0.3	0.4	0.4	0.4	29.1	10.4	0.3	0.3	0.3	0.3	0.3	0.3
1989	0.3	23.4	15.9	0.3	0.3	0.4	1.3	0.4	0.3	0.3	0.3	0.3
1990	0.4	0.4	0.4	0.4	13.1	23.7	6.5	0.3	0.3	0.3	0.3	0.3
1991	0.4	0.4	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3
1992	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
1993	1.1	0.8	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	3.4	1.6
1994	0.4	0.3	0.3	0.3	0.2	0.3	0.4	0.5	0.5	0.4	0.3	0.3
Average	2.6	2.1	2.6	3.3	6.7	9.9	5.2	2.1	1.2	0.5	0.7	4.0
Min	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Max	89.2	27.0	42.0	44.3	84.6	216.6	78.3	51.6	25.5	7.9	26.1	255.7

7.3 ABIOTIC COMPONENTS

7.3.1 Hydrology

Table 7.11 and Table 7.12 provide a summary of the changes in low flow and floods that have occurred under the different scenarios.

7.3.1.1 Low flows

Table 7.11 Summary of the change in low flow conditions to the Mvoti Estuary under a range of flow scenarios

Percentile	Monthly flow (m^3/s)					
	Natural	Present	A and E	B	C	D
30%ile	3.8	1.4	1.7	0.8	1.5	0.3
20%ile	2.9	0.9	1.3	0.5	1.1	0.3
10%ile	2.1	0.8	0.9	0.3	0.8	0.3
% Similarity in low flows		**35.4**	**44.0**	**17.2**	**39.3**	**10.0**

Confidence: High

7.3.1.2 Flood regime

Table 7.12 Summary of the ten highest simulated monthly volumes to the Mvoti Estuary under Reference Condition, Present State and a range of flow scenarios

Date	Monthly volume ($x10^6$ m^3/month)					
	Natural	Present	A and E	B	C	D
Sep 1987	752.2	668.3	668.7	666.5	666.7	662.69
Mar 1925	640.0	584.3	585.0	582.1	584.2	580.13
Mar 1976	323.7	275.2	275.8	272.5	274.5	267.78
Oct 1987	282.8	249.0	249.4	245.9	247.8	238.87
Feb 1985	281.5	204.2	204.7	201.8	201.9	175.21
Feb 1932	263.1	175.2	175.7	151.5	155.3	11.85
Mar 1988	253.0	204.2	204.7	201.5	203.5	196.3
Apr 1925	236.3	213.3	213.8	210.2	212.2	203.05
Apr 1943	223.7	172.7	173.3	170.0	172.0	164.23
Mar 1927	207.9	148.6	149.1	145.9	148.0	53.5
% Similarity in floods		**81.2**	**81.4**	**79.5**	**80.1**	**67.5**

Confidence: Medium

A summary of the hydrology score are provided in Table 7.13.

Table 7.13 EHI scores for hydrology under different scenarios

Variable	Scenario Group						
	Present	A	B	C	D	E	Conf
a. Similarity in low flows	35	44	17	39	10	44	M
b. Similarity floods	81	81	80	80	68	81	M
Hydrology score	**53.4**	**58.8**	**42.2**	**55.4**	**33.2**	**58.8**	

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 did not occur under the Reference Condition. At present mouth closure occurs for about 1% of the time for short periods.
Scenario Group A to E	Mouth closure is not expected to occur for extended periods (i.e. weeks) at a time under Scenario Group A to C, but as flow decreases below 0.5 m^3/s intermitted closures may occur for short periods (i.e < 10 days). These type of closures are a significant feature under Scenario Group B, with flow between 0.2 and 0.5 m^3/s occurring for about 21% of the time. Under Scenario Group D State 2 occurs for 73% of the time and there is a significant decrease in resetting events. Mouth closure is likely to occur for about 30% of the time. Scenario E is similar to A. Note: Mouth closure is scored conservatively following an exponential curve (DWA 2009).

Table 7.14 provides a summary of the hydrodynamics and mouth condition scores for the Mvoti Estuary.

Table 7.14 EHI scores for hydrodynamics and mouth condition under different scenarios

Variable	Scenario Group					
	Present	A	B	C	D	E	Conf
Mouth conditions score	95	99	95	99	70	99	M
Hydrodynamics score	**95**	**99**	**95**	**99**	**70**	**99**	**M**

7.3.3 Water quality

Table 7.15 provides a summary of the occurrence of the abiotic states under the various scenario groups that was used to calculate the water quality scores.

Table 7.15 Occurrence of the abiotic states under the different scenario groups

Abiotic State	Natural	Present	Scenario Group				
			A	B	C	D	E
State 1: Closed mouth	0	1	0	0	0	0	0
State 2: Tidal with intermitted mouth closure	0	3	3	21	2	73	3
State 3: Tidal	21	46	45	44	55	11	45
State 4: Freshwater dominated	79	51	52	35	44	16	52

7.3.4 Water quality

Scoring of Future scenario groups in respect of Salinity/DIN/DIP, SS/Turbidity/ Transparency, DO and Toxic substances, followed a similar approach as described earlier for the Present State. Details on the change in the axial salinity gradient, DIN/DIP, suspended solids, dissolved oxygen, and toxic substances are provided in Table 7.16. A summary of the water quality scores are provided in Table 7.17.

Table 7.16. 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	A	B	C	D	E
Lower	0.5	2	3	3	7	4	15	3
Middle	0.2	2	3	3	4	3	4	3
Upper	0.3	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	A	B	C	D	E
Lower	0.5	90	551	506	457	516	305	297
Middle	0.2	90	645	599	565	627	401	297
Upper	0.3	90	651	605	606	631	547	300

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	A	B	C	D	E
Lower	0.5	10	23	23	20	22	17	20
Middle	0.2	10	23	23	20	22	17	20
Upper	0.3	10	23	23	20	22	17	20

Zones in Estuary	Volume weighting for Zone	Estimated TURBIDITY (NTU based on distribution of abiotic states under a range of Scenario Groups						
		Reference	Present	A	B	C	D	E
Lower	0.5	81	212	218	151	185	65	212
Middle	0.2	81	217	223	159	191	81	212
Upper	0.3	81	217	223	159	191	81	212

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	A	B	C	D	E
Lower	0.5	8	2	2	2	2	2	4
Middle	0.2	8	2	2	2	2	2	4
Upper	0.3	8	4	4	4	4	3	4

Table 7.17 EHI scores for water quality under different scenario groups

	Variable	Scenario Group						
		Present	A	B	C	D	E	Conf
1	**Salinity**							
	Similarity in salinity	80	81	65	79	52	81	M
2	**General water quality in the estuary**							
a	N and P concentrations	44	44	48	45	56	56	L/M
b	Turbidity	55	54	69	60	94	54	L/M
c	Dissolved oxygen	48	48	47	48	45	56	L/M
d	Toxic substances	60	60	60	60	60	70	L
Water quality score		**58.4**	**58.8**	**54.2**	**58.6**	**47.8**	**64.8**	

7.3.5 Physical habitats

Table 7.18 provides a summary of the changes in physical habitat under the different scenarios for the Mvoti Estuary. Physical habitat scores are summarised in Table 7.19.

Table 7.18 Summary of physical habitat changes under different scenarios

Parameter		Scenario Group
1a	% Similarity in intertidal area exposed	Sedimentation processes under Scenario Group A, B and C are similar to the Present State, with some loss of intertidal habitat due to infilling of the intertidal habitat. Under Scenario B State 2 increases markedly, reducing exposed intertidal habitat at low tide due to intermitted mouth closure and greater mouth restriction.
1b	% Similarity in sand fraction relative to total sand and mud	Information is lacking on changes in % similarity in sand fraction relative to total sand and mud, but the score of 80 is based on increase in clay and silt fractions experienced in similar systems, especially in Zone B and C. Sand mining is also changing grains size distribution in the system.
2	% Similarity in intertidal area: depth, bed or channel morphology	There has been some infilling of sub-tidal areas as a result of the decrease/loss in resetting floods and increase sediment yield from the catchment. Under the Reference conditions floods would have scoured the system to mean sea level before the natural deposition cycle causes infilling, Under the Present State resetting events have been significantly reduced and infilling is maintaining the more constricted equilibrium state. While channel stability under Scenario A is similar to present, there is a further loss of the meandering nature of the estuary channels under Scenario B and C.

Table 7.19 EHI scores for physical habitat under different scenarios

Variable	Scenario Group						
	Present	A	B	C	D	E	Conf
1a. Intertidal areas and sediments	70	70	65	70	50	70	M
1b.Similarity in sand fraction	80	80	80	80	60	80	M
2. Subtidal area and sediments	70	70	65	65	50	70	M
Physical habitat score	**73**	**73**	**69**	**70**	**53**	**73**	

7.4 BIOTIC COMPONENT

7.4.1 Microalgae

Changes in microalgae and scores are summarised in Table 7.20 and Table 7.21.

Table 7.20 Summary of change in microalgae component under different scenarios

Scenario	Summary of Changes
A to C	Very small change in microalgae component from present.
D	A further decrease in microalgae component from present.
E	Small recovery in microalgae component from present.

Table 7.21 EHI scores for microalgae component under different scenarios

Variable	Scenario Group						
	Present	A	B	C	D	E	Conf
1. Species richness	80	80	80	80	70	85	M
2. Abundance	80	80	80	80	70	85	M
3. Community composition	80	80	65	80	50	85	M
Biotic component score	**80**	**80**	**65**	**80**	**50**	**85**	**M**

7.4.2 Macrophytes

Changes in macrophytes and scores are summarised in Table 7.22 and Table 7.23.

Table 7.22 Summary of change in macrophyte component under different scenarios

Scenario	Summary of Changes
A	⇧ low flow, ⇩salinity- resembles present conditions. ⇧ floods- more stable environment ⇧ reeds, sedges and grasses and invasive aquatic plant. Overall a 10% change compared to reference conditions.
B	⇧ State 2 (tidal, intermittently closed), ⇩base flows ⇩ floods and loss of the meandering nature of the estuary channel ⇧ reeds and sedge expansion by 15% from present. Aquatic invasive plants would thrive under the calm water conditions.
C	⇩ floods and loss of the meandering nature of the estuary channel ⇧ reeds and sedge expansion This expansion would take place in the open mud and sand flat habitat.
D	Severe ⇩ floods and ⇧ low flow conditions due to dam construction with a restricted estuary channel would ⇧ macrophyte growth. However ⇧ salinity and closed mouth conditions would ⇩ reed growth in the lower reaches of the estuary. ⇧ Invasive aquatics under the calmer fresh conditions causing a change in community composition.
E	⇧ low flow, ⇩salinity- resembles present conditions. ⇧ floods- more stable environment ⇧ reeds, sedges and grasses and invasive aquatic plant. Overall a 10% change compared to reference conditions.

Table 7.23 EHI scores for macrophyte component under different scenarios

Variable	Scenario Group						
	Present	A	B	C	D	E	Conf
1. Species richness	60	60	60	60	50	70	M
2. Abundance	52	47	45	45	40	60	M
3. Community composition	32	33	33	33	25	50	M
Biotic component score	**32**	**33**	**33**	**33**	**25**	**50**	M

7.4.3 Invertebrates

Changes in invertebrates and scores are summarised in Table 7.24 and Table 7.25.

Table 7.24 Summary of change in invertebrates component under different scenarios

Scenario	Summary of Changes
A and C	Very little change in flow scenarios from present. Unless there is a significant change in water quality from present conditions there is unlikely to be any change in the benthic community. The generally strong outflow will also inhibit the development of any zooplankton community.
B	A small increase in State 2, i.e. intermittent closure relative to general open conditions under scenarios A and C. Under prevailing water quality conditions scores will decline relative to Present, A and C.
D	The mouth will remain closed for most of the time, thereby preventing any development of an intertidal fauna. The longer retention time will also allow nutrification processes to become more pronounced resulting in algal blooms, oxygen instability and detrimental effects on the benthic fauna.

Scenario	Summary of Changes
E	Improvement of water quality would allow an increase in the dissolved oxygen levels influencing the abundance and diversity of the invertebrate community

Table 7.25 EHI scores for invertebrates component under different scenarios

Variable	Scenario Group						
	Present	A	B	C	D	E	Conf
1. Species richness	25	25	20	25	15	65	L
2. Abundance	30	30	30	30	10	70	L
3. Community composition	30	30	15	30	10	60	L
Biotic component score	**25**	**25**	**15**	**25**	**10**	**60**	L

7.4.4 Fish

Responses of fishes 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 this study (DWS RDM/WMA11/00/CON/CLA/0814). These are presented in summary format in Table 7.26. Likely health scores of the fish assemblages under these different scenarios are provided in Table 7.27.

Table 7.26 Summary of change in fish component under different scenarios

Scenario	Summary of Changes
A	Slight increase in base flows over the dry period results in a marginal reduction in mouth closure compared to present day. Differences in hydrology, and frequency of abiotic states are marginal. Changes in the fish fauna are likely to be manifest in slight modified community composition.
B	Higher water levels under State 2 (tidal, intermittently closed) and greater estuarine volumes potentially benefit this estuarine and estuarine dependent species, but this is offset by impacts of poorer water quality. Freshwater species will be lost from the lower reaches of the estuary. This results in a slightly lower species abundance in the estuary and changes to the species composition.
C	Changes in hydrology, and frequency of abiotic states are marginal. Changes in the fish fauna are likely to be manifest in slight modified community composition.
D	The estuary will occur in a tidal, intermittently closed state for most of the year. Frequency of occurrence and durations of tidal (State 3) and fresh water (State 4) states are markedly reduced. This results in very different salinity conditions, but also significant water quality degradation. The whole fish assemblage will be impacted and reductions in species richness and abundance will occur, as well as changes in species composition.
E	Flows are similar to those described in Scenario A. Improved water quality will, however, have significant positive impacts for fishes in the estuary. Notably the spread of reed growth would be reduced to some degree, improving fish habitat in the system. Improved oxygen levels (compared to present day conditions), especially in the lower and middle reaches, also result in an improved fish community. All community metrics are likely to increase compared to the Present Scenario.

Table 7.27 EHI scores for fish component under different scenarios

Variable	Scenario Group						
	Present	A	B	C	D	E	Conf
1. Species richness	80	80	70	80	60	85	M
2. Abundance	55	55	55	55	50	75	M
3. Community composition	65	60	65	60	50	75	M
Biotic component score	**55**	**55**	**55**	**55**	**50**	**75**	**M**

7.4.5 Birds

Changes in birds and scores are summarised in Table 7.28 and 7.29.

Table 7.28 Summary of change in bird component under different scenarios

Scenario	Summary of Changes
A - C	Health state is similar to Present as a result of reduced intertidal and supra-tidal areas, ongoing increase in aquatic vegetation, and reduction in foraging areas and food availability.
D	Even worse decrease in waterbird health due to chronic decrease in floods and associated ongoing encroachment by aquatic vegetation.
E	Significant increase in waterbird health due to increase in floodplain habitat including exposed sandflat/mudflats, reduction in aquatic vegetation brought about by lowered eutrophication, increase in food availability in the form of both invertebrates and fish due to improved water quality.

Table 7.29 EHI scores for bird component under different scenarios

Variable	Scenario Group						
	Present	A	B	C	D	E	Conf
1. Species richness	10	10	10	10	5	45	M
2. Abundance	10	10	10	10	5	50	M
3. Community composition	10	10	10	10	5	45	M
Biotic component score	**10**	**10**	**10**	**10**	**5**	**45**	**M**

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

Under Scenario Group A (MV21, 22 and 41) and C (MV42 and 43) the Mvoti Estuary will improve slightly in health, but is expected to remain in a D Category, as a result of as a result of reduced frequency and duration of mouth closure from Reference. While, under Scenario Group B (MV3) the estuary will deteriorate further in health by about 5% as a result of an increase in closed mouth conditions. Under Scenario Group D (MV5) the estuary will deteriorate significantly to a D/E Category as a result of more closed mouth conditions and a further decline in water quality.

None of the Scenarios Groups A to D achieved the REC for the Mvoti Estuary. Therefore a sensitivity test, Scenario Group E, was conducted. Scenario Group E is based on the freshwater inflow simulated for Scenario Group A (MV 21, MV22 and MV41) in conjunction with the following management interventions:

- Improvement of oxygen levels in the estuary, through for example, removal of the high organic content from the SAPPI Stanger effluent;
- Reduce the nutrient input from the catchment by 20% to control growth of reeds and aquatic invasive plants; and
- 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.

Scenario Group E (MV21, 22 and 41 – Non-flow impact) achieved the REC of a C. The PES and Scenario Group C (MV42 and MV43) with the same non-flow related management intervention will also achieve the REC.

Table 7.30 EHI score and corresponding Ecological Categories under the different runoff scenarios

Variable scores	Weight	Scenario Group						
		Present	A (MV 21, 22, 41)	B (MV3)	C (MV42, 43)	D (MV5)	E (MV21, 22, 41 – Non-flow)	Conf
Hydrology	25	53.4	59	42	55	33	59	M
Hydrodynamics	25	95	99	95	99	70	99	H
Water quality	25	58.4	59	54	59	48	65	M
Physical habitat	25	73	73	69	70	53	73	M
Habitat health		**70**	**72**	**65**	**71**	**51**	**74**	
Microalgae	20	80	80	65	80	50	85	M
Macrophytes	20	32	33	33	33	25	50	M
Invertebrates	20	25	25	15	25	10	60	L
Fish	20	55	55	55	55	50	75	M
Birds	20	10	10	10	10	5	45	H
Biotic health		**40**	**41**	**36**	**14**	**28**	**63**	
ESTUARY HEALTH		**55**	**56**	**50**	**56**	**39**	**68**	
ECOLOGICAL STATUS		**D**	**D**	**D**	**D**	**D/E**	**C**	

7.6 STUDY CONFIDENCE

Confidence levels were medium to high for most of the abiotic components, while most of the biotic components had enough data to yield medium confidence assessments. The overall confidence of the study was MEDIUM to reflect the confidence in the drivers (See Section 1.2).

8 RECOMMENDATIONS

8.1 ECOLOGICAL FLOW REQUIREMENTS

From an ecological perspective, it is recommended that the estuary improves to a C REC from its current D EC. The REC could be achieved either by providing the present day flows with management interventions, or providing the scenarios (Scenario Group A or C) with the same management interventions. **Scenario Group A and C both include the development of a large dam. It should be noted that this scenario recommendations do not take cognisance of the potential detrimental impact further flow reduction (and related sediment fluxes) to the nearshore marine environment will be. It is recommended that these impacts are investigated further if the dam development realises.**

The table below (Table 8.1) is an example of the type of flows that will, with management interventions achieve the REC.

Table 8.1 Summary of the monthly flow (in m^3/s) distribution under Scenario Group A

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	89.6	47.3	45.3	49.7	86.8	210.0	81.3	53.2	28.8	11.7	28.2	240.5
99	57.8	41.6	42.0	40.5	84.7	134.1	71.1	36.0	25.9	9.3	14.9	83.0
90	7.2	17.3	18.1	23.5	31.8	33.3	18.3	8.6	5.9	4.0	3.0	5.2
80	4.5	8.2	10.4	14.8	24.0	20.7	11.4	6.2	3.8	3.1	2.4	2.6
70	3.4	6.8	7.3	9.9	15.6	13.5	9.4	4.8	3.0	2.2	1.7	2.2
60	2.7	5.1	5.6	6.6	10.1	10.8	7.9	4.4	2.7	1.6	1.4	1.8
50	2.2	4.3	4.6	5.4	8.1	8.2	6.1	3.0	2.2	1.2	1.2	1.6
40	1.7	3.4	3.5	4.5	6.3	6.8	4.8	2.6	1.8	1.1	0.9	1.4
30	1.5	2.8	3.1	3.2	4.8	5.3	3.8	2.3	1.6	0.9	0.8	1.0
20	1.3	1.7	1.9	1.9	3.7	3.5	2.8	1.9	1.2	0.8	0.6	0.7
10	0.9	1.3	1.3	1.4	2.1	2.8	1.9	1.7	0.9	0.6	0.5	0.5
1	0.3	0.6	0.6	0.9	1.2	1.2	0.8	0.6	0.5	0.3	0.3	0.3
0.1	0.3	0.4	0.6	0.8	0.9	0.9	0.7	0.6	0.5	0.3	0.3	0.3

8.2 ECOLOGICAL SPECIFICATIONS

Ecological specifications are clear and measurable specifications of ecological attributes (in the case of estuaries, hydrodynamics, sediment dynamics, water quality, and different biotic components) that define a specific reserve category which was decided upon by the authorities utilizing environmental, social and economic criteria. Thresholds of potential concern (TPC) are defined as measurable end points related to specific abiotic or biotic indicators that if reached prompts management action. In essence, thresholds of potential concern should be defined such that they provide early warning signals of potential non-compliance to ecological specifications. In essence this concept implies that the indicators (or monitoring activities) selected as part of a long term monitoring programme need to include biotic and abiotic components that are particularly sensitive to ecological changes associated with changes in river inflow into the system.

The ecological specifications for the Mvoti Estuary, as outlined in Table 8.1 and Table 8.2, are set for the REC C. However, as is unlikely that the improved state to a Category C will be accepted in the short term, the RQOs will also be set for maintaining the PES. These will be documented in Report RDM/WMA11/00/CON/CLA/0616.

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

Abiotic component	Ecological specification	Threshold of potential concern	Causes
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 A (i.e. the recommended flow scenario for the Mvoti Estuary). ▪ Monthly river inflow < 1.0 m^3/s. ▪ Monthly river inflow < 2.0 m^3/s persists for longer than 3 months in a row. ▪ Monthly river inflow < 2.0 m^3/s for more than 50% of the time.	Flow reduction.
Hydrodynamics	Maintain a mouth conditions to create the required habitat for birds, fish, macrophytes, microalgae and water quality.	▪ Mouth closure occurs more than 2 - 3 weeks in a year. ▪ Mouth closure occurs for more than 2 years out of ten. ▪ Mouth closure occurs between November and June.	Flow reduction.
Water Quality	Salinity	▪ Salinity > 20 PSU 1 km from the mouth. ▪ Salinity >1 PSU for >50% of the time.	Flow Reduction.
	System variables (pH, dissolved oxygen and turbidity) not to cause exceedence of TPCs for biota (see above).	▪ River inflow: 7.0 < pH > 8.5 over 2 months DO < 4 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 < 4 mg/ℓ	▪ Agricultural return flow. ▪ Industrial effluent (organic loading). ▪ 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 >500 µg/ℓ over 2 months NH_3-N> 50 µg/ℓ over 2 months PO_4-P > 30 µg/ℓ over 2 months ▪ Estuary: Average NO_x-N > 500 µg/ℓ Average NH_3-N > 50 µg/ℓ Average PO_4-P > 30 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). ▪ 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).	▪ Industrial effluent. ▪ Municipal wastewater including industrial trade effluent (e.g. metals).
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). ▪ Changes in tidal amplitude at the tidal gauge of more than 20% from Present State (2013).	▪ Reduced floods. ▪ Sand mining.

Abiotic component	Ecological specification	Threshold of potential concern	Causes
	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).	▪ Reduced floods ▪ Sand mining

Table 8.3 Mvoti Estuary 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: > 3µg/l for more than 50% of the stations. ▪ MPB: > 20 mg 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, particularly the freshwater mangrove, *Barringtonia racemosa* stand at the mouth of the estuary. ▪ Control the spread of hygrophilous grasses into open water area. ▪ Prevent the spread of invasive plants, trees and shrubs as well as aquatic invasive plants. ▪ No sugarcane in the EFZ (estuarine functional zone).	▪ Greater than 10% change in macrophyte habitat. ▪ Increase in reeds & sedges and encroachment into main water channel due to nutrient enrichment, sedimentation and infilling of intertidal habitat. ▪ Decrease in open water habitat to less than 16 ha. ▪ Invasive plants (e.g. syringa berry, Brazilian pepper tree) and aquatic invasives (e.g. water hyacinth) cover >5% of total macrophyte area. ▪ Sugarcane is present in the estuarine functional zone.	▪ Mouth closure and high water level. ▪ Increase in salinity. ▪ Increase in nutrients and disturbance.
Invertebrates	▪ Maintain current levels of zoobenthic abundance (including seasonal variation) ▪ Retain an invertebrate community assemblage in the estuary based on the habitat diversity available (increased from PES) and species diversity and abundance that includes an assessment of the brackish water and freshwater invertebrate communities. ▪ The nektonic invertebrate community should include caridean prawns ▪ Abundance of all taxon groups should be higher during summer high flow periods and lower during winter low flow period.	▪ Decrease in abundance of zooplankton by >30% in terms of numbers per m^3 over entire estuarine area (3 sample sites) over 3 years. ▪ The absence or low abundance of a well-established brackish water community and / or the species predicted to occur in the estuary. ▪ Decrease in abundance of 25% benthic macroinvertebrates excluding seasonal variation. ▪ The nektonic prawns within the estuary should include at least three species of *Macrobrachium* prawns. ▪ Occurrence of invertebrate alien species (e.g. *Tarebia granifera*).	▪ Nutrient enrichment. ▪ Loss of baseflows. ▪ Mouth closure.
Fish	Maintain ecological function as ▪ a nursery for a limited diversity and abundance of estuarine dependant marine fishes, which use the system through to their late juvenile and adult life stages ▪ habitat for a limited diversity and abundance of estuarine resident fishes which complete their life cycles in the estuary ▪ habitat for a limited diversity and abundance of freshwater fishes ▪ a migration corridor for facultative catadromous eels	Loss of: ▪ juvenile of any one of the following species *M. cephalus*, *M. capensis* from Zones A, B and C and late stage juveniles (>160 mm SL) of one of the following species *M. cephalus*, *M. capensis* from Zones B and C ▪ any one of the following species *G. aestuaria*, *Ambassis* spp., *Glossogobius* spp. from the estuary. ▪ any one of the following species *Barbus* spp, *O. mossambicus* from Zones A, B and C. ▪ *Anguilla* spp. from upstream river habitats (this should be noted in ecological specifications in documentation pertaining to the EWR [river EcoSpecs and monitoring]).	▪ Poor water quality and lack of lee water habitats.
Birds	The estuary should contain a rich avifaunal waterbird community, occurring at high densities (relative to available shorelength) 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	▪ Disappearance or lack of successful breeding by Collared Pratincoles and the resident pair of African Fish Eagles. ▪ Numbers of bird species drops below 30 for 3 consecutive counts. ▪ Number of roosting terns recorded in mid-summer fewer than 2000.	▪ Encroachment of aquatic vegetation into the estuary/riverbed, i.e. reedbeds, aquatic grasses and alien trees. ▪ Loss of suitable exposed, flat, un-vegetated islands in the riverbed.

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
	migratory Palaearctic sandpipers, herbivorous waterfowl (e.g. ducks and geese) and roosting terns and gulls		▪ Flow reduction. ▪ Contamination of water supply, e.g. toxins, nutrients, etc. ▪ Reduction/ unavailability in food supply, e.g. due to excessive turbidity, alien floating macrophytes, etc. ▪ Human disturbance.

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10 APPENDIX A: REPORT COMMENTS

Page / Section	Report statement	Comments	Changes made	Author comment
Comments from Mmaphefo Twala: 30 January 2015				
Front pages		Include cover page	Yes	
		The report title could perhaps include EWR and Recommended RQOs?		As discussed with DWS, this is premature as RQOs have not been set. Reference to RQOs in the report has been removed.
Page i	Remove 'comments received from DWS' below the Acknowledgements.		Yes	
Page i	Duplicated: numbering error.		Yes	
Page ii	second paragraph under the table: spelling of **effluent** in the highlighted part.			Influent is not a spelling mistake – it refers to quality of inflowing water.
Page 3, step 3c	" ….**following** the guidelines…"		Yes	
Page 3, second last paragraph	"…estuary cannot be allocated **an** REC…."		Yes	
Page 3, step 4,	remove: "Quantify **of** the…"		Yes	
Page 19, 1st sentence	"…associated **with** the typical…"		Yes	
Page 31, 1st sentence inside the brackets	**"Error! Reference source not found**"; also on page 32 In text references to tables		Yes	
Top of Page 49, 2nd sentence in bold	"…maintain**ing** the beaches and near shore habit**ats**…". "…but should be asses**sed** to ensure that all…."		Yes	
Page 71, 7.4.5	"changes in **birds**…."		Yes	
Page 71, 2nd last paragraph	"…5% as a result of increase **in** closed…." "….and **a** further deteriorate…."		Yes	