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

Volume 2: Mkomazi Estuary Ecological Consequences

Report Number: RDM/WMA11/00/CON/CLA/0714

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DEPARTMENT OF WATER AFFAIRS

CHIEF DIRECTORATE: RESOURCE DIRECTED MEASURES

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

MKOMAZI ESTUARY ECOCLASSIFICATION AND EWR REPORT

Approved for RFA by:

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EXECUTIVE SUMMARY

INTRODUCTION

Study Area

The Mkomazi Estuary is situated 50 km south-west of Durban and is one of only two estuarine systems within the eThekwini Municipal boundary classified as Permanently Open and only of only five between uThukela and uMtamvuna. In effect this classification is not totally rigid and a number of closures have been recorded in the last few decades. With a catchment of ca. 4 300 km^2 it is one of Kwazulu-Natal's largest rivers. The Sappi weir above the old metal bridge and 6 km from the mouth sets an artificial and absolute limit on tidal and to some extent saline penetration. For the purposes of this EWR study, the geographical boundaries of the estuary are defined as follows:

Downstream boundary:	*Estuary mouth 30°12'4.45"S 30°48'8.65"E*
Upstream boundary:	*30°10'25.64"S 30°44'51.42"E*
Lateral boundaries:	*5 m contour above Mean Sea Level (MSL) along each bank*

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

Present Ecological Status

The Mkomazi Estuary in its present state is estimated to be 69% similar to the natural condition, which translates into a Present Ecological Status (PES) of a C Category. This is attributed to the following factors:

- *The weir in the upper reaches reducing the connectivity between the river and estuary;*
- *Sandmining that has taken away the sandbanks in the upper reaches (Zone C), resulting in loss of intertidal areas and back-water refuge areas. It has also impacted on access to grazing areas as the river cannot be crossed in this section anymore;*
- *Recreational activities (e.g. boat launching) in the lower reaches affecting bird abundance;*
- *Over exploitation of living resources (e.g. cast netting and line fishing); and*
- *Agricultural activities and disturbance in the Estuary Functional Zone causing loss of estuarine habitat.*

Estuarine Health Score for the Mkomazi Estuary

Variable	Estuarine health score		
	Overall	**Excluding flow related pressures**	**Conf**
Hydrology	*66.8*	*67*	*M*
Hydrodynamics and mouth condition	*95*	*95*	*M/H*
Water quality	*66.6*	*66.6*	*M*
Physical habitat alteration	*78*	*78*	*M*
Habitat health score	*76*	*76*	**M**
Microalgae	*90*	*99*	*M*
Macrophytes	*21*	*84*	*M*
Invertebrates	*75*	*78*	*H*
Fish	*60*	*70*	*M*
Birds	*60*	*70*	*M*
Biotic health score	*61*	*80*	**M**
ESTUARY HEALTH SCORE	*69*	*78*	
PRESENT ECOLOGICAL STATUS (PES)	*C*	*B*	
OVERALL CONFIDENCE	*M*	*L*	

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 increase in the health score from a PES of 69 to 78, which would raise the health score to a B Category. This suggests that non-flow related impacts have played some in the degradation of the estuary to a C, but that flow-related impacts are also driving degradation.

The highest priority is to address the quality of influent water. *Of the non-flow-related impacts, habitat loss within the 5m contour and the vegetation integrity of these areas along with water quality problems as a result of the high nutrient load associated with the WWTWs were the most important factors influencing ecological health of the system. The excess nutrients in the inflowing water is considered to be an important factor to consider with increased abstraction from the system. Retention of these high concentrations of nutrients will lead to nuisance algal growth, low dissolved oxygens and reduced habitat quality.*

OVERALL CONFIDENCE

Confidence levels were medium to high for most of the abiotic components. Four of the biotic components had enough data to yield medium-high confidence assessments. The overall confidence of the study was MEDIUM.

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. Estuary Importance was estimated at 85, i.e. the estuary is rated as "Highly Important".

Estuarine Importance scores for the Mkomazi Estuary

Criterion	Weight	Score
Estuary Size	*15*	*80*
Zonal Rarity Type	*10*	*30*
Habitat Diversity	*25*	*60*
Biodiversity Importance	*25*	*91.5*
Functional Importance	*25*	*100*
Weighted Estuary Importance Score		**85**

The functional Importance of the Mkomazi Estuary is very high. It serves as an important nursery for exploited fish stock and plays a very important role from a fish egg production perspective. In addition, it is also an important movement corridor for eels (CITES listed species).

The functional importance of Mkomazi Estuary is very high for the nearshore marine environment. It is one of five key systems (Mfolozi, Mvoti, Mgeni, uMkomazi, Mzimkulu) that supply sediment, nutrients and detritus to the coasts. The sediment load from the Mkomazi is especially important as it is habitat forming and plays an important role in maintaining the beaches and near shore habitat 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 done to ensure that all ecological processes and related ecosystem services (e.g. nearshore pelagic and prawn fishery) are addressed.

Mkomazi forms part of the core set of priority estuaries identified in the National Estuary Biodiversity Plan in need of protections to meet biodiversity targets under the Biodiversity Act and National Estuarine Management Protocol promulgated under the Integrated Coastal Management Act. The National Estuary Biodiversity Plan requires that the Mkomazi Estuary be partially protected (e.g. no-take fishing zone and 25% of riverine area left untransformed) with a REC of B.

RECOMMENDED ECOLOGICAL CATEGORY

The REC represents the level of protection assigned to an estuary. The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of importance and level of protection or desired protection of a particular estuary. The PES for the Mkomazi Estuary is a C, but the Estuary is rated as "Very Important" from a biodiversity perspective and should therefore be in a B Category.

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

Protection status and importance	REC	Policy basis
Protected area	**A or BAS***	**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*

* BAS = Best Attainable State

In addition, the system also forms part of the core set of priority estuaries in need of protection to achieve biodiversity targets in the National Estuaries Biodiversity Plan for the National Biodiversity Assessment (Turpie et al., 2013). The NBA 2011 (Van Niekerk and Turpie 2012) recommends that the minimum Category for the Mkomazi be a B, that it be granted full no-take protection, and that 25 % of the estuary margin be undeveloped.

Taking the current conditions (PES=C), the reversibility of the impacts, the ecological importance and the conservation requirements of the Mkomazi Estuary the REC for the system is a B Category.

Ecological Categories associated with scenarios

The individual EHI scores, as well as the corresponding ecological category under different scenarios are provided below. The estuary is currently in a C Category. Under Scenario Group B (MK21 and 42) and Group C (MK22,23,43) the Mkomazi Estuary will decline slightly in health, as a result of more closed mouth conditions, but is expected to remain in a C Category. While, under Scenario Group A (MK2,4), D (MK31) and E (MK32,33) the estuary will deteriorate further in health by about 14%, 8% and 9% respectively as a result of increase closed mouth conditions.

To test the sensitivity of the estuary to the increased nutrient load associated with a 20 ML/d Waste Water Treatment Works, Scenario Group B was evaluated in more detail. Under this scenario, the Mkomazi Estuary declines in health by 13%. Similar responses are expected for any of the future scenarios with this high level of nutrient input. (It should be noted that this is a low confidence assessment as no numerical modelling was done to test the tidal effects on lateral discharges or the effect of entrainment).

For the Mkomazi Estuary, none of the scenarios achieved the REC of a B Category. Therefore, Scenario H (Group B (MK 21 and MK 42) in conjunction with a number of management interventions) is the recommended ecological flow scenario. Scenario Group C (MK22, 23 and 43) *will also achieve the REC. The following management interventions are required to achieve the Mkomazi REC:*

- *Remove sandmining from the upper reaches below the Sappi Weir to increase natural function , i.e. restore intertidal area;*
- *Restoration of vegetation in the upper reaches and along the northern bank in the middle and lower reaches, e.g. remove alien vegetation and allow disturbed land to revert to natural land cover (is already on upwards trajectory);*
- *Curb recreational activities in the lower reaches through zonation and improved compliance;*
- *Reduce/remove castnetting in the mouth area through estuary zonation or increased compliance; and*
- *Relocate upstream, or remove, the Sappi Weir to restore upper 15% of the estuary.*

Mkomazi Estuary health index scores and corresponding Ecological Categories under the different runoff scenarios

Variable	Weight	Scenario Group								
		Pres	A (MK2,4)	B (MK21,42)	C (MK22,23,43)	D (MK31)	E (MK32,33)	F (MK21,42) + WWTW	G MK21, 42 –Ant h but with weir	H MK21, 42 – Anth & Weir
Hydrology	*25*	*66.8*	**45**	*63*	*62*	*59*	*57*	*63*	*63*	*63*
Hydrodynamics and mouth condition	*25*	*95*	**75**	*95*	*95*	*38*	*38*	*95*	*95*	*97*
Water quality	*25*	*66.6*	**61**	*66*	*67*	*66*	*67*	*34*	*66*	*66*
Physical habitat alteration	*25*	*78*	**70**	*75*	*75*	*75*	*75*	*75*	*84*	*90*
Habitat health score		**76**	**63**	**75**	**75**	**60**	**59**	**67**	**77**	**79**
Microalgae	*20*	*80*	**65**	*80*	*80*	*80*	*80*	*50*	*80*	*90*
Macrophytes	*20*	*21*	**20**	*26*	*31*	*33*	*34*	*15*	*46*	*46*
Invertebrates	*20*	*75*	**60**	*75*	*75*	*70*	*70*	*50*	*85*	*90*
Fish	*20*	*60*	**35**	*60*	*60*	*60*	*55*	*50*	*70*	*75*
Birds	*20*	*60*	**50**	*55*	*55*	*55*	*55*	*50*	*57*	*65*
Biotic health score		**59**	**46**	**59**	**60**	**60**	**59**	**43**	**68**	**73**
ESTUARY HEALTH SCORE		**68**	**54**	**67**	**67**	**60**	**59**	**55**	**72**	**76**
ECOLOGICAL STATUS		**C**	**D**	**C**	**C**	**D**	**D**	**D**	**B/C**	**B**

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ACRONYMS AND ABBREVIATIONS

BAS	*Best Attainable State*
CD	*Chief Directorate*
CSIR	*Centre of Scientific and Industrial Research*
DEA: O&C	*Department of Environmental Affairs: Oceans and Coast*
DIN	*Dissolved Inorganic Nitrogen*
DIP	*Dissolved Inorganic Phosphate*
DO	*Dissolved Oxygen*
DRP	*Dissolved Reactive Phosphate*
DRS	*Dissolved Reactive Silicate*
DWA	*Department of Water Affairs*
DWAF	*Department of Water Affairs and Forestry*
EHI	*Estuarine Health Index*
EIS	*Estuarine Importance Score*
ERC	*Ecological Reserve Category*
EWR	*Ecological Water Requirement*
H	*High*
L	*Low*
M	*Medium*
MAR	*Mean Annual Runoff*
MCM	*Million Cubic Metres*
MCM/a	*Million Cubic Metres per annum*
MSL	*Mean Sea Level*
NMMU	*Nelson Mandela Metropolitan University*
NWA	*National Water Act (1998)*
PES	*Present Ecological Status*
ppt	*Parts per thousand*
RDM	*Resource Directed Measures*
REI	*River Estuary Interface*
RQO	*Resource Quality Objectives*
SA	*South Africa*
SDF	*Standard Design Flood*
VL	*Very low*
WMA	*Water Management Area*

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 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 method follows a generic methodology that 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). As this study was initiated in 2012, Version 2 is still applied in this study (DWA 2008), 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 Mkomazi to Umzimkulu WMA study, where considered appropriate.*

This report presented the EcoClassification of the Mkomazi 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 (EHI) 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*	…
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) flowing 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*

** BAS = 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 of 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***, 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 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 meant that we expected the confidence of the study to be low. This is a situation that can only be remedied with some comprehensive and long term data collection on the system. Criteria for the confidence limits attached to statements in this study are:

Confidence level	Situation	Expressed as percentage
Low	*Limited data available*	*<40% certainty*
Medium	*Reasonable data available*	*40 – 80% certainty*
High	*Good data available*	*> 80% certainty*

1.3 ASSUMPTIONS AND LIMITATIONS FOR THIS STUDY

The following assumptions and limitations should be taken into account:

- *The accuracy and confidence of an Estuarine Ecological Water Requirements 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 (60-80), with a particular concern regarding the accuracy of the simulated base flows during the low flow period into the estuary.*

- *Inflow data were only available at the head of the estuary for limited periods, which only allowed for a medium level confidence in the correlation between mouth state and water quality characteristics.*

- *…..*

1.4 STRUCTURE OF THIS REPORT

The report is structured as follows:

Chapter 1	*Provides an overview of EWR methods and confidence of the study.*
Chapter 2	*Summarises important background information related to the hydrological characteristics, catchment characteristics and land-use, as well as human pressures affecting the estuary*
Chapter 3	*Defines the geographical boundaries of the study area, as well as the zoning and typical abiotic states adopted for this estuary;*
Chapter 4	*Provides a baseline ecological and health assessment of the estuary. It describes each of the abiotic and biotic aspects of the estuary - from hydrology to birds – describing an understanding of the present situation and estimation of the reference condition. The health state of each component is computed using the Estuary Health Index (EHI).*
Chapter 5	*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	*Combines the EHI score with the Estuarine Importance Score (EIS) for the system to determine the Recommended Ecological Category.*
Chapter 7	*Describes the ecological consequences of various future flow scenarios, and determines the Ecological Category for each of these using the EHI.*
Chapter 8	*Concludes with recommendations on the ecological water requirements for the estuary, as well as recommended resource quality objectives (ecological specifications). Finally, monitoring requirements to improve the confidence of the EWR assessment are recommended.*

2 BACKGROUND INFORMATION

2.1 HYDROLOGICAL CHARACTERISTICS

The uMkhomazi River is one of KwaZulu Natal's largest rivers and the estuary 30°12'S, 30°49'E is situated approximately 50 km south of central Durban. The suburb of Umkomaas lies on the south bank of the estuary. The Mkomazi river rises in the Drakensberg and there appears to be agreement on the length at 298 km (Begg 1978, Perry 1989). Cited catchment areas range from 4 222 to 4 389 km^2 (Begg 1978) and 4 310 km^2 (Perry 1989) to 4 315 km^2 (Day 1981). The Present MAR is estimated at 943.39 Million m^3. With its length, large catchment (second only to the Thukela in KZN) it has historically been subject to major flood events.

The estuary was classified as a permanently open estuary by Whitfield (2000). It is relatively straight for much of its length only undulating around the headland on which the Sappi Saiccor factory is located. It is a wide shallow system with a mouth that very seldom closes. There are two existing bridges, viz. the combined road and rail bridge at the mouth and the newer N2 freeway bridge further upstream. The old steel bridge is above the present limit of estuarine penetration.

2.2 CATCHMENT CHARACTERISTICS AND LAND-USE

1.4.1 Land-use

A broad over view of the land-use in the Mkomazi Catchment (Figure 2.1) indicated that:

- *About 47% of the catchment is natural grasslands and < 1% planted grasslands, with about 6% classified as degraded grassland;*
- *About 25% of the catchment is thicket and bushland;*
- *Nearly 13% of the catchment is forest plantation (comprising eucalyptus, pine, acacia and clear felled land); and*
- *Sugar cane is estimated at less than 1% of the catchment, while cultivated commercial farming is estimated at 3%, and cultivated temporarily subsistence dryland were estimated at 4%.*

2.3 HUMAN ACTIVITIES AFFECTING THE ESTUARY (PRESSURES)

Table 2.1 provides a summary of significant flow related pressures on the Mkomazi Estuary, while Table 2.2 summarises key non-flow related pressures.

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	✓	

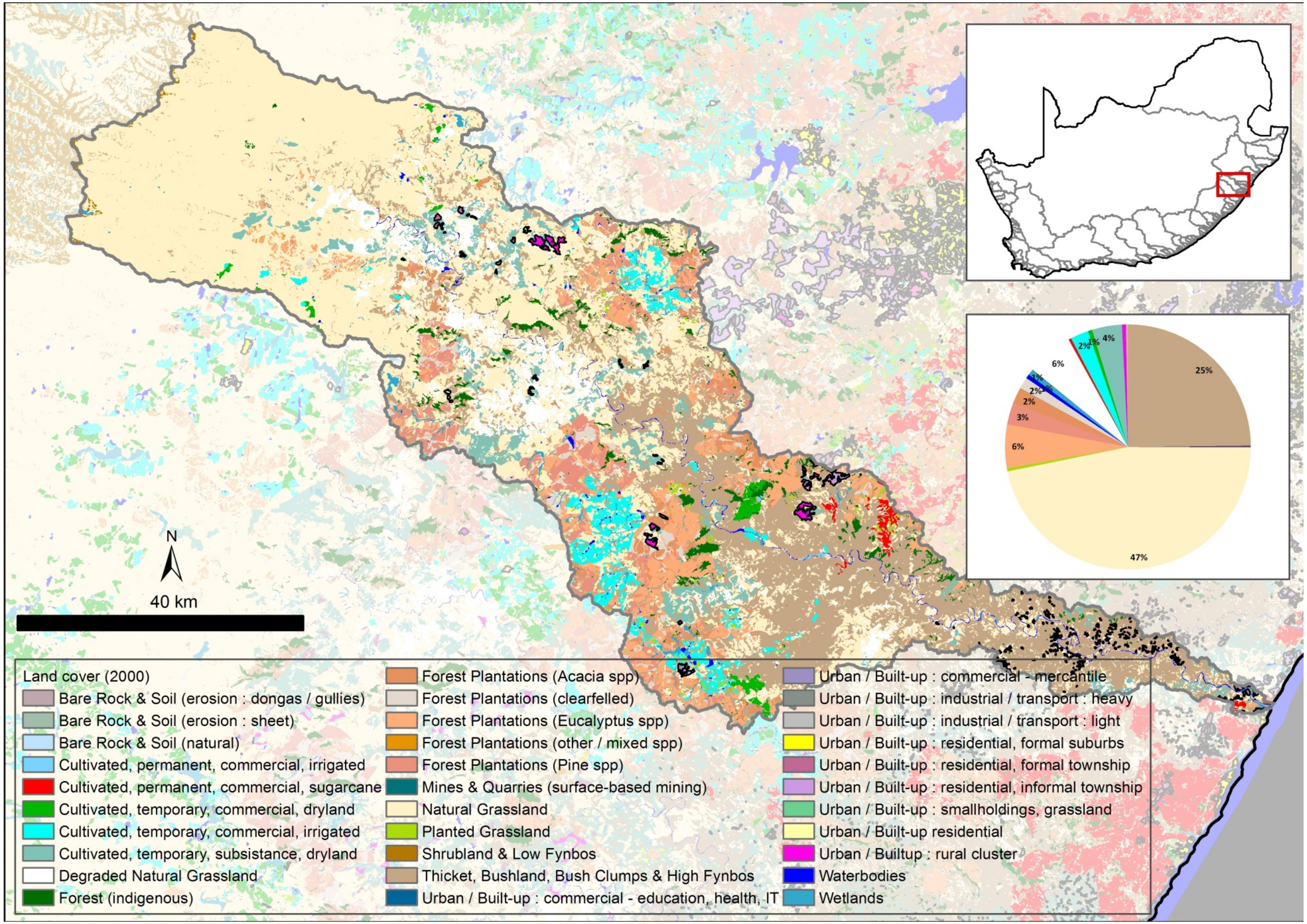


Figure 2.1 **Overview of land-use in the Mkomazi catchment**

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	✓	*Some sugar cane in the floodplain areas.*
SAPPI Paper Mill effluent disposal (just above N2 bridge)	✓	*Industrial effluent from paper mill (high organic content and possibly toxic substances)*
Municipal WWTW	✓	*Umkomaas WWTW (Capacity 1Ml/day, operation at 49% in 2012) discharging in Zone A.*
Ushukela Sugar Mill	✓	*Industrial effluent (high organic content)*
Bridge(s)	✓	*There are two existing bridges, the combined road and rail bridge at the mouth and the newer N2 freeway bridge further upstream.*
Artificial breaching	✓	*Yes, but breaching level unknown.*
Bank stabilisation and destabilisation		*Extensive sand mining in the upper reaches.*
Low-lying developments	✓	*Sugar cane fields and possibly the Sappi pump station.*
Migration barrier in river	✓	*Sappi Saiccor intake weir in the upper estuary.*
Recreational fishing	✓	*Limited. Mostly targets the beach*
Commercial/Subsistence fishing (e.g. gillnet fishery)	✓	*High levels of marginal line fishing (unknown if subsistence)*
Illegal fishing (Poaching)		
Bait collection	✓	*Cast netting for juvenile mullet occurs to support rock and surf anglers*
Grazing and trampling of salt mashes		
Translocated or alien fauna and flora		
Recreational disturbance of waterbirds	✓	*High intensity use of mouth area for launching, recreational beach users and fishers*

3 DELINEATION OF ESTUARY

3.1 GEOGRAPHICAL BOUNDARIES

The mouth of the Mkomazi River is approximately 50 km south of Durban. The Mkomazi Estuary is classified as a “Permanently open” estuary, but the marine influence upstream of the inlet is limited for a large part of the year (Whitfield 1992). The Mkomazi estuary is relatively straight for much of its length only undulating around the headland on which the Sappi Saiccor factory is located. It is a wide shallow system with a mouth that very seldom closes.

For the purposes of this EWR study, the geographical boundaries of the estuary are defined as follows (Figure 3—1):

Downstream boundary:	*Estuary mouth 30°12'4.45"S 30°48'8.65"E*
Upstream boundary:	*30°10'25.64"S 30°44'51.42"E*
Lateral boundaries:	*5 m contour above Mean Sea Level (MSL) along each bank*

Figure 3.1 Geographical boundaries of the Mkomazi Estuary based on the Estuary Functional Zone

The true extent of the upper boundary (marked in dark blue in Figure 3.1) of the Mkomazi Estuary is not known as the full extent of tidal penetration is currently constrained by a weir. However, for the purpose of this study the upper reaches were taken as about 1.7 km upstream of the weir, based on channel and vegetation features. This boundary may well be significantly further upstream. The positioning of the Mkomazi Estuary’s upper boundary is further confounded by back flooding above the weir, which decreases flow velocities that leads to localised sedimentation in *this zone under normal flow conditions. Topographical survey information is needed to accurately determine the upper boundary of this system.*

3.2 ZONATION OF THE MKOMAZI ESTUARY

For the purposes of this study, the Mkomazi Estuary is sub-divided into three distinct zones, primarily based on bathymetry (Figure 3—2):

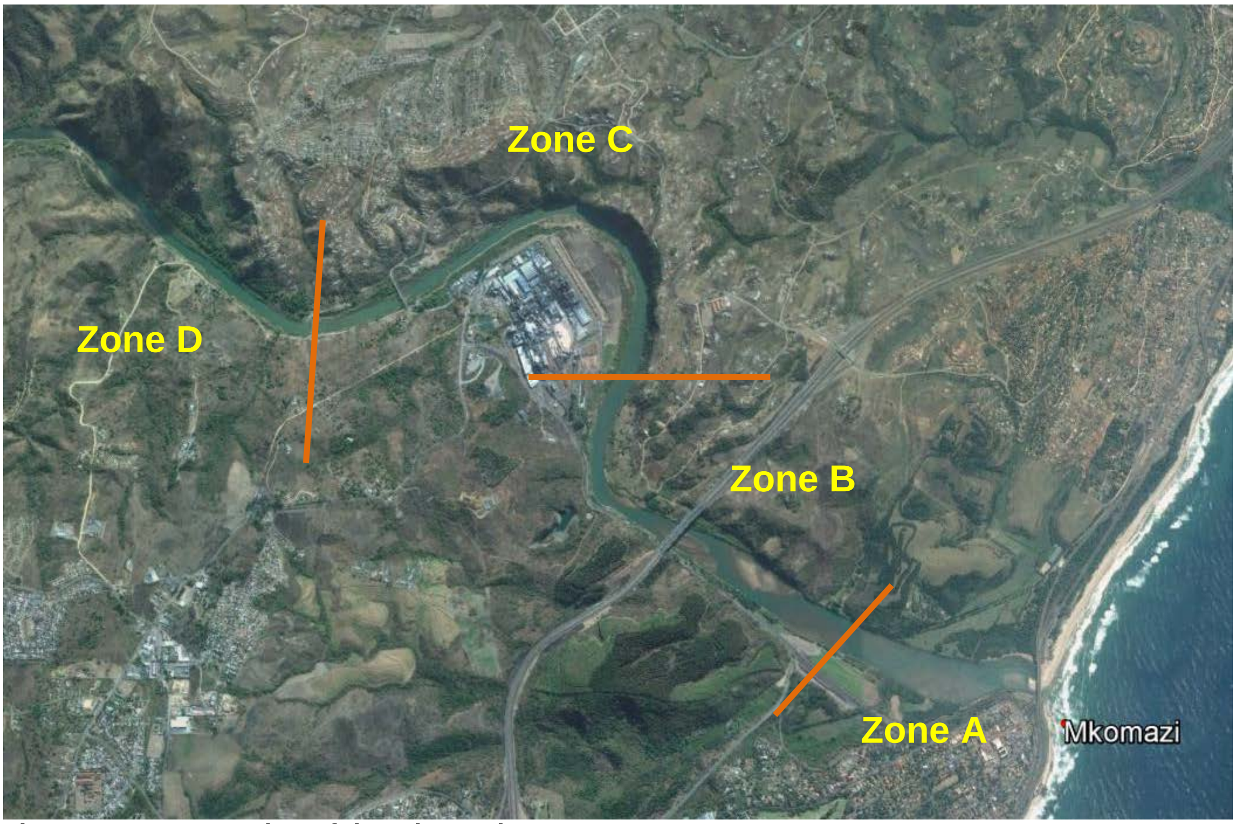


Figure 3.2 Zonation of the Mkomazi Estuary

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

Table 3.1 Key features of the Mkomazi Estuary zonation

	Zone A: Lower	Zone B: Middle	Zone C: Upper	Zone D: Historical upper
Area (ha)	*26.5*	*20.1*	*16.1*	*9.4*
Maximum depth (to MSL)	*-0.5 to -1.0*	*-1.5 to - 2.0*	*-2.0 to -3.0*	*1.0 – 2.0 deep (at about -1. m MSL)*

3.3 TYPICAL ABIOTIC STATES

Based on available literature, a number of characteristic 'states' can be identified for the Mkomazi Estuary, related to mouth condition, tidal exchange, salinity distribution and water quality. These are primarily determined by river inflow patterns, water level 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 Mkomazi Estuary

State	Flow range (m^3/s)	Description
State 1: Closed, brackish	*< 1.0*	*The estuary mouth is closed for weeks to months. Zones A, B, and C are well mixed and salinity is brackish throughout. Zones A, B and C have salinity of about 20, 20 and 10 respectively, Zone D is fresh.*
State 2: Open, full salinity gradient	*1.0 – 2.0*	*The system shows a marine influence due to reduced freshwater inflow and regular breaching. Zones A, B and C have salinity of about 25, 15 and 10 respectively, Zone D is fresh.*
State 3: Open, limited salinity gradient	*2.0 – 5.0*	*Zones C and D are fresh, with limited saline intrusion into Zone B (salinity ~10). Zones A have salinity of about 20, with strong tidal flucuations been tween 30 on the high tide and 10 on the low tide.*
State 4: Open fresh	*> 5*	*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 Mkomazi is provided in Chapter 4. For more detail on the underlying data and assumptions, refer to the Abiotic Specialist Report.

4 ECOLOGICAL BASELINE AND HEALTH ASSESSMENT

4.1 HYDROLOGY

4.1.1 Baseline description

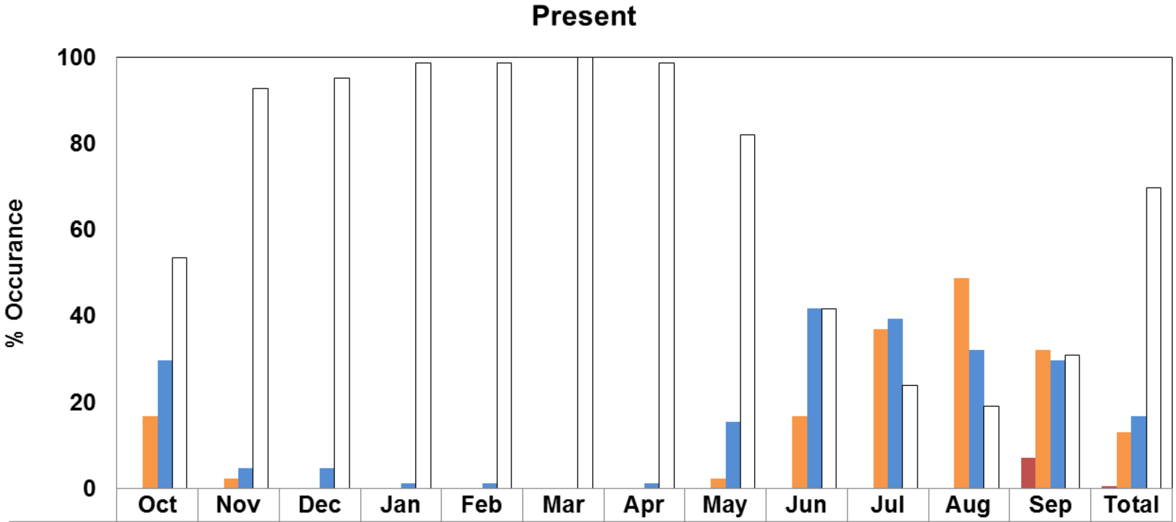
According to the hydrological data provided for this study, the present day MAR into the Mkomazi Estuary is 943.39 Million m^3. This is a decrease of 12% compared to the natural MAR of 1 077.74 Million m^3. The occurrences of flow distributions (mean monthly flows in m^3/s) for the Present State and Reference Condition of the Mkomazi Estuary, derived from the 84-year simulated data set, are provided in Table 4.1 and Table 4.2. A graphic representation of the occurrence of the various abiotic states is presented in Figure 4.1 and Figure 4.2. The full 84-year series of simulated monthly runoff data for the present state and Reference Condition is provided in Table 4.3 and Table 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	203.4	133.8	186.6	205.1	245.6	251.5	136.6	130.8	89.2	44.9	40.9	248.4
99	83.5	131.6	146.0	203.1	221.2	226.4	115.9	103.2	48.2	29.5	32.8	92.0
90	23.6	55.2	95.9	119.6	138.4	111.1	66.7	23.6	12.2	14.2	8.2	12.1
80	15.9	34.5	70.1	92.7	112.3	81.9	47.4	15.3	8.7	5.7	4.7	7.6
70	12.2	28.8	55.9	74.8	87.3	63.7	34.5	14.3	6.2	4.1	3.7	5.1
60	8.1	22.8	47.0	64.7	76.8	58.6	31.5	10.9	5.2	3.3	2.9	3.6
50	5.9	19.1	41.2	52.5	65.9	49.7	29.2	9.7	4.8	2.7	2.3	2.5
40	4.3	14.3	32.2	44.4	58.0	45.7	24.5	8.6	4.1	2.2	1.6	2.0
30	3.4	10.3	26.0	37.5	46.7	41.0	18.4	7.4	3.3	1.6	1.3	1.6
20	2.8	8.8	16.1	29.2	39.8	37.6	15.4	5.3	2.3	1.3	1.1	1.3
10	1.6	6.6	8.7	22.8	26.5	28.6	10.9	3.7	1.6	1.1	1.0	1.1
1	1.1	1.3	3.0	5.5	9.1	12.0	4.9	1.7	1.1	1.0	1.0	1.0
0.1	1.0	1.2	2.6	5.0	4.7	10.0	4.5	1.3	1.0	1.0	1.0	1.0

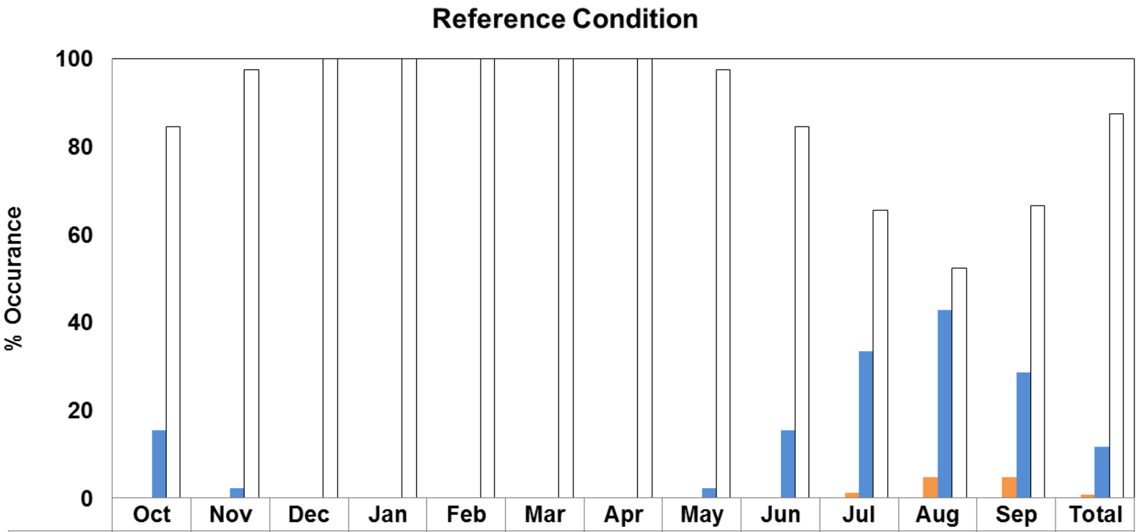
Table 4.2 A summary of the monthly flow (in m^3/s) distribution under the Reference State

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	209.5	145.4	204.5	217.6	255.8	260.3	148.6	142.2	94.6	51.7	48.7	269.7
99	91.6	133.7	160.6	216.8	233.4	236.9	122.2	109.0	55.2	36.0	38.1	101.3
90	27.8	61.9	104.8	126.3	149.3	119.9	73.4	25.6	16.0	16.5	12.2	15.8
80	19.6	39.4	78.1	100.9	122.3	85.3	52.5	19.2	12.2	9.0	8.5	11.5
70	15.6	33.3	61.8	82.8	94.7	68.0	38.6	17.0	9.6	7.3	6.9	8.8
60	11.7	26.9	51.6	70.7	82.1	62.7	35.0	14.4	8.6	6.4	6.1	7.2
50	9.1	23.7	45.2	57.8	71.2	54.9	32.2	13.4	8.0	5.9	5.4	6.0
40	7.7	18.5	36.3	48.7	63.1	49.2	28.5	12.5	7.3	5.3	4.5	5.2
30	6.5	14.1	29.7	41.6	50.3	46.2	23.6	10.9	6.3	4.5	3.8	4.8
20	5.7	12.3	19.2	33.9	44.5	40.7	19.1	8.9	5.3	3.6	3.2	4.1
10	4.3	10.1	11.0	25.6	29.3	32.3	14.5	6.8	4.4	2.8	2.5	2.9
1	2.8	3.8	5.5	8.3	11.9	14.9	8.4	4.8	3.0	2.1	1.8	1.6
0.1	2.6	3.7	5.4	7.8	7.1	12.4	7.8	4.0	2.8	2.0	1.8	1.6



	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	7	1
State 2	17	2	0	0	0	0	0	2	17	37	49	32	13
State 3	30	5	5	1	1	0	1	15	42	39	32	30	17
State 4	54	93	95	99	99	100	99	82	42	24	19	31	70

Table 4.3 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	1	5	5	1
State 3	15	2	0	0	0	0	0	2	15	33	43	29	12
State 4	85	98	100	100	100	100	100	98	85	65	52	67	87

Table 4.4 Graphic presentation of the occurrence of the various abiotic states under the Reference Condition

Table 4.5 Present State simulated monthly flows (in m^3/s) to the Mkomazi Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1925	15.4	11.0	11.3	17.7	23.6	30.5	18.4	5.6	4.5	2.8	1.2	12.5
1926	20.4	21.5	52.9	57.7	47.4	88.0	55.1	9.7	1.7	1.1	3.7	4.0
1927	10.9	13.3	47.4	105.6	79.5	53.9	30.1	6.8	2.3	1.1	1.3	1.8
1928	7.2	10.3	31.5	52.5	37.4	47.4	33.0	12.2	19.9	21.5	12.3	13.8
1929	18.0	37.3	46.7	75.5	66.3	45.5	24.9	6.0	2.6	1.5	2.4	3.4
1930	5.0	10.0	42.8	70.2	59.6	40.4	24.8	8.6	2.2	4.3	4.4	1.6
1931	2.1	4.0	8.2	26.7	84.4	59.6	18.3	5.7	4.2	2.3	1.1	1.5
1932	5.9	21.5	32.0	19.8	20.4	24.3	15.8	5.2	1.3	1.0	1.0	1.0
1933	1.0	54.9	107.4	148.3	101.7	40.9	29.4	20.6	10.7	5.8	4.8	4.1
1934	8.0	65.8	109.7	61.1	38.3	32.2	22.3	11.4	38.9	26.1	7.1	2.1
1935	1.4	1.3	3.0	26.3	82.9	71.7	31.1	18.0	12.3	4.3	1.2	1.3
1936	4.4	75.0	54.4	42.7	77.2	47.0	15.6	3.4	1.1	1.0	1.0	1.0
1937	1.5	9.9	19.3	55.6	108.3	55.8	33.1	18.6	6.3	3.4	4.1	3.1
1938	22.7	31.9	68.6	61.4	166.6	110.5	30.3	8.3	3.3	1.5	1.4	7.5
1939	15.2	33.3	43.6	45.8	46.6	48.8	30.4	37.2	34.6	14.8	4.4	2.4
1940	7.0	31.1	119.4	102.0	78.1	48.3	22.8	7.7	1.9	1.1	1.0	1.0
1941	3.4	7.9	15.0	64.2	136.2	120.4	63.9	21.6	6.6	2.3	2.5	2.8
1942	11.3	59.4	126.6	120.7	86.7	48.9	139.0	96.9	27.0	15.5	30.9	21.2
1943	56.0	134.1	121.6	74.6	65.1	58.8	30.2	5.5	1.9	1.4	1.1	12.7
1944	18.3	14.1	7.3	23.1	43.6	103.5	66.8	14.3	4.0	1.2	1.0	1.0
1945	1.2	1.2	4.3	19.1	40.3	39.0	25.0	10.0	2.7	1.0	1.0	1.0
1946	1.2	21.8	26.1	33.3	89.1	96.4	48.9	13.6	11.5	8.8	4.0	1.6
1947	4.3	34.4	55.7	77.7	75.0	70.6	46.5	14.8	4.9	1.2	1.0	1.0
1948	3.2	8.6	17.0	27.6	48.1	51.0	29.6	8.7	2.2	1.0	1.0	1.4
1949	4.1	17.1	41.1	34.1	62.4	111.4	73.2	23.2	9.0	4.2	9.3	8.9
1950	3.9	6.9	59.2	103.2	73.3	28.2	14.1	5.4	1.3	1.0	3.3	6.8
1951	12.2	8.7	25.0	64.8	88.8	45.6	20.2	10.4	4.8	2.4	2.4	1.9
1952	2.9	16.5	27.6	38.3	72.7	39.3	10.7	3.1	1.3	1.0	1.3	4.4
1953	12.3	25.3	52.9	59.8	90.2	63.5	24.4	11.6	8.4	3.4	1.2	2.2
1954	26.9	34.8	33.9	135.8	178.6	82.7	28.0	10.5	5.2	2.0	1.1	1.1
1955	1.9	5.1	38.8	29.7	110.6	139.4	66.3	11.3	2.6	1.1	1.1	1.4
1956	5.0	29.4	136.8	152.2	87.1	75.3	52.3	15.4	4.9	1.6	2.9	26.6
1957	48.2	38.6	41.3	74.5	91.1	43.8	29.4	16.2	5.0	1.2	1.0	1.2
1958	2.9	12.7	63.9	74.8	64.4	34.5	15.5	133.9	93.7	14.9	4.1	2.3
1959	4.4	21.9	33.1	24.4	32.3	46.1	39.3	17.9	6.0	1.3	1.0	1.4
1960	2.9	20.0	87.3	49.4	46.7	67.2	100.6	29.3	8.6	3.5	1.6	1.9
1961	1.7	12.1	30.8	51.7	83.6	58.7	23.7	9.7	3.7	1.6	1.9	2.8
1962	2.7	25.9	47.1	117.0	48.5	108.5	34.4	10.1	6.5	24.5	6.0	2.8
1963	10.7	55.4	58.1	101.0	45.3	30.2	14.4	7.4	13.1	6.6	3.2	7.8
1964	14.5	44.5	34.5	60.5	69.2	12.5	7.6	3.2	15.9	10.3	5.4	12.6
1965	15.3	29.7	15.4	84.4	90.2	13.4	6.0	6.1	3.1	1.7	1.4	2.5
1966	2.0	29.2	31.8	43.2	139.4	142.2	111.2	24.2	10.6	8.3	5.0	2.7
1967	2.9	29.0	26.6	22.7	21.9	40.7	33.4	7.6	3.6	2.3	2.9	2.0
1968	1.3	8.2	25.5	5.0	12.0	65.6	42.7	10.7	5.2	3.4	1.9	3.4
1969	24.0	14.8	48.5	39.1	64.3	16.3	4.5	2.9	1.5	1.5	14.6	8.4
1970	56.3	23.3	22.6	27.3	66.2	33.5	25.9	15.2	5.8	5.6	22.1	7.6
1971	16.5	25.3	59.5	99.6	130.3	124.3	35.7	13.5	7.4	4.4	3.1	1.7
1972	4.0	17.5	13.7	11.0	65.0	46.9	79.8	23.8	4.9	2.7	3.7	5.1
1973	17.7	28.6	30.1	142.5	215.6	146.0	77.7	24.2	12.0	8.3	4.6	2.4
1974	3.3	13.4	29.4	88.1	114.7	61.5	25.7	8.1	4.3	2.7	1.8	7.4
1975	5.1	13.6	88.4	202.7	248.3	254.3	91.5	23.7	9.8	6.9	5.3	4.1
1976	35.6	20.3	16.7	44.2	63.0	63.5	34.7	9.2	4.2	2.9	2.0	2.3
1977	7.3	10.2	16.5	84.7	65.6	57.4	41.5	15.0	6.3	3.6	2.5	5.8
1978	17.2	24.1	88.1	34.5	46.5	49.5	17.3	9.2	4.1	4.1	4.5	6.1
1979	4.3	8.9	11.5	31.8	39.0	44.8	11.2	3.0	1.6	1.3	1.1	7.6
1980	10.7	8.2	35.6	68.3	117.5	44.3	8.4	4.8	3.0	1.6	1.6	11.1
1981	3.7	9.1	15.2	17.6	10.1	60.2	17.8	4.9	3.2	1.7	1.2	1.4
1982	1.4	9.0	6.4	5.6	4.3	9.7	5.0	1.2	1.0	1.0	1.1	1.1
1983	3.5	18.4	79.1	69.8	26.5	62.5	53.4	9.7	4.8	3.4	2.2	2.0
1984	4.7	7.1	6.5	52.5	171.3	44.3	8.2	3.6	2.3	1.5	1.1	1.1
1985	8.0	63.1	90.0	76.4	51.3	44.6	15.1	7.7	4.0	2.1	1.7	3.6
1986	9.9	39.9	42.4	45.0	26.1	52.6	16.9	5.6	3.6	2.6	6.1	265.7
1987	216.7	131.1	44.0	37.7	176.0	220.7	60.1	14.5	8.8	12.8	5.8	4.6
1988	4.6	17.0	80.7	103.1	152.2	66.8	22.2	14.9	7.0	5.2	2.6	1.7
1989	2.0	95.7	98.4	34.8	29.8	59.0	58.4	10.3	4.8	3.1	2.9	5.1
1990	5.9	8.1	39.0	79.7	133.9	55.8	18.3	7.7	4.6	2.9	1.6	2.0
1991	18.2	21.1	33.8	35.1	26.5	19.5	5.8	1.8	1.2	1.0	1.0	1.0
1992	1.1	3.0	3.1	10.0	33.0	35.6	19.2	3.6	1.3	1.0	1.0	1.0
1993	15.1	19.8	45.4	109.3	120.0	39.3	11.2	5.0	2.6	2.6	3.1	1.6
1994	3.5	4.3	7.8	39.3	19.2	40.1	32.2	9.7	5.8	3.3	41.8	56.4
1995	33.3	16.9	191.1	205.3	175.1	109.9	32.0	11.0	6.1	46.6	15.7	7.8
1996	8.1	17.3	68.2	122.6	47.4	81.3	43.0	14.7	14.8	17.4	8.6	7.5
1997	11.4	44.6	72.2	69.2	125.7	67.6	29.1	9.9	5.7	3.4	3.2	2.4
1998	2.9	9.1	47.9	45.9	74.6	27.1	8.6	3.7	1.9	1.3	1.1	1.0
1999	8.7	13.8	113.3	150.1	83.9	145.7	76.9	24.8	8.9	5.2	3.1	7.4
2000	6.1	24.6	61.1	65.7	42.5	29.3	37.0	11.5	5.0	2.9	1.8	20.0
2001	14.1	71.2	67.8	48.9	51.6	39.8	11.7	5.2	5.8	15.0	14.8	10.3
2002	4.3	5.6	10.0	26.1	52.3	33.9	24.0	9.0	4.3	2.2	1.2	2.1
2003	1.4	9.1	13.6	42.3	57.6	49.9	14.8	4.2	1.6	2.2	2.8	3.9
2004	8.1	28.8	82.3	84.4	42.8	41.0	31.6	7.9	3.7	2.3	1.5	1.2
2005	1.6	4.3	2.6	37.5	74.6	58.3	29.0	14.9	5.3	3.1	4.3	4.0
2006	30.5	23.0	48.5	28.5	38.1	21.5	13.2	4.5	3.5	4.1	1.4	1.2
2007	14.4	38.2	41.7	51.3	43.0	45.1	31.9	14.3	6.2	2.9	1.4	1.7

2008	2.0	6.5	20.0	37.1	135.9	99.5	32.8	9.7	3.4	1.4	2.0	1.3

Table 4.6 Reference Condition simulated monthly flows (in m^3/s) to the Mkomazi Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1925	15.5	14.6	14.0	21.3	26.8	34.2	23.6	9.1	7.6	6.2	3.6	15.9
1926	24.4	26.1	57.5	63.4	50.6	98.5	62.2	12.6	4.6	3.2	6.9	7.9
1927	14.5	17.4	53.1	117.4	84.8	56.2	34.1	10.2	5.3	3.0	3.7	5.0
1928	10.6	14.1	35.5	56.9	40.6	53.3	39.3	16.0	23.0	26.1	16.9	17.7
1929	21.8	41.8	51.5	83.4	70.6	48.1	28.9	9.7	5.6	4.6	5.6	7.1
1930	8.6	13.4	46.1	78.1	65.5	43.3	29.0	12.5	5.2	7.3	8.5	5.0
1931	5.0	7.4	10.6	30.1	92.1	65.7	23.3	8.9	7.4	5.5	3.2	4.2
1932	9.0	25.4	35.9	23.9	23.1	27.1	20.5	9.1	3.8	2.7	2.6	2.0
1933	2.6	62.4	121.8	159.5	104.4	42.2	33.0	24.5	14.5	9.1	8.5	7.7
1934	11.4	71.3	120.4	66.7	40.3	35.3	25.8	15.5	46.3	32.4	10.7	5.6
1935	4.1	3.9	5.5	29.5	96.3	82.0	35.4	20.6	16.7	7.9	3.7	3.8
1936	7.7	88.0	61.8	45.0	84.8	51.9	19.2	6.5	3.0	2.1	1.8	1.7
1937	4.1	13.5	22.4	62.9	120.1	61.7	36.1	23.5	9.8	6.5	7.5	6.6
1938	26.4	36.6	72.8	65.5	179.9	115.8	31.4	11.7	6.9	4.5	4.3	11.5
1939	19.4	38.8	49.0	50.5	50.4	53.0	34.6	41.4	39.1	19.2	8.1	5.6
1940	10.3	35.8	131.4	109.3	80.1	50.2	26.2	11.7	5.0	3.0	2.4	2.4
1941	6.4	11.6	18.3	68.9	147.1	130.6	68.6	24.3	10.1	5.4	5.6	6.3
1942	15.0	67.2	138.3	126.0	87.4	50.9	151.6	101.4	28.4	19.0	35.7	26.7
1943	64.7	146.7	127.5	76.7	66.8	62.1	34.2	9.1	4.8	4.1	3.1	16.3
1944	22.7	18.4	10.2	25.7	47.5	116.2	74.9	17.1	7.3	3.4	2.1	1.6
1945	3.3	3.7	6.5	22.6	46.1	44.3	30.2	13.9	5.8	2.7	1.8	1.6
1946	3.2	25.9	29.6	37.9	97.2	106.9	55.3	17.0	14.4	13.1	7.9	4.8
1947	7.5	39.4	60.3	82.8	79.2	75.1	50.7	18.7	8.2	3.5	1.9	1.7
1948	6.1	12.7	20.3	31.8	51.9	55.9	34.5	12.5	5.3	2.7	2.5	4.1
1949	7.3	22.7	45.6	38.1	68.2	120.6	78.3	26.1	12.5	7.3	12.9	13.2
1950	7.4	10.2	66.9	113.5	76.2	29.7	18.5	8.9	3.8	2.0	6.2	10.7
1951	16.2	13.1	27.5	71.2	94.6	48.2	23.7	14.8	8.4	5.7	5.5	5.0
1952	5.9	19.9	31.2	42.7	80.1	44.8	14.4	6.3	3.7	2.6	3.8	8.2
1953	16.2	30.1	59.1	66.2	95.9	66.9	27.5	14.9	12.2	6.8	3.6	5.4
1954	31.9	39.5	37.5	148.7	191.9	85.0	29.9	14.2	8.6	5.2	3.1	3.1
1955	4.8	8.5	42.8	34.5	122.2	153.4	69.7	13.6	5.7	3.3	3.2	4.2
1956	8.4	34.1	150.6	162.7	87.7	80.4	56.4	18.9	8.3	4.5	5.8	31.2
1957	55.2	44.0	44.8	79.2	98.3	48.1	31.9	20.6	8.5	3.5	2.0	3.5
1958	5.9	15.8	72.6	85.1	71.1	37.6	18.9	145.9	99.0	16.5	7.6	5.9
1959	7.8	26.0	37.4	28.6	34.6	51.6	44.7	22.2	9.5	4.0	2.8	4.1
1960	6.0	24.6	97.8	56.8	50.0	74.2	109.8	32.8	11.8	6.6	4.5	4.8
1961	4.8	15.7	34.6	56.9	92.2	66.7	28.4	13.5	6.8	4.3	4.6	6.1
1962	5.6	30.6	51.6	126.4	53.2	118.0	39.0	13.8	9.8	27.8	10.2	6.6
1963	14.3	60.7	61.8	110.6	49.8	33.0	17.9	11.3	16.1	10.5	6.7	11.5
1964	18.0	50.0	37.6	65.5	73.1	15.5	11.1	6.3	18.9	14.9	9.0	17.5
1965	18.6	34.9	18.9	94.1	99.1	16.5	9.4	9.2	6.5	5.0	4.3	6.0
1966	5.3	33.3	36.1	48.0	149.7	153.2	116.2	25.3	14.1	12.0	8.9	6.3
1967	5.8	33.4	30.0	25.5	24.6	44.7	38.3	11.3	6.7	5.3	6.0	5.3
1968	4.2	11.7	29.7	7.7	13.9	73.4	49.6	14.0	8.6	6.6	5.0	6.7
1969	28.4	19.1	53.5	43.7	68.9	19.4	7.7	5.9	4.2	4.4	18.1	12.7
1970	63.1	27.1	25.5	31.3	70.2	36.3	30.4	18.7	9.6	9.0	26.3	12.2
1971	19.9	29.2	63.6	107.5	138.1	130.6	37.6	16.9	11.0	7.9	6.6	4.9
1972	7.1	21.9	17.7	13.6	71.3	54.0	88.0	25.8	7.9	5.5	6.5	8.7
1973	22.8	32.5	33.7	156.6	228.3	150.1	80.3	26.1	15.8	12.0	8.1	5.8
1974	6.5	16.8	32.9	96.6	122.3	64.5	28.9	11.9	7.5	5.9	4.8	10.9
1975	9.2	17.6	95.4	216.6	258.3	262.9	87.9	25.9	14.0	11.1	9.2	7.7
1976	40.6	24.6	19.5	48.6	68.5	66.9	38.6	13.1	7.3	6.1	5.0	5.1
1977	10.8	13.9	19.4	93.2	71.4	62.7	45.8	19.4	9.7	6.9	5.7	9.3
1978	21.4	29.7	95.6	38.4	50.4	53.4	20.5	13.1	7.6	7.4	8.0	9.8
1979	7.7	12.1	13.9	35.6	43.5	49.0	14.6	6.3	4.4	3.5	2.9	10.7
1980	15.2	11.5	41.4	74.9	125.1	46.7	11.5	8.1	6.2	4.6	4.2	15.5
1981	6.9	12.3	18.7	21.5	13.0	65.7	23.9	8.5	6.3	4.7	3.7	4.1
1982	3.8	13.2	9.1	8.5	6.5	12.1	8.5	3.9	2.8	2.4	3.1	3.1
1983	6.6	22.8	88.7	80.8	29.4	67.8	56.9	13.1	8.1	6.4	5.2	5.2
1984	7.0	11.1	9.5	58.7	188.6	48.9	11.6	6.6	5.1	4.2	3.1	3.0
1985	12.4	74.0	99.1	83.2	53.4	48.6	19.5	10.9	7.0	5.2	4.4	7.2
1986	13.0	45.7	47.5	49.5	29.2	58.8	22.0	9.0	6.6	5.9	9.4	288.5
1987	222.6	131.1	45.8	40.9	188.7	231.6	60.0	16.5	12.3	16.5	9.4	8.0
1988	7.9	20.9	91.0	111.4	160.3	70.5	24.7	18.9	10.8	8.6	6.0	4.8
1989	4.8	112.9	107.2	36.0	32.4	65.5	65.2	13.7	8.1	6.4	6.0	9.2
1990	9.0	12.4	42.8	86.8	145.6	59.2	21.8	11.0	8.0	6.3	4.8	5.1
1991	22.4	25.9	37.2	38.4	29.2	22.6	9.6	4.9	3.2	2.3	2.0	2.1
1992	2.9	6.2	5.9	13.1	36.2	40.1	23.4	7.2	4.0	2.7	2.5	2.9
1993	19.4	25.9	51.1	118.3	126.3	41.1	15.9	8.3	5.5	5.5	6.6	5.0
1994	6.5	7.8	10.2	43.9	23.4	43.8	38.0	13.3	8.8	6.7	49.9	63.0
1995	35.7	19.8	209.4	217.7	180.7	114.4	34.5	14.5	9.4	53.4	22.1	11.8
1996	11.2	20.3	77.7	132.8	48.5	85.7	45.9	18.4	18.1	22.0	12.9	11.8
1997	14.8	52.3	78.8	76.0	134.9	70.2	32.4	13.5	9.2	6.6	6.4	5.8
1998	5.8	12.6	52.6	50.4	82.5	31.9	12.2	6.7	4.5	3.6	3.0	2.6
1999	11.6	17.3	130.8	164.6	86.1	151.1	78.9	27.0	12.6	8.8	6.4	10.8
2000	9.7	28.5	67.6	72.8	45.2	33.0	40.3	15.4	8.3	6.0	4.7	24.2
2001	19.0	82.0	75.9	52.5	56.3	42.8	15.1	8.7	9.3	18.6	19.0	15.3
2002	7.9	9.0	12.1	30.0	56.1	37.0	27.7	12.8	7.7	5.3	3.6	5.0
2003	4.2	12.1	16.3	47.0	62.5	55.8	18.9	7.5	4.4	5.1	6.1	7.3
2004	11.7	35.6	92.7	91.8	47.4	46.3	38.0	11.1	6.7	5.4	4.3	3.6
2005	4.3	7.8	5.4	41.7	80.7	62.6	32.6	19.0	8.7	6.3	7.3	7.7
2006	36.5	28.0	54.7	33.0	41.3	25.0	18.6	8.1	6.3	7.8	4.4	3.5
2007	18.0	49.3	47.8	55.6	47.8	48.6	35.1	18.7	9.5	6.3	4.3	4.6

2008	5.1	10.0	24.0	42.8	148.3	109.1	36.1	13.2	6.4	4.0	4.7	4.1

1.1.1 Low flows

Winter inflows never decrease below 1.0 m^3/s and less than 1% below 2 m^3/s under the Reference condition (Table 4.5), thereby maintaining open mouth conditions and ingress of salinity into the middle and upper reaches of the estuary. Under the Reference Condition monthly flow exceeded 5 m^3/s for 87% of the time, while under the Present State river inflow exceeds 5 m^3/s for 70% of the time.

Table 4.7 Summary of the change in low flow conditions to the Mkomazi Estuary from the Reference Condition to the Present State

Percentile	Monthly flow (m^3/s)		% Remaining
	Natural	Present	
30%ile	*8.5*	*5.0*	*58.6*
20%ile	*6.3*	*3.1*	*48.8*
10%ile	*4.4*	*1.6*	*35.8*
% Similarity in low flows			**47.7**

Confidence: High

1.1.2 Flood regime

To provide an indication of the change in flood regime from the Reference Condition to the Present State the ten highest simulated monthly flow volumes were compared for the 84-year period (summarised Table 4.8). The analysis of the simulated monthly flow data indicate that under Reference Conditions floods were about 6 % higher than at present, depending on the size class.

Table 4.8 Summary of the ten highest simulated monthly volumes to the Mkomazi Estuary under Reference Condition and Present State

Date	Monthly Volume ($x10^6$ m^3/month)		% Remaining
	Natural	Present	
Sep 1987	*92.1*	*688.8*	*88.8*
Mar 1976	*96.7*	*681.1*	*91.3*
Feb 1976	*96.1*	*606.1*	*85.0*
Mar 1988	*95.3*	*591.0*	*88.0*
Oct 1987	*97.3*	*580.5*	*72.5*
Jan 1996	*94.3*	*550.0*	*66.6*
Jan 1976	*93.5*	*542.8*	*80.7*
Dec 1995	*91.3*	*511.8*	*90.2*
Feb 1974	*94.4*	*526.4*	*77.2*
Feb 1955	*93.1*	*436.0*	*71.5*
% Similarity in floods			**94.4**

Confidence: Medium

4.1.2 Hydrological health

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

Table 4.9 Calculation of the hydrological health score, giving examples in italics

Variable	Summary of change	Score	Conf
a.% Similarity in period of low flows		*48*	*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.*	*95*	*M*
Hydrology score			

4.2 PHYSICAL HABITAT

4.2.1 Baseline description

Sedimentary deposits and processes in the Mkomazi 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, 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-depositional cycle, leading to the estuary being more in the shallow constricted phase of the cycle because of the loss of resetting events. In addition, there has been some loss of intertidal and subtidal area above the Sappi Weir.

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 hydrological health of the Mkomazi Estuary.

Table 4.10 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*	*80*	*Sedimentation processes are similar to Reference conditions, but there is some loss of intertidal habitat due to deposition and infilling of the intertidal*	*M*

	area exposed		*habitat. There has been some loss of intertidal area above the Sappi weir.* *During States 1 and 2 there is also less exposed intertidal habitat to increased mouth closure and greater mouth restriction.*	
1b	*% Similarity in sand fraction relative to total sand and mud*	*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 increase in clay and silt fractions experienced in similar systems, especially in Zone B, C and D.* *Sand mining will also change grain size distribution in the system.*	*M*
2	*% Similarity in subtidal component s: depth, bed or channel morphology*	*80*	*There has been some infilling of sub-tidal areas as a result of the decrease/loss in resetting floods and increased 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 somewhat reduced and infilling is maintaining the more constricted equilibrium state.* *There has been about a 10% loss of subtidal area due to the Sappi weir. There are also indications that the bridges are causing localise changes in bathymetry..*	*M*
	Physical habitat score	*80*		

Anthropogenic influence:			
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 off set to some extend by sand mining*	*M*
Percentage of overall change in sub<u>tidal habitat</u> caused by ***anthropogenic*** *modifications (e.g. bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary*	*70*	*Poor agricultural practises and developments in the catchment are causing degradation and changes in sedimentation.*	*M*

1 $Score = \frac{(\min(a \text{ to } d) + \text{mean}(a \text{ to } d))}{2}$

4.3 HYDRODYNAMICS

4.3.1 Baseline description

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

Table 4.11 Summary of the abiotic states, and associated hydrodynamic characteristics

PARAMETER	State 1: Closed, brackish	State 2: Open, full salinity gradient	State 3: Open, limited salinity gradient	State 4: Open, fresh
Flow range (m^3/s)	*<1*	*1 - 2*	*2 – 5*	*>5*
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 (m)	*0*	*0.3 – 0.5*	*0.5-1.0*	*2.0 m, but suppressed during floods*
Dominant circulation process	*Wind*	*Tides*	*Tides and river*	*River*
Retention	*Weeks to months*	*1 - 2 weeks*	*< 1 week*	*< 1 day*

4.3.2 Hydrodynamic health

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

Table 4.12 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*	

4.4 WATER QUALITY

4.4.1 Baseline description

Table 4.11 presents a summary of the water quality characteristics for the various states, in each of the four zones. This summary derives from available information on the estuary as presented in the Abiotic Specialist Report. The future scenarios with WWTW assumed effluent discharges at General limits (General authorisation).

Table 4.13 Summary of water quality characteristics of different abiotic states in the Mkomazi 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, brackish				State 2: Open, full salinity gradient				State 3: Open, limited salinity gradient				State 4: Open, fresh			
Salinity	20	20	10	0	30	20	10	0	25	10	0	0	0	0	0	0
Temperature (^oC)	Summer				Summer				Summer				Summer			
	26 - 30				26 - 30				26 - 30				26 - 30			
	Winter				Winter				Winter				Winter			
	14 - 23				14 - 23				14 - 23				14 - 23			
pH	7.5 – 8.5				7.5 – 8.5				7.5 – 8.5				7.5 – 8.5			
DO (mgl/l)	Reference/Present/Future				Reference/Present/Future											
	6	6	4	6	6	6	4	6	6	6	6	6	6	6	6	6
	Future with WWTW															
	6	6	2	4	6	6	2	4								
Turbidity (NTU)	Reference				Reference				Reference				Reference			
	10	10	10	*10*	10	10	10	10	10	10	10	10	>200	>200	>200	>200
	Present/Future				Present/Future				Present/Future				Present/Future			
	10	10	10	10	10	10	10	10	10	10	10	10	>200	>200	>200	>200

NOTE: For the purposes of this assessment the estuary was sub-divided into three zones representing from left to right: Zone A (lower), Zone B (middle), Zone C (upper) and Zone D (historical upper) (Figure 3—1)

Parameter	State 1: Closed, brackish	State 2: Open, full salinity gradient	State 3: Open, limited salinity	State 4: Open, fresh

				gradient	
DIN (µg/l)	**Reference**	**80 80 80 80**	**80 80 80 80**	**80 80 80 80**	**100 100 100 100**
	Present/Future	**150 150 150 200**	**100 150 150 200**	**100 150 200 200**	**250 250 250 250**
	Future with WWTW	**2200 2200 3500 5000**	**500 1600 2200 3500**	**500 1200 1600 1600**	**500 500 500 500**
DIP (µg/l)	**Reference**	**10 10 10 10**	**10 10 10 10**	**10 10 10 10**	**10 10 10 10**
	Present/Future	**10 10 10 10**	**10 10 10 10**	**10 10 15 15**	**20 20 20 20**
	Future with WWTW	**1000 1000 1600 2400**	**240 700 1000 1600**	**200 500 700 700**	**140 140 140 140**
DRS (µg/l)		**800 800 2000 6000**	**200 800 4000 6000**	**200 4000 6000 6000**	**6000 6000 6000 6000**

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), Zone C (upper) and Zone D (historical upper see *Figure 3—1)*

Calculation of River inflow quality assuming a WWTW effluent discharge in Future Scenarios:

Future Scenarios (with WWTW Effluent at General Limits)

STATE	Flow (m3/s)			DIN (ug/l)				DIP (ug/l)			
	Total	WWTW	River Fraction	WWTW	RIVER	Inflow	Estimate	WWTW	River	Inflow	Estimate
1	1	0.24	0.76	21000	200	5192	**5000**	10000	10	2408	**2400**
2	1.5	0.24	1.26	21000	200	3528	**3500**	10000	10	1608	**1600**
3	3.5	0.24	3.26	21000	200	1626	**1600**	10000	15	700	**700**
4	20	0.24	19.76	21000	250	499	**500**	10000	20	140	**140**

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

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

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

Parameter	Summary of change	Zone	Reference	Present
Salinity	*Due to decrease in the baseflows to the system (i.e. an increase in the occurrence of monthly flows below 3 m^3/s)*	*Lower*	*4*	*9*
		Middle	*3*	*6*
		Upper	*1*	*3*
		Upper (H)	*0*	*0*
DIN (µg/ℓ)	*Due to increased nutrient input from anthropogenic sources in the catchment concentrations in the estuary increased under Present state (and future scenarios) compared with reference.*	*Lower*	*97*	*207*
		Middle	*97*	*222*
		Upper	*97*	*230*
		Upper (H)	*97*	*237*
DIP (µg/ℓ)	*Due to increased nutrient input from anthropogenic sources in the catchment concentrations in the estuary increased slightly under Present state (and future scenarios) compared with reference.*	*Lower*	*10*	*17*
		Middle	*10*	*17*
		Upper	*10*	*18*
		Upper (H)	*10*	*18*
Turbidity (NTU)	*System becomes less turbid under Present and Future scenarios due to reduction in State 4*	*Lower*	*175*	*143*
		Middle	*175*	*143*
		Upper	*175*	*143*
		Upper (H)	*175*	*143*
DO (µg/ℓ)	*No marked changes in dissolved oxygen, system remains well flushed in general.*	*Lower*	*6*	*6*
		Middle	*6*	*6*
		Upper	*6*	*6*
		Upper (H)	*6*	*6*
Toxic substances	*Industrial and urban development (e.g. Sappi) may have introduced toxic substances into the estuary, but only assumed to be limited, 85% for present*	*85% 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. Lower = 0.50; Middle = 0.20; Upper = 0.30)*
- *Different* **abiotic states (S)** *(i.e. States 1 to 4)*
- *Define the* **flow scenarios** *(i.e. Reference, Present, Future scenarios)*
- *Determine the* **% occurrence** *of abiotic states for each scenario*
- *Define* **WQ concentration range (C)** *(e.g. 6 mg/l; 4 mg/l; 2 mg/l)*

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

- *Calculate Average concentration for each Zone for Reference and Present/Future Scenarios, respectively:*

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

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

Variable		Summary of change	Score	Conf
1	**Salinity**			
	Similarity in salinity	*⇧ due to increase in low flows*	*66*	*M*
2	**General water quality in estuary**			
a	*DIN and DIP concentrations*	*⇧ due to nutrient enrichment in catchment*	*67*	*M*
b	*Turbidity (transparency)*	*⇩ due to reduction in high flow state (State 4)*	*90*	*M*
c	*Dissolved oxygen (mg/l)*	*No marked changes, remains well flushed*	*99*	*M*
d	*Toxic substances*	*⇧ industrial and urban inputs*	*85*	*M*
Water quality health score[1]				**M**
% of impact non-flow related			**50**	**H**
Adjusted score				

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

4.5 MICROALGAE

4.5.1 Overview

The microalgae component comprises the autotrophic microorganisms, i.e. those that contain chlorophyll and, as a result, are able to convert sunlight into living material. In this capacity they are at the base of the food chain and responsible for most of the food consumed by the primary consumers. This is especially important in that they provide the food resources for the juvenile fish and benthic microorganisms, including those that, in the adult form, are found in the sea and play an important role in the South African economy.

i) Main grouping and baseline description

They are grouped into two main types, the planktonic and the benthic. The planktonic group are the phytoplankton (plants in the water column) while the benthic group comprise the microphytobenthos (small plants found mostly attached to sediment particles (mud, sand, gravel, rocks). The true phytoplankton usually have flagellae which enable them to maintain a position in the water column, while the microphytobenthos are not flagellated and are therefore unable to maintain a position in the water column.

These organisms are greatly influenced by the amount of water flowing through the estuary as well as the way it passes through the estuary, i.e. they are sensitive to the hydrology and the hydrodynamic flows. The amount of water in the system and the continuity of flow determine the volume available and thus the absolute maximum amount of material available, while the hydrodynamic factor influences the stability of the system and especially the microphytobenthos (MPB). Estuaries with a large MAR are open more often, are usually larger and therefore are in the open mouth state for longer than those with a smaller MAR. Estuaries with a large MAR tend to be less sensitive to flow variation than do those with a small MAR. The importance of the *hydrodynamic flow is that the flooding regime influences the state of the mouth, (open or closed-faunal recruitment or not).*

The MPB are very important both when they are attached to sediment particles but also when they are attached to submerged or emergent plants (epiphytes), thus the status of the macrophyte community also impacts on the state of the microalgal community and whether or not the juvenile fish have an available food source in a protected environment, i.e. they have a measure of protection plus a source of food in amongst the living plant material.

Microalgae respond to the nutrient status of the water column. Under reference conditions, the nitrogen and phosphorus contents are usually low, but might occasionally be raised by an abundance of large terrestrial animal excreta. Thus the reference condition is considered to be one of low nutrient status to which the microalgae respond by having a high diversity of species. Where pollution raises the nutrient levels, the biomass rises but the species diversity is lowered, but only under extreme conditions.

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) 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. The phytoplankton are more sensitive to extreme floods than are the MPB which are only lost from the system under very strong flooding conditions. All records appear to show that the microalgae are a very resilient group of organisms.

Under reference conditions, the flagellate community would be relatively small while under polluted conditions the heterotrophic component of the flagellate community would be expected to be high because of a high organic component in the water.

ii) Description of factors influencing microalgae

Table 4.16 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 (37-16)*	*Proportional reduction with loss of open water area (43% remaining)*
Salinity	*Very little effect when > 5 psu. When < 5 psu there can be a few freshwater species present. Very seldom that freshwater*	*Very little salinity effect with estuary MPB. This was established during at prolonged survey at St. Lucia where salinity rose from normal to ~150 psu.*

	diatoms appear in an estuary sample	
Mouth condition	Mouth open - Biomass maximum at ~15psu. Vertical salinity gradient.	Mouth never closed - MPB elevated at low flows.
Water flow rate	Under water high flow rates most of the microalgae are suspended in the water column.	Many diatoms that are commonly benthic (epipelic) are found in the water column. This is especially the case where the fine sediment fraction is suspended due to turbulence
Water retention time	Phytoplankton biomass elevated at long retention time with diatoms on the sediment.	MPB biomass elevated at long retention time.
Floods	Only temporary reduction in phytoplankton biomass as a result of flooding. Consumer population also reduced - therefore little effect	Only temporary reduction in MPB biomass as a result of flooding. Consumer population also reduced - therefore little effect.
Turbidity	Because high turbidity occurs at the time of flooding there is very little effect on phytoplankton	Possible small reduction in MPB productivity.
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

Table 4.17 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 but the recovery would be quick

iii) Reference condition

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

Key drivers	Change
Open water area	10% reduction in subtidal area
Closed mouth conditions	1% reduction (with artificial opening)
Nutrient increases	10% increase in biomass (compensation)
Toxic substances	Likely 0% reduction
TOTAL CHANGE	10%

4.5.2 Microalgae health

Table 4.19 Microalgae component health score

Variable	Summary of change	Score	Conf
1. Species richness	*Unlikely to be any significant changes*	*95*	*H*
2. Abundance	*Some increase in biomass for much of the year*	*90*	*M*
3. Community composition	*Likely a very small shift in community structure*	*95*	*M*
Biotic component health score		**90**	
% of impact non-flow related		*95*	*M*
Adjusted score			

4.6 MACROPHYTES

4.6.1 Overview

i) Main grouping and baseline description

Mkomazi Estuary has historically supported limited estuarine vegetation. However these macrophytes are important as they add to the aesthetic appearance of the lower reaches, filter sediments and nutrients and stabilize the banks. From a site visit in July 2014, mapping and assessment of past aerial photographs updated information on the macrophytes is provided in Table 4.18. Swamp forest with coastal or lagoon Hibiscus (Hibiscus tiliaceus) was the most abundant habitat. Reeds and sedges, covered the second largest area and fringed both banks of the estuary. A stand of black mangroves, Bruguiera gymnorrhiza, and a few large white mangrove, Avicennia marina, trees were located on the south bank along the Impisini stream inlet close to the mouth of the estuary. A few tall B. gymnorrhiza trees were also located amongst a stand of invaded coastal forest on the north bank near the mouth. Common reed (Phragmites australis), bush tick berry (Chrysanthemoides monilifera), morning glory creeper (Ipomoea pes-capre) and inkberry (Scaevola plumieri) were visible amongst this invaded stand.

A small patch of coastal forest occurred on the sloping north bank in the middle reaches. A steep rock face, vegetated with Acacia natalensis, was present in the middle reaches, opposite the SAPPI SAICCOR Factory. Hygrophilous grasses interspersed the reeds and sedges in the middle reaches of the estuary. Grasses present were antelope grass (Echinocloa pyramidalis), Panicum maximum, broad-leaved bristle grass (Setaria megaphylla), buffalo grass (Stenotaphrum secundatum) and the exotic Paspalum dilatum and Paspalum urvillei. A number of invasives were present in the estuary including Spanish/giant reed (Arundo donax), black wattle (Acacia mearnsii), beefwood (Casuarina cunninghamiana), Brazilian pepper tree (Schinus terebinthifolius) peanut butter bush (Senna didymobotrya) and syringa (Melia azedarach).

Some areas previously cultivated have been colonised by opportunistic grasses, weeds and exotic species. Species present in these disturbed areas were pennywort (Centella asiatica), climbing/spreading dayflower (Commelina diffusa), Conyza scabrida, prickly lettuce (Lactuca serriola), River nettle (Laportea penduncularis), Persicaria decipiens and bulrush (Typha capensis). Sediment in the reed areas was soft and muddy and no macroalgae were visible. No submerged macrophytes were found. There was no evidence to suggest the historical occurrence of any Red Data List species. Species composition of Mkomazi Estuary, including exotics is provided in the specialist report.

Table 4.20 Macrophyte habitats and functional groups recorded in the estuary (spp. examples in italics).

Habitat type	*Distribution*
Open surface water area	*Serves as a possible habitat for phytoplankton.*
Intertidal sand and mudflats	*Intertidal zone consisting of sand/mud banks that provide a possible area for microphytobenthos to inhabit.*
Swamp forest	*Swamp forest fringed both banks in the lower reaches of the estuary. Near the mouth a single row of H. tiliaceus trees occurred in front of a concrete bank. Wild date palm (Phoenix reclinata) was conspicuous in this macrophyte habitat, particularly on the north bank at the mouth. S. terebinthifolius has replaced some swamp forest habitat and creepers, such as Ipomea species, were abundant.*
Mangroves	*Mangroves were present in the lower reaches of Mkomazi Estuary, mostly on the south bank. The mangroves occurred along the narrow Impisini stream inlet, near the old ski boat slipway. This stand consisted almost entirely of B. gymnorrhiza trees that were set back from the water channel by a fringe of reeds and sedges. A few large A. marina trees occurred further inland of this stand. The area was polluted with litter and debris that was wrapped around the mangrove trunks. Wood harvesting was evident on some of the individuals present on the north bank. A few older individuals of B. gymnorrhiza were sparsely distributed along the north bank of Mkomazi Estuary close to the mouth, as indicated by the points in Figure 4—1. These tall individuals were situated in a disturbed area of coastal dune forest.*
Reeds and sedges	*Reed and sedge habitat extended along the length of the estuary as a thin, disjointed fringe on both banks of the water channel (Fig. 1). Species present were: Cyperus natalensis, Juncus effuses, Juncus kraussii, Phragmites australis, Phragmites mauritianus, Schoenoplectus scirpoides and Typha capensis.*

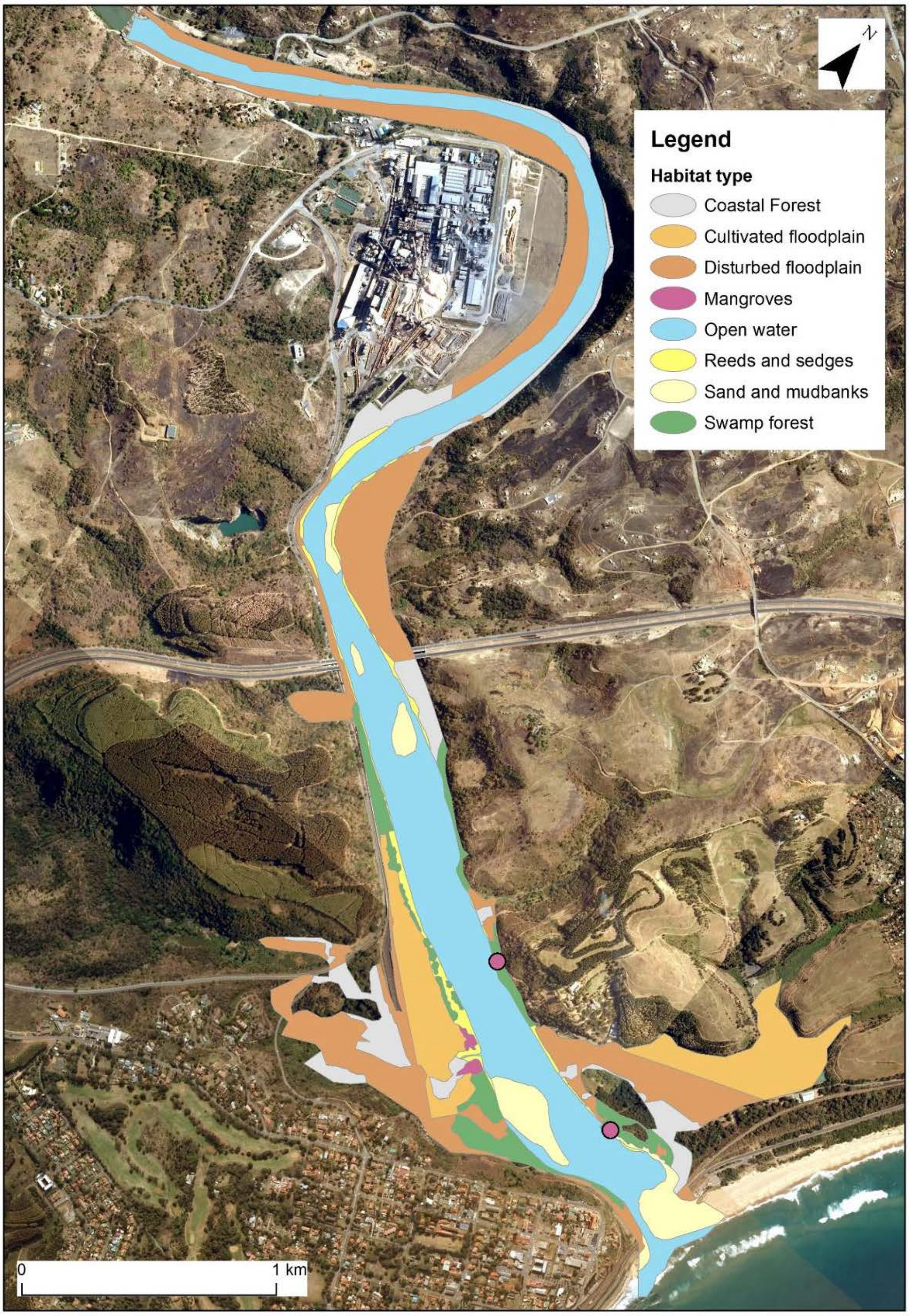


Figure 4.1 Macrophyte habitat distribution at Mkomazi Estuary in 2013.

ii) Description of factors influencing macrophytes

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

Variable	Grouping		
	Reeds and sedges	Swamp forest	Mangroves
Mouth conditions	*Open mouth conditions and high river inflow prevent the establishment of submerged macrophytes and macroalgae.*		
Retention times of water masses	*Under natural and present conditions the estuary remains permanently open. If the estuary were to remain closed for an extended period of time, which is highly unlikely, the increased water levels may cause waterlogging and dieback of macrophytes.*		
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	*Longitudinal salinity gradient present along the estuary increases macrophyte diversity.*		
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	*Although the estuary has become more saline over time, the brackish conditions enable the proliferation of reeds, sedges and swamp forest.*		*Due to reduced baseflows salinity has increased from natural conditions enabling the growth and expansion of mangrove habitat.*
Turbidity	*High turbidity as a result of high flows and catchment disturbance prevents the establishment of submerged macrophytes.*		
Dissolved oxygen	*This would not influence the macrophytes.*		
Nutrients	*High nutrients levels encourage the proliferation of Phragmites spp. and other macrophytes.*		
Sediment characteristics (including sedimentation)	*Sedimentation increases the available habitat for the establishment of reeds, sedges and swamp forest.*		*Accumulation of sediments in the mangrove habitat could smother seedlings thus causing a decline in the population.*
Other biotic components	*Little natural floodplain remains due to surrounding developments and sugarcane cultivation. Invasive species are abundant replacing natural vegetation.*		

Table 4.22 Summary of Macrophyte responses to different abiotic states

State	Response
State 1: Closed, brackish	*Mouth closure is infrequent under current conditions. Should the mouth remain closed for an extended period, which is unlikely, the open water area will increase potentially displacing some macrophytes.*
State 2: Open, full salinity gradient	*Saline conditions would favour the growth and expansion of mangrove habitat.*
State 3: Open, limited salinity gradient	*This state favours the growth of reeds and sedges.*
State 4: Open fresh	*This is the dominant state under both natural and present conditions. Flooding events would reset the estuary by removing macrophyte habitat.*

ii) Reference condition

Development and sugarcane cultivation has removed macrophyte habitat since natural conditions with large areas of reeds and sedges, swamp forest, mangrove and coastal forest lost. Table 4.21 provides the areas (ha) mapped for 1937 and 2013. These data assist with the assessment of changes over time from natural to present (Table 4.22). A stand of reeds described by Day (1981) and Begg (1984) located above the steep south bank near the mouth of the estuary has been lost.

Begg (1984) suggested that the construction of the R102 road and rail bridge at the mouth led to the loss of most of the mangrove population that naturally occurred on the north bank. The mangrove community on the south bank was in poor condition due to impeded drainage and inadequate tidal exchange. Adams and Bate (1998) described a few scattered A. marina and B. gymnorrhiza trees on both banks at the mouth.

Mangrove habitat was not distinguishable in the 1937 aerial photographs, but the last reported area of mangroves at Mkomazi Estuary was 2 ha (Ward & Steinke, 1982; Rajkaran et al., 2009). Thus the area of mangrove habitat in 2013 has halved since 2006. In 2013 swamp forest had increased by 3 ha from 1937 (Table 4.21). The increase may be inaccurate due to the difficulty in distinguishing swamp forest from interspersed invasive plants such as S. terebinthifolius as well as coastal forest. A similar difficulty was encountered for the mapping of the area covered by mangroves. In 2013 cultivated land occupied less area than in 1937; this disturbed habitat has been colonised by reeds, grasses and invasive species.

Under natural conditions, the dominance of the open, fresh State 4 would have been unfavourable for mangroves. Mangroves have likely been opportunistic in the estuary as conditions have become more saline. The naturally fresh conditions would have encouraged the proliferation of reeds and sedges, which covered large areas of the Mkomazi Estuary floodplain.

Table 4.23 Comparison of area (ha) for the different macrophyte habitats at Mkomazi Estuary under reference (1937) and present (2013) condition

Macrophyte habitat	1937	2013
Open water	*36*	*47*
Natural floodplain	*8*	*12*
Disturbed floodplain	*3*	*44*
Cultivation	*63*	*19*
Sand and mudbanks	*14*	*10*
Reeds and sedges	*14*	*4*
Swamp forest	*7*	*10*
Mangroves	*0*	*1*

Table 4.24 Comparison of area (ha) for the different macrophyte habitats at Mkomazi Estuary under natural and present (2013) conditions.

Macrophyte habitat	Natural	Present
Open water	*50*	*64*
Natural floodplain	*34*	*15*
Disturbed floodplain	*0*	*47*
Cultivation	*0*	*19*
Sand and mudbanks	*20*	*9*
Reeds and sedges	*45*	*4*
Swamp forest	*25*	*10*
Mangroves	*0*	*1*
Alien vegetation	*0*	*5*
TOTAL	*174*	*174*

Table 4.25 Summary of relative changes from Reference Condition to Present state

Key drivers	Change
Removal of habitat due to development and sugarcane cultivation	*⇩ floodplain habitat, reeds, sedges, mangroves and swamp forest.*
⇧ nutrients from catchment activities	*⇧ growth of all macrophytes, in particular reed, sedge and grass expansion.*
⇩ flow 5 $m^3 s^{-1}$ for 70% time and ⇩ floods	*⇧ reeds and sedges due to sediment deposition and infilling of intertidal habitats.*
⇧ catchment and floodplain disturbance	*⇧ invasive species*
TOTAL CHANGE	*Loss of all macrophyte habitats due to development and cultivation. The flow related changes are small compared to this greater loss of habitat.*

4.6.2 Macrophyte health

The data in Table 4.22 were used to inform the changes in the macrophyte habitats over time. The health of the macrophytes was assessed in terms of species richness, abundance and community composition using the methods described in RDM draft Version 3 (2010). Change in species richness was measured as the loss in the average species richness expected during a sampling event, excluding species thought to not have occurred under Reference conditions. Abundance was measured as the change in area cover of macrophyte habitats. The following was used to measure change: % similarity = 100 x present area cover / reference area cover. Change in community composition was assessed using a similarity index (Table 4.24) which is based on estimates of the area cover of each habitat in the reference and present state. (Czekanowski's similarity index: $\sum(\min(ref,pres) / (\sum ref + \sum pres)/2)$.

Invasive species have become more prevalent in the estuary and have likely displaced native species. Thus an alien plant subgroup was added for the calculation of the community composition (Table 4.24). In 2013 only 30 ha were covered with macrophyte habitats (including natural floodplain). Reeds and mangrove habitat has been lost since natural conditions. This represents a similarity of 21 % in macrophyte habitat abundance. Based on these changes the 2013 macrophyte community composition has a resemblance of 51 % to that of natural conditions.

Table 4.26 Area (ha) covered by macrophyte habitats and calculation of the similarity in community composition.

Macrophyte habitat	Natural area (ha)	2013 area	Minimum score
Open water	*50*	*64*	*50*
Natural floodplain	*34*	*15*	*15*
Disturbed floodplain	*0*	*47*	*0*
Cultivation	*0*	*19*	*0*
Sand and mudbanks	*20*	*9*	*9*
Reeds and sedges	*45*	*4*	*4*
Swamp forest	*25*	*10*	*10*
Mangroves	*0*	*1*	*0*
Alien vegetation	*0*	*5*	*0*
SUM	*174*	*175*	*88*
	=88/174		
	51% similarity to reference		

Table 4.27 Macrophyte component health score

Variable	Summary of change	Score	Conf

1. Species richness	*Species have been lost due to floodplain transformation increased salinity and displacement by invasive species.*	*80*	*M*
2. Abundance	*Sugarcane cultivation and development has removed macrophyte habitat, particularly reeds and swamp forest. Mangrove habitat has been lost due to decreased inundation and disturbance. Sand mining and disturbance in the upper reaches has also resulted in habitat loss.*	*21*	*M*
3. Community composition	*Invasive species have colonised disturbed areas. Grasses and invasive species have interspersed into reed habitat. Swamp forest habitat in the lower reaches has been reduced by development (roads, canalisation, railway line and pipe lines).*	*51*	*M*
Biotic component health score		**21**	
% of impact non-flow related		*80*	
Adjusted score		*37.8*	

4.7 INVERTEBRATES

4.7.1 Overview

i) Main grouping and baseline description

Benthic invertebrate communities are generally separated into two major size classes. The meiofauna are organisms (metazoans plus foraminiferans) that typically range from 63 to 500 mm in size, and the macrofauna are all of the larger organisms greater than 500 mm in size. Both groups include species that are considered to be either epifauna because they reside primarily on the surface of the sediments and other substrata, or infauna because they burrow or live beneath the surface of the sediment water interface. A brief description of the invertebrate community assemblages from the estuarine and freshwater areas of the Mkomazi is provided as a baseline description below.

The invertebrate community of the Mkomazi estuary has a naturally low diversity and abundance at any one time. For the purposes of this EWR the estuary was sampled for invertebrates, at six sites from the mouth to the upper estuary, during the low flow winter and high flow summer periods. There was a strong contrast between the diversity and abundance of the macrobenthos in August-September 2013, when 27 taxa were recorded, and February 2014 when this number dropped to 12 (Figure 4—2). The numbers of taxa at each site in August 13-September 14 were lowest at the two upper sites (6), increasing to 12-13 at the N2 bridge, skiboat and mouth with a maximum of 16 in the Mpisini stream. The fauna at the three upper sites was totally dominated by amphipod crustaceans. This changed to a dominance of the polychaete Desdemona ornata at the skiboat site. The tanaid crustacean Apseudes digitalis was numerically dominant in the muddy Mpisini stream but the small crab Paratylodiplax blephariskios, a typical inhabitant of this area, made the major biomass contribution. As indicated above, the diversity and particularly the abundance, crashed in February after the high summer flows with a maximum of five species recorded at the N2 bridge site. The only species that retained any of their winter abundance were the tanaid A.digitalis and the crab P.blephariskios, both in the relatively physically stable Mpisini stream. This is in keeping with current understanding of benthic invertebrate communities which will be disturbed and depressed by repeated strong river flows and depositional events.

All the physico-chemical parameters measured during this particular study period, and when seen in conjunction with data accumulated during the past decade (MER, 2002 - 2013) as well as the historical records (Day 1981, Begg 1978, 1984) characterise the uMkhomazi estuary as a naturally *highly variable environment which has arguably been further modified by the actions of extensive sand mining between the N2 bridge and the weir. The variability is derived from seasonal flow*

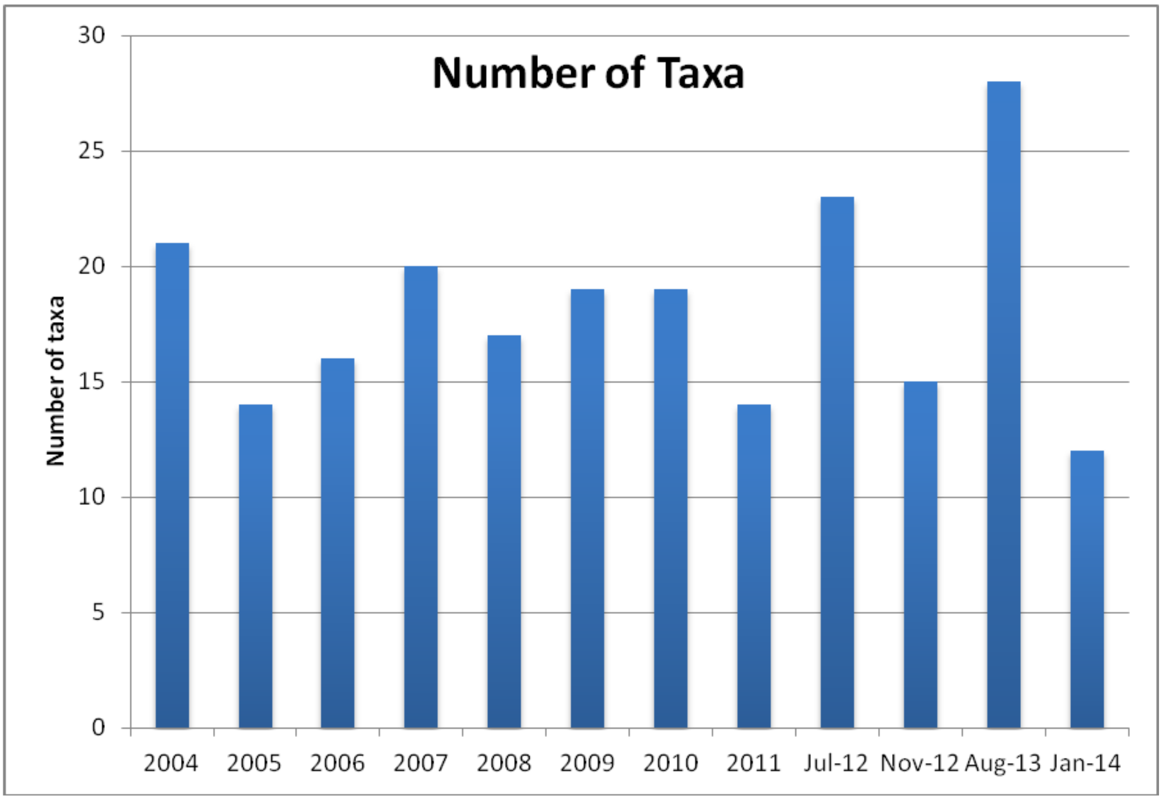


Figure 4.2 The number of taxa recorded in the Mkomazi annually during the low flow period 2004 – 2011 and during low flow and high flow 2012 - 2014

fluctuations coupled with periodic major flood events such as last occurred in 1987. The seasonal variations are enough to alter sediment distribution, salinity gradients, temperature and turbidity, all of which have spin off effects on the biota. These are aptly demonstrated by the above comparison of the benthos under winter and summer conditions and between years which exhibit different flow regimes. From an estuarine status or health point of view, the variable nature of the benthic macrofauna can be attributed directly to the natural physico-chemical variability of the system.

On a broader scale, it is worth noting that the species making up the benthos are largely small in comparison with other known estuarine benthic taxa such as bivalves and the larger burrowing crustaceans such as the sandprawn Callianassa (Callichirus) kraussi and the mudprawn Upogebia africana. There are no records of C.kraussi and rare incidences of bivalves although individuals of U.africana do appear in muddy samples. The absence of C.kraussi and rarity of bivalves can be attributed to sediment instability and periodic high flows while the appearance of U.africana can be linked to the existence of a marine larval phase in this species which will allow recruitment from other estuaries.

Superimposed on this is the question of the long term impact of sand winning on the macrobenthos of the estuary which is difficult to quantify. In ways dredging disturbance could be equated with major flood events; the latter however would naturally be followed by a stable period during which recovery of the benthos could occur. In the context of the Mkomazi estuary, with its flood history and the consequent dominance of the macrobenthos by short lived, opportunistic species, short *term sand winning is less likely to have a major impact here than in systems occupied by larger, longer lived species.*

The different states which occur in response to varying runoff conditions the Mkomazi (Table 4—27) are strong drivers of the invertebrate community. With increases in State 1 producing higher abundance and diversity than state 4 (Figure 4—3).

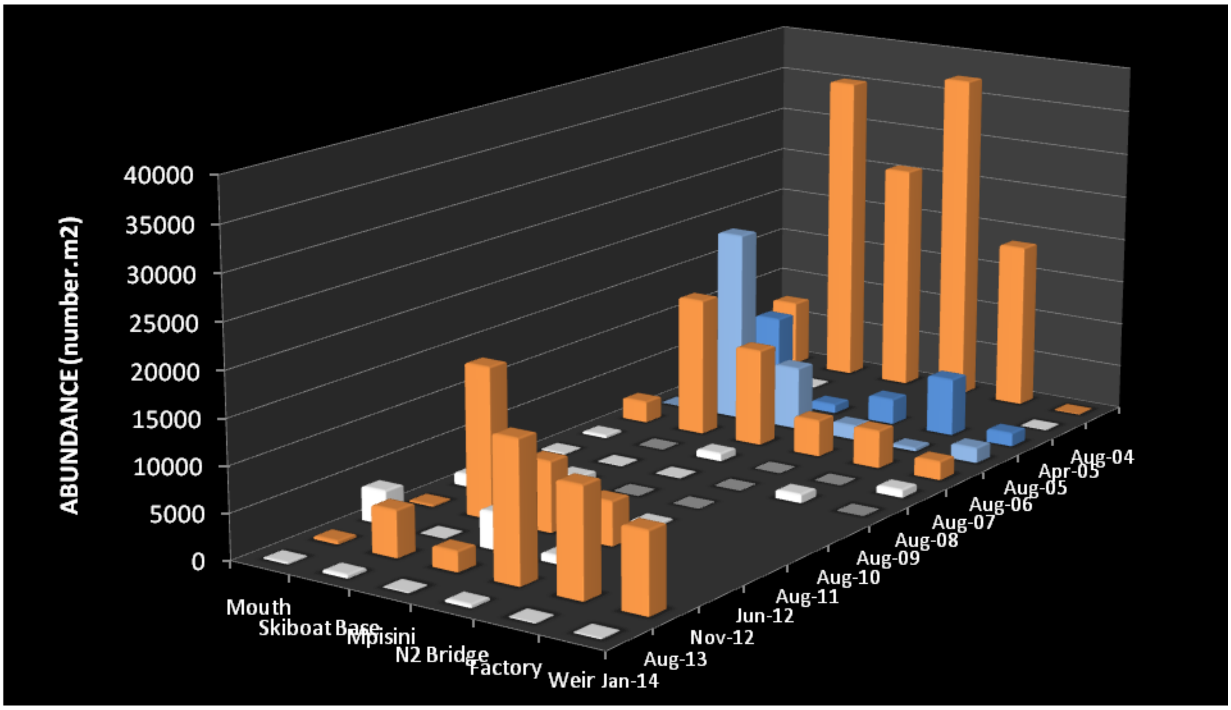


Figure 4.3 Benthic invertebrate abundance at six sites during low flow and high flow conditions. Colours correspond to the described states

Table 4.28 Summary of Invertebrate responses to different abiotic states

State	Response
State	**Response**
State 1: Closed, brackish	*Freshwater communitychanges, increases in abundance with stability and increases in food resources, increased light penetration - likely to reach higher levels of abundance*
State 2: Open, full salinity gradient	*Numbers of species recorded increases as survival increases and rarer species are more likely to be found, increases in abundance with stability and increases in food resources, increased light penetration*
State 3: Open, limited salinity gradient	*Estuarine invertebrates confined to the lower parts of the system, high flows and mobile sediments exclude most species other than those areas away from main flows*
State 4: Open fresh	*Highly dynamic and excludes most estuarine species leaving only resilient freshwater tolerant species.*

iii) Reference condition

Table 4.29 Summary of relative changes from Reference Condition to Present state

Key drivers	Change
⇧ in State 2 and addition of state 3	*Changes in estuarine invertebrate distribution with extension into zones B and C. Increased abundance relative to reference due to increased retention times within the system and more suitable salinity conditions*
⇧ in nutrients	*Perhaps a minor effect as a result of an increase in micro-algal food resources*
TOTAL CHANGE	*Decreases in flow and concomitant increases in salinity and retention times have increased diversity and abundance of estuarine and marine species*

4.7.2 Invertebrate health

Table 4.30 Invertebrate component health score

Variable	Summary of change	Score	Conf
1. Species richness	*No driver to eliminate species - 5% precautionary for the ones which may have been eliminated but not recorded*	*95*	*M*
2. Abundance	*Increase in abundance of estuarine invertebrates as a result of the extension of state 1,2 & 3 temporally (extended low flow conditions) and spatially into zones B & C. Increased nutrients may increase food organisms.*	*75*	*M*
3. Community composition	*The changes in conditions i.e. increased salinity and stability may favour species previously depressed by strong outflows, sediment instability and low salinity*	*80*	*M*
Biotic component health score		**75**	
% of impact non-flow related		*10*	
Adjusted score		*78*	

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. 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).

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

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

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

- *Catadromous: Anguillid eels, which use estuaries only as transit routes between the marine and freshwater environments (Whitfield's category Vb).*

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

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

A wide variety of fishes has been sampled in the system (60 distinct species) and this is reflective of reference conditions. Comparative few dominate the assemblage numerically, however. This is typical of estuarine fish assemblages. Estuarine dependent marine species, followed by estuarine resident fishes, dominate the fish fauna by both numbers of species and abundance of individuals. The relative abundance of estuarine dependent marine species across indicates the nature of the Mkomazi to be strongly estuarine and that the system is an important nursery area for these fishes. Marine taxa are more abundant than freshwater species, a fact suggestive of regular saltwater penetration under present day conditions. Under reference conditions marine taxa would hgave occurred with less frequency and in lower abundances. Catadromous fishes (Anguillid eels) transit through the estuary, rather than spending significant time in it.

Trophically, the fish assemblage has typically been dominated by zoobenthivores and detritivores. On average zooplanktivores and piscivores contribute very little to the abundance of fishes in the system. The paucity of zooplanktivores is likely the result of poorly developed zooplankton biomass. The relative abundance of benthivores is atypical of KZN estuaries, which are usually dominated by detritivores (mullet in particular contributing high abundances). Zoobenthic feeders form a significant component of the fish assemblage. This is likely to be reflective of reference conditions.

Overall, estuarine dependent marine fishes dominate the Mkomazi fish assemblage in terms of frequency of occurrence, number of species and relative abundance. This is brought about by an abundance of juveniles of euryhaline marine fishes that are strongly dependent on estuaries (Whitfield's category IIa fish). While mullet play an important role in this, several other perciform fishes contribute significantly. These fishes occur in highest abundances the lower sections of Zone C of the estuary. This area of the estuary is where fine sediments are deposited naturally under the influence of flow and flocculation. Muddy sandbanks with stratified overlying waters (5 - 20 PSU) are strongly favoured habitat for several key estuarine as well as estuarine dependent marine fish species.

The estuarine plume in coastal waters off the Mkomazi is an important feature of the system, playing a role in the recruitment of marine spawned fishes as well as acting as estuarine habitat during periods of high flow. In the Mkomazi where salinity can fluctuate widely over the tidal cycle, even during normal flows, some fishes are likely to use estuarine plume waters on a tidal basis, occurring in the brackish turbid coastal waters at low tide and following them into the estuary as they are pushed back with incoming high tides. Under reference conditions tidal freshwaters would *have occurred upstream of the Sappi Saiccor weir. This section of the estuary would have been favoured habitat for a number of estuarine and estuarine dependent marine fishes.*

ii) Description of factors influencing fish

The main flow related factors influencing fish in the Mkomazi estuary are listed below (Table 4.30). A summary of fish responses to different estuarine states is given in Table 4.31.

Table 4.31 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various groupings

Variable	Grouping			
	Estuarine resident	*Estuarine dependent marine*	*Marine*	*Freshwater*
Mouth condition: Mouth closure	*Most resident species proliferate under closed mouth conditions.*	*Recruitment of marine spawning fishes is reduced by mouth closure. Short periods of closure may benefit fishes (more so the estuarine dependent than marine species) that are already in the system. However, prolonged closure, especially if associated with reduced salinity, negatively impacts this component of the ichthyofauna. Numbers of species and abundance therefore declines with prolonged mouth closure. Category IIc and III fishes especially become increasingly less common and abundant.*		*Increase in abundance if salinity is low. Oreo mossambicus especially becomes abundant through both breeding in the estuary as well as recruitment from freshwater reaches.*
Salinity	*Resident and estuarine dependent marine species are generally tolerant of a wide range in salinity, often from fresh- to sea water. Species distribute themselves across the estuarine gradient according to salinity preferences (and other factors).*		*Inhabit waters close to 35 PSU and become stressed at salinities under 20 PSU.*	*Highly variable. Most species are likely to avoid waters where salinities are > 1 PSU. O. mossambicus capable of much surviving much higher levels.*
Dissolved oxygen	*Most resident and estuarine dependent marine species are stressed when oxygen drops below* $4\ mg.l^{-1}$*.*		*Little tolerance to low oxygen levels.*	*Respond variously. Some species tolerant of low oxygen.*
River flow	*During spates these species may be washed out to sea but many return as flood waters recede.*	*Also susceptible to being washed out to sea in flood waters, but recruit back following the receding flood front. Juvenile marine and catadramous species use river flows (and flood waters) as a cue for locating and migrating into the estuary. Major river flooding associated with high sediment loads can cause gill clogging for fishes. Marine fishes are most sensitive to this.*		*Some individuals may be washed out to sea where mortalities occur because of osmoregulatory shock. Very high water levels and floodplain inundation promotes spawning of some freshwater species.*

Table 4.32 Summary of fish responses to different abiotic states

State	Response
State 1: Closed, brackish	*No estuarine plume ("offshore estuary") exists. Marine spawning fishes cannot recruit into the estuary, with the exception of a very limited number of species which recruit during wave overwash events. Abundance and species diversity of estuarine dependent and marine species declines. Nearly all species that are in the system at the time of closure survive however, unless severe cold snaps occur. Food availability improves for most species and estuarine residents that are zooplanktivorous become more abundant. Oxygen concentrations might limit abundance of some estuarine and estuarine dependent taxa however, notably in Zone C of the estuary, which is important nursery habitat. This would be much more problematic in nutrients loads into the estuary were high (e.g. from treated wastewater).*
State 2: Open, full salinity gradient	*Good conditions within the estuary for marine, estuarine dependent and estuarine fishes. The offshore plume does not develop to its full potential but recruitment of estuarine dependent species is unaffected by mouth closure. Marine species use the lower reaches of the estuary, some on a tidal basis. Zone C is a particularly important nursery are for estuarine dependent species.*
State 3: Open, limited	*Good conditions within the estuary for estuarine dependent and estuarine fishes. The*

State	Response
salinity gradient	*offshore plume does not develop to its full potential but recruitment of estuarine dependent species is unaffected by mouth closure. Marine species use the lower reaches of the estuary but mostly on a tidal basis. Some estuarine dependent species migrate freely between estuarine and turbid coastal waters with the tide.*
State 4: Open fresh	*The offshore plume develops to its full potential and acts as a strong recruitment cue for estuarine dependent species as well as catadromous eels. Marine species do not occur in the estuary, and several estuarine dependent marine fishes are limited to the systems lower reaches. Many use the estuary on a tidal basis. Even some estuarine species migrate freely between estuarine and turbid coastal waters with the tide. Freshwater fishes occur all the way down the estuary, but these are generally limited to a few taxa.*

iii) Reference condition

Under reference conditions, the Mkomazi estuary occurred in a fresh water state over much of the high flow season (summer). A well-developed estuarine plume occurred in the nearshore coastal waters off the systems mouth. These waters would have been used by estuarine dependent fishes (and probably, to a limited extent, also by estuarine resident species). Under flood conditions, this water was brackish, turbid and extended a considerable distance offshore and even further along the coast. These waters acted as a strong recruitment cue for estuarine dependent marine fishes, which would have entered the system in large abundances. Flows dissipated naturally during the dry season and the estuary was increasingly tidal during winter with a greater occurrence of a limited salinity gradient. This benefitted fishes that had recruited into the system and good nursery habitat existed in the form of gently sloping sand- and mud banks. The best nursery are would have occurred in the upper reaches of Zone B and lower reaches of Zone C. Tidal freshwaters would have extended all the way into Zone D. These would have been used as preferential habitat by a variety of estuarine and estuarine dependent species. Under these conditions all fish categories would have occurred in the estuary, although marine species only sporadically so when river flows dropped below 2 $m^3.s^{-1}$.

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

Table 4.33 Summary of relative changes from Reference Condition to Present state

Key drivers	Change
Salinity gradients (estuarine state)	*Under reference conditions a higher frequency of open fresh conditions (State 4), and lower frequency of full salinity gradient conditions occurred, especially during the low flow (winter) months. Present day conditions in the estuary during winter are more favourable for estuarine, estuarine dependent and marine fishes. A better developed "offshore estuary" existed under reference conditions however, and this also served as a recruitment cue for marine spawning species. There was a much stronger link, and high functional connectivity, between the estuary proper and these offshore transitional waters.*
Connectivity with tidal fresh waters	*The Sappi Saiccor weir cuts across the functional estuary. Under reference conditions Zone D was tidal fresh water that was used as preferential habitat by a variety of estuarine and estuarine dependent species.*
Nursery habitat	*Key nursery area for estuarine dependent species under reference conditions occurred as sand- and mud banks in the upper reaches of Zone B and lower reaches of Zone C. Under present day conditions Zone C has the most favourable salinity and flow characteristics. Sand- and mud banks in this zone of the estuary are impacted negatively by sand mining and this reduces the systems value as a nursery for key fish species.*

4.8.2 Fish health

The Present Ecological State of the Mkomazi fish assemblage is described and scored in Table 4.33 below.

Table 4.34 Fish component health score

Variable	Summary of change	Score	Conf
1. Species richness	A similar number of species uses the estuary as was the case under reference conditions. Increased marine straggler component probably offset losses in species numbers that might have occurred.	95	H
2. Abundance	Some species are markedly reduced in abundance in the estuary. These include estuarine residents and some estuarine dependent marine species in the reduced tidal freshwaters (flow related) as well as some specialist turbid water species such as kob (flow related, overfishing) and grunter (overfishing). The loss of offshore transitional waters (flow related) contributes to reduced recruitment and reduced flood buffer, and also leads to reduced abundance of species compared to reference.	60	M
3. Community composition	Species composition remains similar to reference conditions with the exception that some estuarine and estuarine dependent marine species have been replace by marine stragglers.	75	M
Biotic component health score		**60**	
% of impact non-flow related		25	
Adjusted score		70	

4.9 BIRDS

4.9.1 Overview

i) Main grouping and baseline description

The avifaunal investigation done as part of this study (see Avifaunal Specialist Report) confirmed that the Mkomazi Estuary does not support a particularly rich diversity, or large numbers, of waterbird species. The estuary also does not appear to support significant habitat for any Red Data waterbird species and the only two such species to have been recorded during counts are the Pink-backed Pelican and Woolly-necked Stork, both recorded only on single occasions. The configuration of the mouth, the bridges present there and, especially, the high level of human disturbance precludes the use of the area by large numbers of roosting terns and gulls. The reason for this relatively depauperate waterbird community is likely the absence under normal circumstance of particularly attractive waterbird habitats, e.g. there are no extensive, natural floodplain habitats associated with the estuary.

The October 2014 field survey coincided with a period of peak back-flooding of the estuary, with the mouth closed and high inflow from the river. Relatively high numbers of a wide diversity of waterbirds were noted exploiting the ephemerally flooded areas on both the north and south banks of the estuary. This opportunistic observation demonstrates the particular value of the estuary to waterbird populations during these temporarily ideal conditions.

Table 4.35 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. 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. As a major river, the Mkomazi offers fairly substantial habitat suitable for cormorants.
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). Many terns often use open sandbanks in estuaries for roosting but the mouth of the Mkomazi Estuary is too disturbed to support any major tern roosts.
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, unless there is extensive back-flooding during closed-mouth conditions as observed at the Mkomazi Estuary.
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. Such suitable inter-tidal habitat, however, is rare at Mkomazi Estuary. 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, 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.*
Carnivorous and scavenging gulls	*Gulls, primarily the Kelp and Grey-headed gulls along the KZN coastline, have an unparalleled dietary breadth as carnivores, feeding on both vertebrate and invertebrate matter both live and dead (scavenged). Their breadth of foraging strategies is equally broad. Gulls, like terns, often also use estuaries as roosting sites, coming in from the nearby coastline for this purpose. Gulls are rare at Mkomazi Estuary, however, which offers little in the way of foraging or roosting habitat for these birds.*

iii) Description of factors influencing birds

The table below lists the effects of various abiotic and biotic factors on the different waterbird feeding guilds present at the Mkomazi Estuary.

Table 4.36 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 & large wading piscivores	**Aerial piscivores**	**Swimming herbivorous waterfowl**	**Small wading invertebrate feeders**
Mouth condition	*Indirectly, through influence on water level and fish – can be positive when extensive back-flooding accompanies mouth closure.*		*Indirectly, through influence on macrophytes – can be positive when extensive back-flooding accompanies mouth closure.*	*Mouth closures has negative effect on preferred inter-tidal sandbanks in lower estuary. Can also affects roosting terns (not relevant at Mkomazi)*
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 macroinvertebrat es*
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*	*Critically important habitat for waders which rely mostly on intertidal areas for*

			habitat also exposed at low tide	*feeding*
Sediment characteristics (including sedimentation)	*Indirectly, through influence on fish*		*Can enhance macrophyte growth, e.g. reeds*	*Most waders prefer medium to fine sand; a few prefer coarse sand and mud. Sedimentation can smother benthic macroinvertebrates*
Primary productivity	*Indirectly though influence on food supply*			
Submerged macrophytes abundance	*Indirectly, through influence on fish (food and cover)*		*Has positive influence on herbivorous waterfowl numbers*	*Indirectly, if affects benthic macroinvertebrates*
Abundance of reeds and sedges	*Indirectly, through influence on fish (food and cover)* *Encroaches on roosting habitat of terns*		*Has positive influence on some herbivorous waterfowl species*	*Encroachment of macrophytes largely at expense of open habitats required by waders*
Abundance of zooplankton	*Indirectly, through influence on fish*		*Assumed positive for some omnivorous species*	
Benthic invertebrate abundance	*Indirectly, through influence on fish*			*Primary food source for invertebrate-feeding waders*
Fish biomass	*Piscivores will increase with increasing numbers of small to medium-sized fish*			*Indirectly, if fish compete for benthic macroinvertebrates*

Table 4.37 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 as observed at Mkomazi Estuary, 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 waterbirds.*
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 favoured by roosting waterbirds.*
State 4: Freshwater dominated	*Probably the least productive scenario from a waterbird perspective under normal circumstances and the likely typical condition of this relatively waterbird-poor estuary.*

iv) Reference condition

Evidence from earlier waterbird counts dating back to the 1980s and synthesised in the Avian Specialist Report suggest that waterbird species richness and abundance have remained relatively constant since at least that time. The major ecological perturbations to the estuary had likely already manifested by that time, however, and our knowledge of the reference waterbird condition at the estuary can only be a matter for conjecture. The system was clearly much deeper in its original state, as evidenced by sea-faring vessels once having been able to penetrate far upstream.

Known threats that operate to shift the system away from its reference condition include: habitat loss (including bridge construction, incursions into the floodplain and sand-mining in the upper estuary), water pollution and eutrophication (especially from the Umkomaas waste-water treatment works), and water extraction (including from the SAPPI SAICCOR weir and further upstream in the catchment) (Forbes & Demetriades 2008). Lesser threats include chemical contamination (including from dive boats), litter and debris, and over-fishing. These threats can be expected to translate into negative impacts on waterbird populations.

Table 4.38 Summary of relative changes from Reference Condition to Present state

Key drivers	Change
Siltation	*Loss of deep-water conditions. Increased turbidity negatively affects visual predatory piscivores.*
Disturbance at the mouth	*Precludes large numbers of roosting terns and gulls.*
Agriculture and other anthropogenic modifications in the floodplain	*Reduction in estuarine habitat.*
Water pollution and eutrophication	*Impact on food chain. Increased growth of alien plants.*
Angling	*Reduction in food and entanglement danger to waterbirds from discarded tackle.*
TOTAL CHANGE	

4.9.2 Bird health

Waterbird species richness and abundance appear stable at present.

Table 4.39 Bird component health score

Variable	Summary of change	Score	Conf
1. Species richness	*Likely retains majority of species ancestrally present*	*80*	*M*
2. Abundance	*Fairly significant loss in overall waterbird abundance probable, due to habitat destruction in the floodplain, and, perhaps especially, disturbance of the mouth area, precluding roosting by large numbers of terns and gulls.*	*60*	*M*
3. Community composition	*Probably still retains basic structure of original waterbird community composition with the greatest changes likely related to coastal and marine species now excluded from the estuary by shallowing brought about by siltation and gross disturbance in the mouth area.*	*70*	*M*
Biotic component health score		**60**	**M**
% of impact non-flow related		*80*	*M*
	Adjusted score	*92*	

5 PRESENT ECOLOGICAL STATUS

5.1 OVERALL ESTUARINE HEALTH INDEX SCORE

The Mkomazi Estuary in its present state is estimated to be 69% similar to natural condition, which translates into a Present Ecological Status (PES) of a C Category. This is mostly attributed to the following factors:

- *The weir in the upper reaches severing connectivity with the catchments;*
- *Sandmining that have taken away the sandbanks in the upper reaches (Zone C), resulting loss of intertidal areas and back-water refuge areas. It has also impacted on access to grazing areas as the river cannot be crossed in this section anymore;*
- *Recreational activities (e.g. boat launching) in the lower reaches affecting birds abundance;*
- *Over exploitation of living resources (e.g. cast netting and line fishing); and*
- *Agricultural activities in the Estuary Functional Zone causing loss of estuarine habitat.*

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

Variable	Estuarine health score		
	Overall	Excluding flow related pressures	Conf
Hydrology	*66.8*	*67*	*M*
Hydrodynamics and mouth condition	*95*	*95*	*M/H*
Water quality	*66.6*	*66.6*	*M*
Physical habitat alteration	*78*	*78*	*M*
Habitat health score	*76*	*76*	**M**
Microalgae	*90*	*99*	*M*
Macrophytes	*21*	*84*	*M*
Invertebrates	*75*	*78*	*H*
Fish	*60*	*70*	*M*
Birds	*60*	*70*	*M*
Biotic health score	*61*	*80*	**M**
ESTUARY HEALTH SCORE	*69*	*78*	
PRESENT ECOLOGICAL STATUS (PES)	*C*	*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 increase in the health score from a PES of 69 to 78, which would raise the health score to a B Category. This suggests that non-flow related impacts have played some in the degradation of the estuary to a C, but that flow-related impacts are also driving degradation.

The highest priority is to address the quality of influent water. *Of the non-flow-related impacts, habitat loss within the 5m contour and the vegetation integrity of these areas along with* *water quality problems as a result of the high nutrient load associated with the WWTWs were the most important factors influencing ecological health of the system. The excess nutrients in the inflowing water is considered to be an important factor to consider with increased abstraction from the system. Retention of these high concentrations of nutrients will lead to nuisance algal growth, low dissolved oxygens and reduced habitat quality.*

5.3 OVERALL CONFIDENCE

Confidence levels were medium to high for most of the abiotic components. Four of the biotic components had enough data to yield medium-high confidence assessments. The overall confidence of the study was MEDIUM.

6 THE RECOMMENDED ECOLOGICAL CATEGORY

6.1 CONSERVATION IMPORTANCE

The Estuary Importance Score (EIS) takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (Table 1.3). Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. These importance scores ideally refer to the system in its present state. The scores have been determined for all South African estuaries (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 (Table 1.4) is presented in Tables 6.2 and 6.3, respectively.

Table 6.1. Estimation of the functional importance score of the Mkomazi Estuary

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

The functional Importance of the Mkomazi Estuary is very high. It serves as an important nursery for exploited fish stock and plays an very important role from a fish egg production perspective. In addition it is also an important movement corridor for eels (CITES listed species).

The functional importance of Mkomazi Estuary is very high for the nearshore marine environment. It is one of five key systems (Mfolozi, Mvoti, Mgeni, uMkomazi, Mzimkulu) that supply sediment, nutrients and detritus to the coasts. The sediment load from the Mkomazi is especially important as it is habitat forming and plays an important role in maintain the beaches and near shore habit 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. nearshore) are addressed.

Table 6.2 Estuarine Importance scores for the Mkomazi Estuary

Criterion	Weight	Score
Estuary Size	*15*	*80*
Zonal Rarity Type	*10*	*30*
Habitat Diversity	*25*	*60*
Biodiversity Importance	*25*	*91.5*
Functional Importance	*25*	*100*
Weighted Estuary Importance Score		**85**

Mkomazi forms part of the core set of priority estuaries identified in the National Estuary Biodiversity Plan in need of protections to meet biodiversity targets under the Biodiversity Act and National Estuarine Management Protocol promulgated under the Integrated Coastal Management Act. The National Estuary Biodiversity Plan requires that the Mkomazi Estuary be partially protected (e.g. no-take fishing zone and 25% of riverine area left untransformed) with a REC of B.

6.2 RECOMMENDED ECOLOGICAL CATEGORY

The REC represents the level of protection assigned to an estuary. The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of importance and level of protection or desired protection of a particular estuary. The PES for the Mkomazi Estuary is a C, but the Estuary is rated as "Very Important" from a biodiversity perspective and should therefore be in a B Category.

In addition, the system also forms part of the core set of priority estuaries in need of protection to achieve biodiversity targets in the National Estuaries Biodiversity Plan for the National Biodiversity Assessment (Turpie et al.,2013). The NBA 2011 (Van Niekerk and Turpie 2012) recommends that the minimum Category for the Mkomazi be a B, that it be a granted full no-take protection, and that 25 % of the estuary margin be undeveloped.

Taking the current conditions (PES=C), the reversibility of the impacts, the ecological impotence and the conservation requirements of the Mkomazi Estuary the REC for the system is a B Category.

6.3 DESCRIPTION OF SCENARIOS

The location of the Mkomazi River Catchment is illustrated in Figure 7.1. The proposed scenarios for the Mkomazi catchment are summarised in Table 7.1 and each scenario and its associated variables are described in the sub-sections that follow.

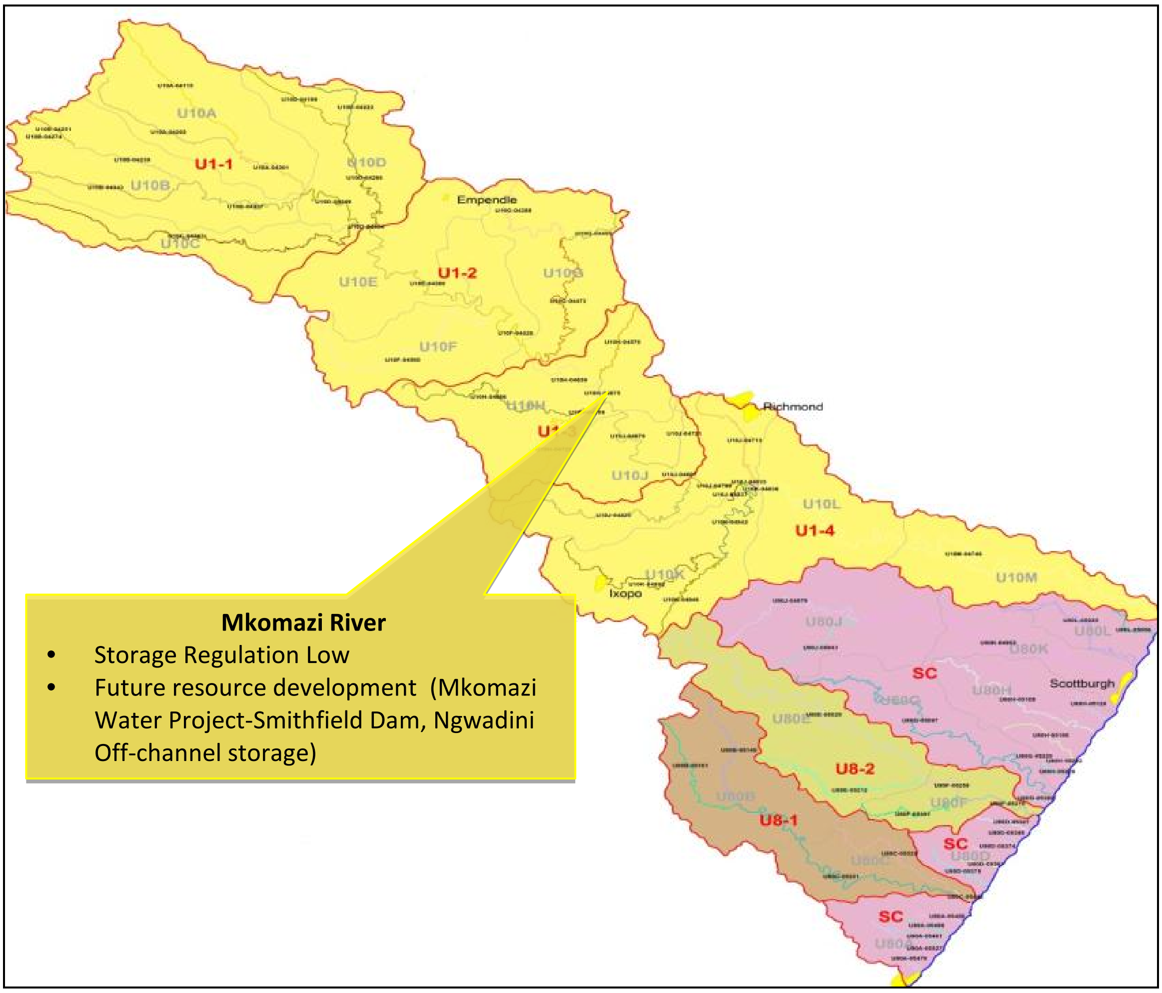


Table 7.1. Mkomazi River Catchment

Table 7.2 Summary of the Mkomazi Scenarios

Scenario	Scenario Variables				
	Update Water Demands	**Ultimate Development Demands & Return Flows (2040)**	**EWR[1]**	**MWP[2]**	**Ngwadini OCD**
MK1	*Yes*	*No*	*No*	*No*	*No*
MK2	*Yes*	*Yes*	*No*	*Yes*	*Yes (no support)*
MK21	*Yes*	*Yes*	*REC tot[3] (EWR 2)*	*Yes*	*Yes (no support)*
MK22	*Yes*	*Yes*	*REC low[4] (EWR 2)*	*Yes*	*Yes (no support)*
MK23	*Yes*	*Yes*	**REC low+[5] (EWR 2)*	*Yes*	*Yes (no support)*
MK31	*Yes*	*Yes*	*REC tot[3] (EWR 3)*	*Yes*	*Yes (no support)*
MK32	*Yes*	*Yes*	*REC low[4] (EWR 3)*	*Yes*	*Yes (no support)*

Scenario	Scenario Variables				
	Update Water Demands	Ultimate Development Demands & Return Flows (2040)	EWR[1]	MWP[2]	Ngwadini OCD
MK33	*Yes*	*Yes*	**REC low+[5] (EWR 3)*	*Yes*	*Yes (no support)*
MK4	*Yes*	*Yes*	*No*	*Yes*	*Yes (with support)*
MK41	*Yes*	*Yes*	*REC tot[3] (EWR 2]*	*Yes*	*Yes (with support)*
MK42	*Yes*	*Yes*	*REC low[4] (EWR 2)*	*Yes*	*Yes (no support)*

1 Ecological Water Requirement for river sites 2 Mkomazi Water Project (Smithfield Dam)
3 Recommended Ecological Category (Total Flows) 4 Recommended Ecological Category (Low Flows)
5 Recommended Ecological Category (Total Flows for January, February, March and Low Flows remaining months)

6.3.1 Scenario MK2: Ultimate Development, Mkomazi Water project (MWP) and Ngwadini OCD (No MWP Support)

This scenario will include estimates of increased water use and return flows for the domestic sector due to population growth and improved service delivery for the ultimate development scenario, developed in accordance with the Ethekwini Spatial Development Framework and Umgeni Water Planning.

The MWP is also included in the scenario as proposed by the DWA Water Reconciliation Strategy Study for the Kwazulu Natal Coastal Metropolitan Areas as a required augmentation option to meet the projected future water requirements of the Mgeni River System. The MWP will impact directly on the flows of the Mkomazi due to the Smithfield Dam impoundment and abstraction to support the eThekwini municipalities projected water requirements and will hence contribute to projected increase in return flows of the Mkomazi WWTW and also in neighbouring rivers that the eThekwini WWTW discharge into. The projected requirements will be sourced from the Mkomazi Water Project Phase 1: Module 1: Technical Feasibility Study Raw Water.

Umgeni Water has recently commissioned the Lower Mkomazi Bulk Water Supply Scheme: Service Provider for the Detailed Feasibility Study and Preliminary Design which includes the Ngwadini OCD in the lower Mkomazi River. This option is also included in the scenarios and will also impact directly on the flows of the Mkomazi due to the proposed weir construction and abstraction. The Ngwadini OCD was configured in the WRPM in such a way that no support is provided from Smithfield Dam The projected water requirements will be sourced directly from the Umgeni Water feasibility study.

The purpose of this scenario is to assess the flows at the EWR sites for the ultimate development level with MWP and Ngwadini OCD (with no support from Smithfield Dam) in place.

6.3.2 Scenarios MK21, MK22, MK23: Ultimate Development, REC EWR (Site 2), MWP and Ngwadini OCD (No MWP Support)

These scenarios are based on Scenario **MK2** *where the flows at the EWR sites will be assessed for the following EWR flows:*

- *Total flow EWRs (***Site 2)** *set to achieve the REC (***MK21***)*
- *Low flow EWRs (***Site 2)** *set to achieve the REC (***MK22***)*
- *Total Flows for January, February, March and Low Flows remaining months (EWR* **Site 2***) set to achieve the REC (***MK23***)*

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 at EWR **Site 2***. The 'cost' of releasing an EWR from the future Smithfield Dam can also be determined as an impact on the current socio-economics.*

6.3.3 Scenarios MK31, MK32, MK33: Ultimate Development, REC EWR (Site 3), MWP and Ngwadini OCD (No MWP Support)

These scenarios are based on **MK2** *where the flows at the EWR sites will be assessed for the following EWR flows:*

- *Total flow EWRs (***Site 3***) set to achieve the REC (***MK31***)*
- *Low flow EWRs (***Site 3***) set to achieve the REC (***MK32***)*
- *Total flows for January, February, March and low flows remaining months (EWR* **Site 3***) set to achieve the REC (***MK33***)*

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 at EWR **Site 3***. The 'cost' of releasing an EWR from the future Smithfield Dam can also be determined as an impact on the current socio-economics.*

6.3.4 Scenario MK4: Ultimate Development, MWP and Ngwadini OCD (No MWP Support)

This scenario is based on MK2 with the only change being that the Ngwadini OCD was configured in the WRPM in such a way that support is provided from Smithfield Dam

The purpose of this scenario is to assess the flows at the EWR sites for the ultimate development level with MWP and Ngwadini OCD (with support provided from Smithfield Dam) in place.

6.3.5 Scenarios MK41 and MK42: Ultimate Development, REC EWR (Site 2), MWP and Ngwadini OCD (With MWP Support)

These scenarios are based on Scenario **MK2** *where the flows at the EWR sites will be assessed for the following EWR flows:*

- *Total flow EWRs (***Site 2***) set to achieve the REC (***MK41***)*
- *Low flow EWRs (***Site 2***) set to achieve the REC (***MK42***)*

*The purpose of these scenarios is to determine to what degree the total flow and low flow EWRs (***Site 2***) together with the dam spills and tributary inflows from the dam will achieve the REC at EWR sites. 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.*

The above mentioned water resource development scenarios were then grouped into five groups (Group A to E) based on how the simulated runoff would affect the Mkomazi Estuary Table 7.2.

Table 7.3 Summary of flow scenarios

Scenarios		Description	MAR (X10^6 m^3)	% Remaining
Reference		*Natural Flow*	*1077.74*	*100*
Present		*Present*	*943.39*	*88*
Group A	*S2*	*Ultimate Development, Mkomazi Water project (MWP) and Ngwadini OCD (No MWP Support)*	*719.12*	*67*
Group B	*S21*	*Ultimate Development, REC EWR (Site 2), MWP and Ngwadini OCD (No MWP Support), Total flow EWRs at Site 2*	*779.09*	*72*
Group C	*S22*	*Ultimate Development, REC EWR (Site 2), MWP and Ngwadini OCD (No MWP Support), Low flow EWRs at Site 2*	*770.76*	*72*
Group C	*S23*	*Ultimate Development, REC EWR (Site 2), MWP and Ngwadini OCD (No MWP Support), Total Flows for January to March and Low Flows for remainder at EWR Site 2*	*771.25*	*72*
Group D	*S31*	*Ultimate Development, REC EWR (Site 3), MWP and Ngwadini OCD (No MWP Support), Total flow EWRs at Site 3*	*773.14*	*72*
Group E	*S32*	*Ultimate Development, REC EWR (Site 3), MWP and Ngwadini OCD (No MWP Support), Low flow EWRs at Site 3*	*761.64*	*71*
Group E	*S33*	*Ultimate Development, REC EWR (Site 3), MWP and Ngwadini OCD (No MWP Support), Total flows for January to March and low flows remainder (EWR at Site 3)*	*761.64*	*71*
Group A	*S4*	*Ultimate Development, MWP and Ngwadini OCD (No MWP Support)*	*728.25*	*68*
Group B	*S41*	*Ultimate Development, REC EWR (Site 2), MWP and Ngwadini OCD (With MWP Support), Total flow EWRs at Site 2*	*788.11*	*73*
Group C	*S42*	*Ultimate Development, REC EWR (Site 2), MWP and Ngwadini OCD (With MWP Support), Low flow EWRs at Site 2*	*779.81*	*72*

6.4 VARIABILITY IN RIVER INFLOW

The occurrences of the flow distributions (mean monthly flows in m^3/s) under the future Scenarios of the Mkomazi Estuary, derived from a 84-year simulated data set are provided in Table 7.3 to Table 7.7 and Figure 7.2 to Figure 7.6. The full sets 84-year series of simulated monthly runoff data for the future Scenarios are provided in Table 7.8 to Table 7.12.

Table 7.4 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	196.6	127.3	179.6	198.7	239.0	245.8	130.5	125.1	81.5	36.2	32.3	228.3
99	76.7	124.8	131.1	196.3	214.5	219.9	109.2	96.3	41.8	21.8	25.5	80.1
90	8.4	34.8	82.6	112.8	131.4	104.5	59.1	16.3	5.1	6.3	1.6	1.9
80	2.8	17.9	60.9	86.2	105.6	75.3	40.4	8.3	1.8	1.2	1.2	1.2
70	1.3	11.0	43.4	67.7	80.4	56.5	27.0	7.0	1.3	1.2	1.2	1.2
60	1.2	5.8	32.3	54.1	67.4	50.4	24.0	3.8	1.2	1.1	1.0	1.2
50	1.2	2.5	21.0	42.8	58.6	42.8	22.1	2.5	1.2	1.0	0.8	1.0
40	1.2	1.5	9.8	32.7	51.0	39.2	17.2	1.5	1.2	0.8	0.7	0.8
30	1.2	1.3	4.6	21.4	40.1	34.6	10.8	1.3	1.1	0.7	0.6	0.7
20	1.0	1.3	2.6	13.4	32.1	27.5	7.9	1.2	0.9	0.6	0.6	0.6
10	0.8	1.2	1.3	3.3	17.7	19.4	3.6	1.0	0.6	0.5	0.5	0.5
1	0.6	0.6	0.9	0.8	1.2	1.3	1.1	0.6	0.5	0.5	0.4	0.4
0.1	0.5	0.6	0.6	0.5	0.6	1.2	0.9	0.6	0.5	0.4	0.4	0.4

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

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	198.0	129.1	174.9	200.2	240.4	247.5	132.3	126.9	82.9	32.4	32.3	226.7
99	78.4	126.7	131.5	197.8	215.7	221.7	110.9	98.2	39.5	22.3	27.0	79.9
90	12.3	32.9	77.8	112.8	133.2	106.1	60.6	18.0	7.2	7.8	4.5	4.1
80	9.5	21.0	55.6	80.7	105.1	76.8	42.1	11.6	6.2	4.7	3.9	3.8
70	8.0	17.8	39.2	68.0	81.9	58.3	28.7	10.6	5.6	4.0	3.4	3.5
60	6.8	14.3	27.1	52.3	69.3	52.0	25.7	9.5	5.1	3.6	3.0	3.1
50	5.7	12.5	20.2	39.9	60.0	44.0	24.1	8.5	4.7	3.0	2.3	2.5
40	4.6	10.5	16.3	29.6	46.7	40.3	19.0	7.1	3.8	2.5	1.7	2.0
30	3.8	8.2	12.0	22.0	41.6	36.4	12.7	5.8	3.1	1.9	1.5	1.7
20	2.8	5.6	8.2	13.9	32.9	28.8	10.0	4.5	2.2	1.5	1.4	1.5
10	1.6	3.1	3.8	8.1	19.6	21.3	6.6	3.5	1.8	1.3	1.3	1.3
1	1.3	1.6	1.9	3.3	4.5	7.9	5.2	2.0	1.4	1.2	1.2	1.2
0.1	1.3	1.6	1.9	2.9	2.1	6.5	4.7	1.6	1.3	1.2	1.2	1.2

Table 7.6 Summary of the monthly flow (in m³/s) distribution under Scenario Group C

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	197.7	128.9	178.3	199.9	240.1	247.3	132.1	126.7	82.7	31.6	32.2	225.4
99	78.1	126.4	131.9	197.6	215.5	221.4	110.6	97.9	39.0	22.0	26.8	79.7
90	9.7	33.4	82.5	114.3	132.9	105.8	60.4	17.8	7.2	7.8	4.5	4.1
80	5.7	16.9	61.1	87.8	107.1	76.5	41.8	11.6	6.2	4.7	3.9	3.8
70	4.9	10.4	43.6	69.2	82.0	58.0	28.5	10.6	5.6	4.0	3.4	3.5
60	4.1	7.5	30.9	55.6	69.0	51.7	25.4	9.5	5.1	3.6	3.0	3.1
50	3.4	6.3	19.9	43.4	59.7	43.7	23.8	8.5	4.7	3.0	2.3	2.5
40	2.9	4.8	10.8	34.0	48.2	40.7	18.8	7.1	3.8	2.5	1.7	2.0
30	2.2	3.5	6.9	22.9	41.6	36.1	12.4	5.8	3.1	1.9	1.5	1.7
20	1.8	3.1	5.1	12.6	32.7	29.0	9.4	4.5	2.2	1.5	1.4	1.5
10	1.5	2.5	3.4	6.6	19.3	21.3	6.4	3.5	1.8	1.3	1.3	1.3
1	1.3	1.6	1.9	3.3	4.5	7.9	5.2	2.0	1.4	1.2	1.2	1.2
0.1	1.3	1.6	1.9	2.9	2.1	6.5	4.7	1.6	1.3	1.2	1.2	1.2

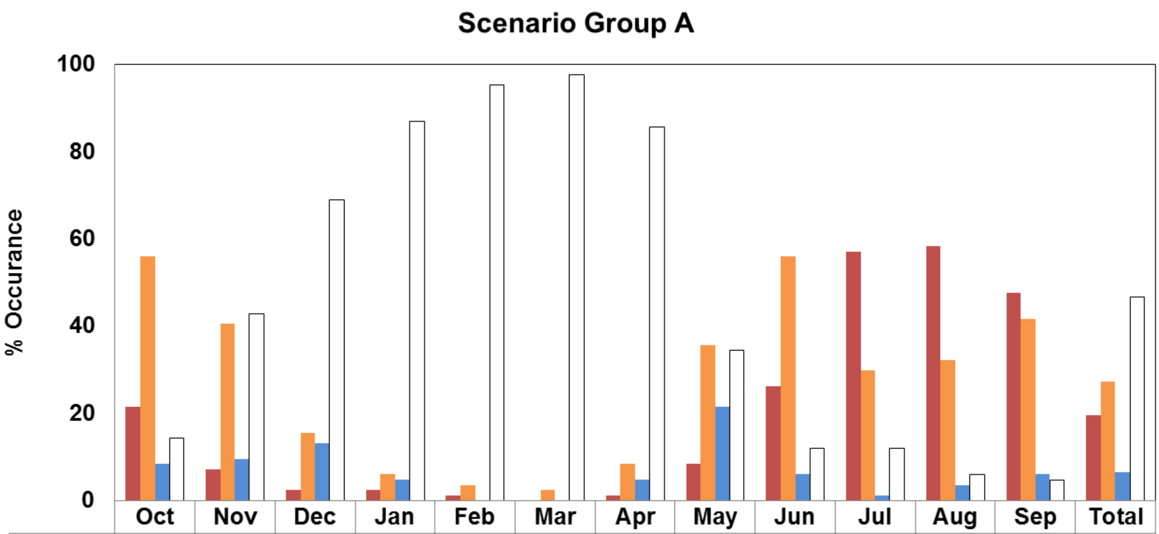
Table 7.7 Summary of the monthly flow (in m³/s) distribution under Scenario Group D

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	197.8	128.9	177.9	200.0	240.2	247.4	132.1	126.7	82.9	34.5	32.5	228.1
99	78.2	126.5	131.9	197.6	215.6	221.5	110.7	98.0	41.1	22.6	26.9	80.3
90	10.5	35.2	82.9	114.3	133.0	105.9	60.5	17.8	5.9	6.4	2.8	2.5
80	6.6	19.6	58.2	85.5	107.2	76.6	41.9	9.9	4.7	3.5	2.7	2.4
70	6.1	14.6	44.4	69.3	81.7	58.1	28.5	8.7	4.3	3.0	2.4	2.3
60	5.5	13.0	29.4	54.7	69.3	51.8	25.5	7.9	4.1	2.8	2.3	2.2
50	4.9	11.6	18.1	40.4	60.3	43.8	23.9	7.1	3.8	2.5	1.8	2.0
40	4.3	10.3	15.4	30.5	46.5	40.3	18.9	6.0	3.2	2.1	1.6	1.8
30	3.6	8.4	12.1	19.3	41.6	36.2	12.5	5.1	2.8	1.8	1.5	1.6
20	2.4	5.5	7.8	14.0	32.7	29.1	9.8	4.1	2.1	1.5	1.3	1.5
10	1.5	2.2	3.0	6.6	19.0	22.2	5.5	3.5	1.8	1.3	1.3	1.3
1	1.3	1.5	1.9	3.3	3.8	6.5	4.7	1.8	1.3	1.1	1.0	1.0
0.1	1.3	1.5	1.9	2.9	1.9	4.4	4.3	1.6	1.3	1.1	1.0	1.0

Table 7.8 Summary of the monthly flow (in m³/s) distribution under Scenario Group E

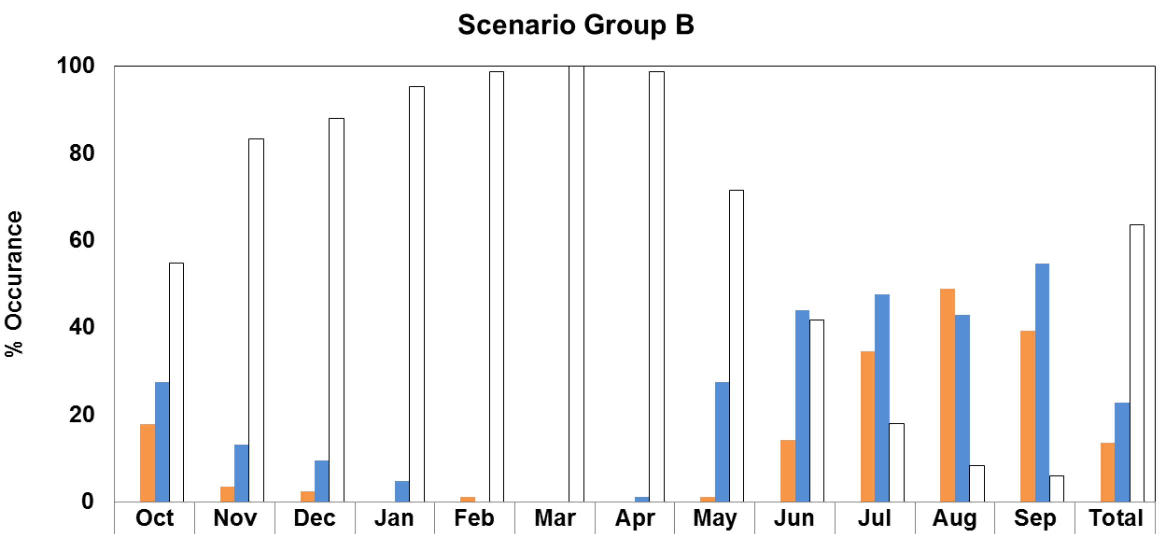
%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	197.4	128.6	180.0	199.6	239.9	247.0	131.8	126.4	82.5	33.5	32.4	226.3
99	77.8	126.1	132.0	197.3	215.2	221.2	110.4	97.6	40.4	22.1	26.6	79.9
90	9.9	35.8	83.8	114.0	132.6	105.5	60.1	17.5	5.8	6.1	2.8	2.5
80	3.4	18.4	62.3	87.5	106.8	76.2	41.5	9.6	4.7	3.5	2.7	2.4
70	3.3	10.8	44.6	69.0	81.7	57.7	28.2	8.6	4.3	3.0	2.4	2.3
60	2.9	5.6	34.3	55.3	68.9	51.5	25.2	7.9	4.1	2.8	2.3	2.2
50	2.4	4.8	23.4	44.0	60.0	44.0	23.5	7.1	3.8	2.5	1.8	2.0
40	2.1	3.5	10.8	34.2	51.1	40.4	18.5	6.0	3.2	2.1	1.6	1.8

30	1.9	2.8	5.9	22.8	41.3	35.8	12.1	5.1	2.8	1.8	1.5	1.6
20	1.6	2.3	3.9	15.1	33.4	28.7	9.1	4.1	2.1	1.5	1.3	1.5
10	1.5	2.0	2.7	5.5	18.9	21.8	5.4	3.5	1.8	1.3	1.3	1.3
1	1.3	1.5	1.9	3.3	3.8	6.2	4.7	1.8	1.3	1.1	1.0	1.0
0.1	1.3	1.5	1.9	2.9	1.9	4.4	4.3	1.6	1.3	1.1	1.0	1.0



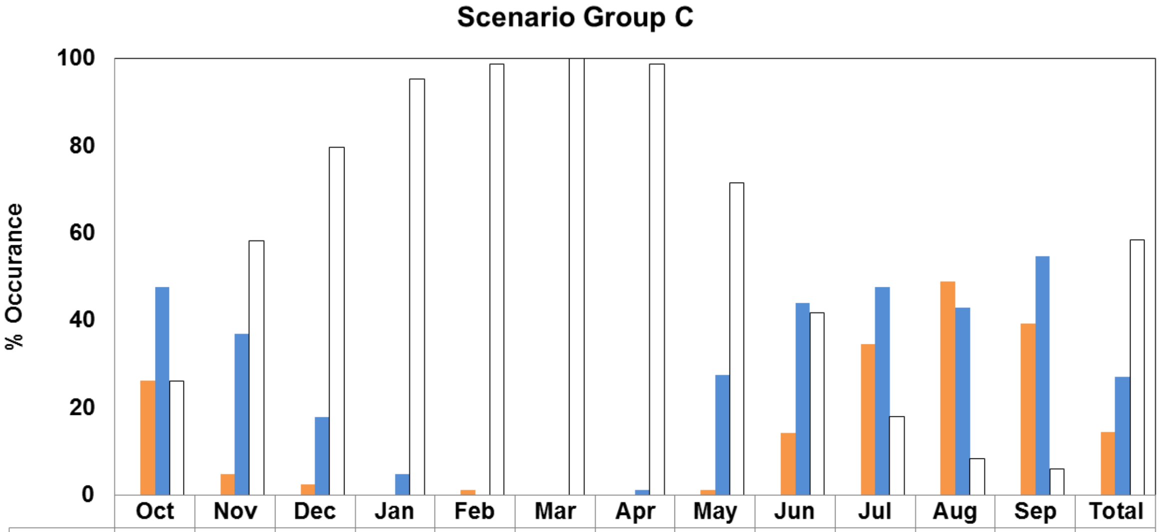
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	21	7	2	2	1	0	1	8	26	57	58	48	19
State 2	56	40	15	6	4	2	8	36	56	30	32	42	27
State 3	8	10	13	5	0	0	5	21	6	1	4	6	7
State 4	14	43	69	87	95	98	86	35	12	12	6	5	47

Table 7.9 **Graphic presentation of the occurrence of the various abiotic states under the Scenario Group A**



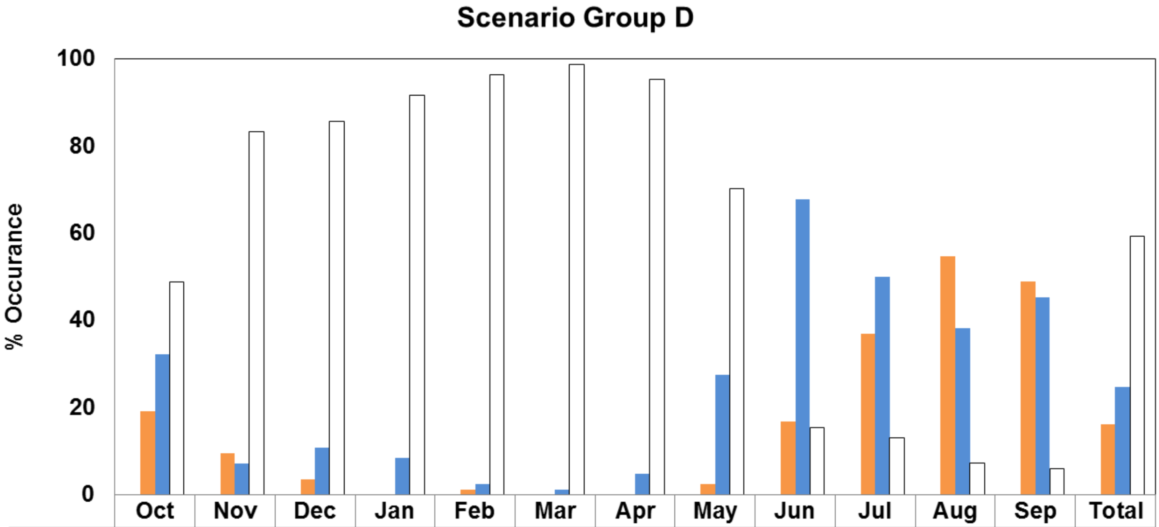
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	18	4	2	0	1	0	0	1	14	35	49	39	14
State 3	27	13	10	5	0	0	1	27	44	48	43	55	23
State 4	55	83	88	95	99	100	99	71	42	18	8	6	64

Table 7.10 **Graphic presentation of the occurrence of the various abiotic states under Scenario Group B**



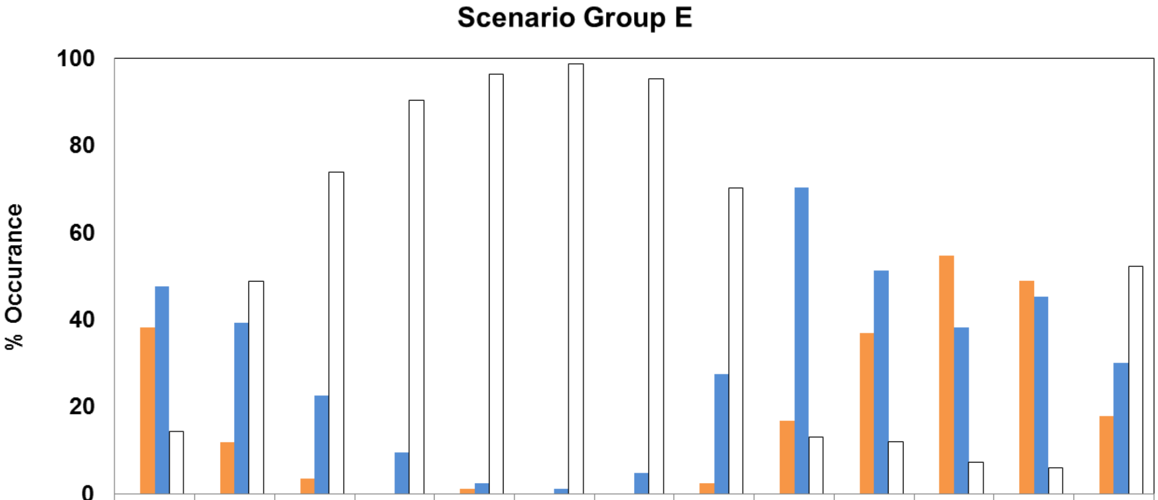
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	26	5	2	0	1	0	0	1	14	35	49	39	14
State 3	48	37	18	5	0	0	1	27	44	48	43	55	27
State 4	26	58	80	95	99	100	99	71	42	18	8	6	59

Table 7.11 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	19	10	4	0	1	0	0	2	17	37	55	49	16
State 3	32	7	11	8	2	1	5	27	68	50	38	45	25
State 4	49	83	86	92	96	99	95	70	15	13	7	6	59

Table 7.12 Graphic presentation of the occurrence of the various abiotic states under Scenario Group D



	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	38	12	4	0	1	0	0	2	17	37	55	49	18
State 3	48	39	23	10	2	1	5	27	70	51	38	45	30
State 4	14	49	74	90	96	99	95	70	13	12	7	6	52

Table 7.13 Graphic presentation of the occurrence of the various abiotic states under Scenario Group E

Table 7.14 Simulated monthly flows (m^3/s) to the Mkomazi Estuary for Scenario Group A

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1925	8.5	3.9	4.6	11.0	16.8	24.0	10.8	1.2	1.2	0.8	0.6	1.0
1926	1.4	11.5	46.1	50.4	40.6	82.1	47.6	2.4	1.0	0.6	1.2	1.2
1927	1.2	1.3	24.7	98.8	72.6	47.6	22.5	1.2	0.7	0.5	0.6	0.7
1928	1.2	1.3	1.4	42.0	30.5	40.8	25.4	5.1	13.3	14.3	4.7	6.8
1929	10.8	30.3	40.0	69.1	59.3	39.0	17.4	1.3	1.2	1.0	1.2	1.2
1930	1.2	1.5	8.0	63.1	52.8	33.9	17.6	1.5	1.1	1.2	1.2	0.9
1931	1.1	1.2	1.3	3.8	61.1	52.6	10.6	1.4	1.2	0.9	0.6	0.5
1932	1.2	1.4	8.7	12.6	13.9	17.7	8.5	1.2	0.7	0.5	0.5	0.5
1933	0.5	7.1	97.3	141.8	94.6	34.3	22.6	13.6	3.5	1.3	1.2	1.2
1934	1.2	47.6	102.7	54.2	32.0	25.8	15.4	4.2	32.8	18.6	2.1	1.2
1935	1.0	0.6	0.6	1.2	66.1	64.8	23.7	11.4	5.1	1.3	0.8	0.7
1936	1.2	44.2	46.9	36.2	70.9	40.0	8.2	1.1	0.6	0.5	0.5	0.5
1937	0.8	1.2	2.6	16.3	101.1	49.0	26.5	11.0	1.4	1.2	1.2	0.8
1938	1.5	22.6	61.8	54.6	161.4	103.4	23.0	1.6	1.2	1.0	0.8	1.3
1939	4.1	10.2	36.4	39.3	40.1	42.1	23.1	30.8	27.6	7.4	1.3	0.9
1940	1.2	12.4	112.8	94.9	71.3	41.6	15.7	1.4	1.0	0.6	0.5	0.5
1941	1.2	1.3	1.3	28.0	129.0	113.2	56.7	14.5	1.3	0.9	1.0	1.1
1942	1.3	35.8	120.0	113.8	80.0	42.3	132.9	89.8	19.8	8.8	24.0	13.5
1943	49.4	127.6	114.9	67.7	58.7	52.4	22.8	1.3	0.9	0.6	0.5	1.2
1944	1.3	1.5	1.3	11.4	36.8	96.8	59.2	7.1	1.2	0.6	0.5	0.4
1945	0.7	0.6	1.2	2.0	8.0	19.1	17.7	2.6	1.0	0.5	0.5	0.4
1946	0.7	1.3	2.7	18.4	82.4	89.4	42.2	6.4	4.9	1.6	1.2	0.9
1947	1.2	11.3	48.7	71.1	68.5	64.0	39.3	7.5	1.2	0.6	0.5	0.4
1948	1.2	1.3	3.0	3.1	33.1	44.3	22.4	1.3	0.8	0.5	0.5	0.6
1949	1.2	7.0	9.7	22.3	55.9	105.0	66.1	16.2	1.8	1.2	1.2	1.2
1950	1.2	1.2	43.1	96.3	66.4	21.8	6.9	1.2	0.6	0.5	0.9	1.2
1951	1.3	1.3	2.0	53.6	81.7	38.5	13.4	3.2	1.3	1.0	0.7	0.6
1952	0.9	1.3	4.6	29.7	66.0	32.2	3.5	1.0	0.6	0.5	0.9	1.2
1953	1.5	3.7	33.0	52.8	83.8	56.5	17.1	4.9	1.3	1.1	0.6	0.8
1954	11.4	17.7	27.2	129.9	172.1	76.0	21.1	3.3	1.3	0.9	0.6	0.6
1955	1.1	1.3	2.7	17.9	104.3	132.5	58.7	4.1	1.2	0.8	0.7	0.8
1956	1.2	1.6	119.0	145.4	80.3	69.1	45.3	8.1	1.3	0.7	0.7	4.4
1957	40.8	31.4	34.8	67.9	84.5	36.8	23.0	8.7	1.3	0.7	0.5	0.6
1958	0.8	1.6	29.6	67.6	57.9	27.8	8.4	128.3	85.9	7.7	1.3	1.2
1959	1.2	6.0	20.3	17.4	26.1	39.7	32.5	10.5	1.3	0.7	0.6	0.6
1960	1.2	2.3	60.9	42.6	40.1	61.2	93.8	21.8	1.8	1.0	0.6	0.8
1961	1.0	1.3	3.3	44.8	76.6	52.0	16.6	2.4	1.1	0.5	0.7	0.6
1962	1.2	5.1	25.8	110.2	41.1	102.2	26.9	2.8	1.3	15.9	1.3	1.2
1963	1.2	41.3	51.2	94.8	38.2	23.8	7.4	1.3	5.1	1.2	1.0	1.2
1964	4.0	32.6	27.9	53.8	62.4	5.4	1.2	0.9	5.3	1.5	1.2	2.1
1965	7.9	23.0	8.5	78.2	83.2	6.0	1.3	1.5	1.2	1.0	0.9	1.2
1966	1.0	2.4	8.8	36.8	132.2	135.8	104.4	16.8	3.5	1.9	1.3	1.2
1967	1.2	10.2	15.1	15.9	15.2	34.1	26.2	1.3	1.0	0.8	1.2	1.1
1968	0.9	1.0	2.5	0.5	1.5	46.3	35.0	3.6	1.2	0.9	0.8	1.0
1969	4.2	4.8	38.5	31.9	57.7	9.1	0.9	1.0	0.6	0.7	1.3	1.2
1970	33.1	16.3	16.2	20.3	59.4	26.9	18.6	8.5	1.2	1.2	9.5	1.4
1971	8.2	18.3	53.0	93.1	123.7	117.5	28.1	6.5	1.5	1.2	1.2	0.8
1972	1.1	1.3	3.1	1.8	51.3	39.9	72.7	16.3	0.8	0.6	0.6	1.2
1973	2.1	14.0	23.3	136.5	208.9	139.4	70.5	17.2	4.8	1.6	1.2	0.9
1974	1.2	1.2	11.5	81.5	107.6	54.5	18.7	1.4	1.2	1.0	0.8	1.2
1975	1.2	1.7	65.2	195.8	241.7	248.7	84.3	16.6	5.8	4.8	2.9	1.3
1976	21.0	4.2	8.8	37.6	55.9	57.0	27.4	1.8	1.1	1.0	0.7	0.5
1977	1.2	1.2	2.9	64.7	58.6	50.7	34.8	7.6	1.3	1.2	1.1	1.2
1978	3.7	8.1	81.2	27.6	40.4	42.8	10.2	2.0	1.2	1.2	1.2	1.2
1979	1.2	0.9	1.3	11.0	32.2	37.8	3.9	1.1	0.5	0.5	0.5	1.2
1980	1.3	1.4	6.6	59.2	110.3	37.1	1.2	1.2	1.0	0.7	0.5	1.3
1981	0.8	1.5	1.5	3.8	1.7	46.6	10.1	1.2	1.1	0.7	0.6	0.7
1982	0.9	1.3	1.4	0.8	0.6	1.2	1.2	0.5	0.5	0.5	0.6	0.6
1983	0.6	1.3	9.9	50.5	20.1	55.4	46.2	2.5	1.2	0.7	0.6	0.6
1984	1.2	1.2	1.2	20.1	163.8	36.8	1.3	0.9	0.7	0.6	0.6	0.5
1985	1.3	21.8	83.1	69.6	44.5	38.4	8.1	0.7	1.0	0.7	0.6	1.1
1986	1.2	13.1	35.2	38.0	19.7	46.1	9.5	1.2	1.2	1.1	1.2	244.8
1987	210.0	124.3	37.2	30.7	169.8	214.0	52.8	7.3	1.9	5.6	1.2	1.0
1988	1.2	1.3	71.7	96.2	146.2	59.6	15.2	7.6	3.5	1.2	1.0	0.9
1989	1.0	62.5	91.1	28.0	23.3	52.9	50.8	2.9	1.2	1.2	1.2	1.2
1990	1.3	1.7	14.1	70.2	127.5	49.2	10.8	1.5	1.2	1.2	1.0	1.0
1991	1.6	4.8	22.6	28.3	20.2	12.6	1.2	0.7	0.5	0.4	0.4	0.4
1992	0.7	1.0	1.2	1.0	1.3	1.3	6.4	1.2	0.6	0.5	0.5	0.6
1993	2.4	2.6	19.4	101.7	112.5	32.6	3.8	1.0	0.8	0.9	1.1	0.7
1994	1.2	1.2	1.3	1.4	8.1	33.9	24.9	2.4	1.2	1.0	33.1	46.4
1995	24.5	6.6	185.0	198.9	168.7	103.2	24.7	3.9	1.2	37.8	8.0	1.4
1996	1.3	9.1	61.6	115.8	40.4	74.8	36.0	7.6	8.3	10.2	1.8	3.8
1997	1.4	36.8	65.3	62.4	119.3	60.9	21.9	2.6	1.3	1.2	1.2	1.1
1998	0.9	0.8	17.2	39.3	67.7	20.0	1.2	0.6	0.5	0.5	0.5	0.5
1999	1.1	0.6	80.8	142.5	77.3	140.0	69.8	17.6	1.7	1.2	1.1	1.2
2000	1.2	5.1	54.2	58.9	35.6	22.5	30.0	4.3	1.2	0.8	0.8	2.1
2001	3.4	63.5	61.0	43.0	44.7	33.1	4.4	1.2	1.3	6.6	5.3	2.1
2002	1.2	1.2	1.2	13.5	45.6	27.0	17.1	1.7	1.0	0.7	0.5	0.6
2003	0.6	1.2	1.3	13.3	50.9	42.8	7.5	0.7	0.8	0.8	0.8	1.2
2004	1.3	11.0	59.5	78.2	36.1	34.7	24.1	1.3	1.1	1.0	0.6	0.6
2005	0.6	1.0	0.9	2.0	55.8	51.4	21.9	7.6	1.1	0.9	1.0	1.2
2006	7.2	15.6	41.7	21.5	31.2	15.3	5.9	1.2	1.2	1.2	0.7	0.6
2007	1.3	23.2	21.6	45.0	36.1	38.4	25.2	7.0	1.3	1.1	0.6	0.6

2008	*1.2*	*1.3*	*5.6*	*9.3*	*129.4*	*92.7*	*25.5*	*2.5*	*0.9*	*0.5*	*0.5*	*0.7*

Table 7.15 Simulated monthly flows (m^3/s) to the Mkomazi Estuary for Scenario Group B

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1925	10.4	8.7	5.6	11.0	18.7	25.9	12.7	4.6	4.3	3.4	1.4	3.4
1926	9.4	13.5	39.8	52.4	42.5	83.3	48.9	7.2	2.0	1.4	3.5	3.3
1927	7.6	9.9	22.8	92.5	74.1	49.3	24.4	5.3	2.2	1.4	1.5	1.8
1928	6.5	7.7	13.7	27.3	32.4	42.8	27.4	9.8	12.3	16.1	6.6	8.7
1929	12.7	32.2	41.7	70.8	60.9	40.8	19.2	4.8	2.6	1.9	2.4	3.2
1930	5.2	6.2	18.2	53.5	54.6	35.7	19.4	7.0	2.2	4.2	3.8	1.7
1931	2.0	2.3	3.6	8.0	59.2	54.5	12.5	4.5	4.0	2.7	1.4	1.5
1932	5.7	12.9	14.8	6.0	8.6	19.5	10.4	4.5	1.6	1.3	1.3	1.3
1933	1.3	21.2	91.5	143.2	96.0	36.0	24.4	15.4	6.2	4.7	3.9	3.2
1934	6.6	43.1	104.4	56.0	33.8	27.5	17.2	10.5	29.6	20.0	4.8	2.2
1935	1.5	1.6	1.9	8.2	66.0	66.2	25.3	13.2	7.2	4.3	1.5	1.5
1936	4.7	45.5	48.5	38.0	72.6	41.8	10.1	3.3	1.4	1.2	1.2	1.2
1937	1.5	7.8	9.1	23.0	93.8	50.7	28.2	12.9	5.6	3.7	3.6	2.8
1938	9.6	18.2	60.7	56.5	162.5	105.0	24.9	6.4	3.4	1.9	1.6	4.0
1939	9.7	20.9	24.8	41.2	41.9	43.9	24.9	32.5	29.3	9.2	4.0	2.3
1940	6.1	18.3	107.7	96.6	73.1	43.4	17.5	6.3	2.2	1.4	1.3	1.3
1941	3.7	4.6	7.6	25.2	131.1	114.7	58.3	16.3	5.7	2.5	2.4	2.8
1942	7.7	32.1	121.6	115.6	81.9	44.1	134.7	91.6	21.7	10.6	25.8	15.4
1943	51.2	129.4	116.8	69.5	60.6	54.2	24.6	4.5	2.0	1.7	1.3	3.7
1944	9.1	10.4	3.3	5.8	34.5	98.6	60.8	10.5	3.8	1.5	1.2	1.2
1945	1.4	1.6	2.4	5.2	13.3	21.0	19.6	9.1	2.6	1.3	1.2	1.2
1946	1.4	13.3	11.7	13.1	74.5	91.0	43.7	11.1	7.2	5.6	3.9	1.7
1947	4.6	20.6	37.4	73.0	70.2	65.7	41.0	10.8	4.8	1.5	1.2	1.2
1948	3.3	5.4	8.3	9.4	24.6	46.2	24.3	7.4	2.2	1.3	1.3	1.5
1949	4.3	13.4	20.0	14.5	53.4	106.5	67.7	18.0	6.0	4.0	4.1	3.9
1950	4.3	3.6	39.2	98.1	68.0	23.5	8.7	4.4	1.6	1.2	3.1	3.6
1951	8.0	5.8	11.0	41.8	83.7	40.4	15.2	9.8	4.8	2.8	2.4	1.9
1952	3.1	10.9	12.7	16.4	64.2	34.0	6.6	3.1	1.6	1.3	1.5	3.5
1953	8.0	15.1	25.9	51.8	85.5	58.2	19.0	9.6	6.0	3.7	1.4	2.2
1954	15.2	22.3	20.0	131.2	172.5	77.0	22.7	9.2	5.2	2.4	1.3	1.4
1955	1.8	2.7	16.2	10.6	102.4	133.8	60.3	8.5	2.6	1.5	1.4	1.5
1956	5.2	16.0	108.5	147.1	82.1	71.0	47.1	11.7	4.7	1.9	2.8	4.2
1957	42.4	33.1	36.5	69.8	86.2	38.6	24.9	11.5	5.0	1.5	1.2	1.4
1958	3.1	9.2	28.2	67.8	59.4	29.5	10.3	130.1	87.8	9.6	3.9	2.5
1959	4.7	14.4	18.4	15.6	27.9	41.5	34.2	12.4	5.6	1.6	1.3	1.5
1960	3.0	12.3	56.3	44.3	41.8	62.7	95.5	23.6	6.4	3.7	1.7	1.8
1961	1.7	9.2	13.4	32.9	78.4	53.5	18.2	8.2	3.5	1.8	1.8	2.6
1962	2.6	15.8	23.0	106.3	42.9	103.8	28.7	8.8	5.6	11.3	4.1	3.0
1963	7.4	38.3	53.0	96.4	39.9	25.6	9.3	6.2	7.2	4.9	3.3	3.8
1964	9.4	25.2	29.8	55.7	64.2	8.2	5.9	3.2	8.4	5.7	3.7	4.6
1965	10.5	21.0	8.8	75.9	84.7	9.0	5.8	4.7	3.1	2.2	1.6	2.8
1966	2.2	15.9	14.6	22.6	134.1	137.1	106.0	18.6	7.2	5.6	4.1	2.9
1967	2.9	19.1	12.0	12.5	17.0	35.9	27.9	6.2	3.4	2.5	2.9	2.0
1968	1.5	5.0	11.6	2.9	5.2	36.9	37.0	9.3	5.1	3.6	1.9	3.0
1969	11.3	11.8	25.1	34.0	59.4	10.9	4.6	2.9	1.8	1.8	4.2	3.9
1970	33.7	18.1	18.0	22.2	61.2	28.7	20.4	11.3	5.4	4.6	7.0	4.0
1971	10.3	19.3	54.6	94.8	125.2	118.9	29.8	10.9	6.0	4.2	3.4	1.8
1972	4.2	11.5	7.0	4.6	34.8	41.7	73.9	18.0	4.7	2.9	3.1	3.4
1973	9.4	16.7	16.3	137.9	210.1	141.1	72.3	19.0	7.1	5.4	3.9	2.5
1974	3.4	9.9	14.0	73.9	109.2	56.2	20.5	6.5	4.1	3.1	1.9	3.8
1975	5.6	10.0	55.1	197.3	243.2	250.4	86.1	18.4	8.5	6.7	5.1	3.5
1976	21.1	13.2	8.8	34.8	57.7	58.7	29.2	7.8	4.0	3.2	2.0	2.2
1977	6.5	8.2	8.0	51.6	60.5	52.3	36.5	10.9	5.6	3.8	2.5	3.6
1978	9.9	16.3	68.7	29.5	42.1	44.5	12.0	7.8	4.1	4.1	3.8	3.5
1979	4.6	5.7	5.4	11.5	22.0	39.6	6.6	3.1	1.8	1.5	1.3	3.7
1980	7.7	4.5	16.4	49.3	112.4	39.0	5.9	4.0	2.9	1.9	1.7	4.0
1981	4.0	5.0	7.7	5.3	5.0	38.6	12.0	4.1	3.0	2.0	1.5	1.5
1982	1.5	6.2	3.2	3.4	1.8	6.4	5.3	1.6	1.3	1.3	1.3	1.4
1983	3.9	11.8	27.4	29.3	21.6	57.4	48.1	8.5	4.7	3.5	2.1	2.1
1984	4.4	4.2	3.1	20.4	159.7	38.5	6.1	3.4	2.2	1.8	1.3	1.3
1985	7.2	24.6	80.4	71.2	46.2	40.1	9.9	6.1	3.6	2.4	1.7	3.1
1986	7.2	17.8	27.7	40.1	21.6	47.7	11.3	4.5	3.3	3.0	3.8	243.0
1987	211.3	126.1	39.1	32.7	171.6	215.8	54.6	11.6	6.5	5.7	3.8	3.2
1988	4.8	11.2	60.4	97.9	148.0	61.4	17.1	13.0	6.9	4.6	2.8	1.7
1989	1.8	61.6	91.5	29.9	25.1	54.7	52.6	8.6	4.7	3.6	2.9	3.7
1990	5.7	4.8	20.3	58.7	128.7	50.8	12.7	5.8	4.5	3.4	1.8	1.9
1991	9.2	13.9	15.0	25.6	22.1	14.4	5.6	2.1	1.4	1.3	1.2	1.3
1992	1.4	1.9	2.3	3.8	8.6	14.2	10.7	3.8	1.7	1.3	1.3	1.4
1993	9.0	12.7	21.4	81.6	114.6	34.6	7.2	4.0	2.4	2.7	3.3	1.8
1994	3.8	2.2	3.4	15.6	5.6	26.6	26.8	8.9	5.3	3.7	32.8	46.6
1995	24.7	12.0	179.8	200.4	170.6	105.1	26.5	9.7	5.5	33.5	9.8	3.9
1996	6.7	12.4	58.0	117.6	42.2	76.6	37.8	11.4	8.5	11.6	4.6	5.4
1997	7.6	33.4	67.1	64.2	121.2	62.7	23.8	8.5	5.5	3.8	3.3	2.5
1998	2.9	7.0	19.8	30.6	69.6	21.9	5.9	3.4	1.9	1.5	1.3	1.3
1999	6.6	9.7	71.6	144.7	79.0	141.8	71.6	19.5	6.2	4.6	3.3	3.7
2000	6.1	14.1	41.9	60.7	37.3	24.3	31.8	9.6	5.0	3.3	1.8	4.7
2001	10.0	54.7	62.5	44.7	46.5	34.9	7.2	4.4	5.5	8.3	6.5	4.7
2002	4.7	2.5	4.3	9.5	47.5	28.9	19.0	8.3	4.4	2.5	1.4	1.9
2003	1.5	5.7	6.6	16.6	41.8	44.8	9.4	3.6	1.9	2.4	3.0	3.1
2004	6.8	19.6	51.6	80.0	38.0	36.4	25.8	6.1	3.4	2.6	1.6	1.4
2005	1.6	2.0	1.9	14.6	48.9	53.3	23.9	9.8	5.1	3.5	3.4	3.3
2006	13.1	15.0	39.0	23.5	33.2	17.3	8.0	4.1	3.1	4.3	1.7	1.4
2007	8.5	27.5	22.9	39.7	37.9	40.2	26.9	10.2	5.6	3.4	1.6	1.7

2008	2.0	2.9	10.6	16.7	121.5	93.9	27.1	8.2	3.1	1.7	1.8	1.5

Table 7.16 Simulated monthly flows (m^3/s) to the Mkomazi Estuary for Scenario Group C

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1925	10.1	5.5	6.2	12.6	18.4	25.6	12.4	4.6	4.3	3.4	1.4	3.4
1926	5.1	7.5	47.8	52.2	42.2	83.1	48.7	7.2	2.0	1.4	3.5	3.3
1927	4.6	4.3	21.2	100.3	73.8	49.0	24.1	5.3	2.2	1.4	1.5	1.8
1928	3.8	3.6	6.7	38.7	32.2	42.5	27.1	9.8	11.7	15.8	6.3	8.4
1929	12.4	31.9	41.4	70.5	60.7	40.5	19.0	4.8	2.6	1.9	2.4	3.2
1930	3.2	3.2	10.4	63.8	54.3	35.4	19.1	7.0	2.2	4.2	3.8	1.7
1931	1.7	2.2	3.5	5.9	59.1	54.2	12.2	4.5	4.0	2.7	1.4	1.5
1932	3.1	6.3	8.0	12.8	15.5	19.3	10.1	4.5	1.6	1.3	1.3	1.3
1933	1.3	10.3	99.9	143.0	95.8	35.8	24.1	15.2	6.2	4.7	3.9	3.2
1934	3.9	44.3	104.1	55.7	33.5	27.3	17.0	10.5	29.1	19.8	4.8	2.2
1935	1.5	1.6	1.9	5.5	67.0	66.0	25.0	12.9	7.2	4.3	1.5	1.5
1936	2.9	45.7	48.3	37.8	72.4	41.5	9.8	3.3	1.4	1.2	1.2	1.2
1937	1.5	3.3	5.2	20.6	102.7	50.4	28.0	12.6	5.6	3.7	3.6	2.8
1938	5.1	18.1	63.5	56.3	162.2	104.7	24.6	6.4	3.4	1.9	1.6	4.0
1939	6.2	12.1	34.8	40.9	41.6	43.6	24.6	32.3	29.1	9.0	4.0	2.3
1940	3.4	12.9	114.2	96.4	72.9	43.2	17.2	6.3	2.2	1.4	1.3	1.3
1941	2.2	2.9	4.3	29.2	130.8	114.4	58.1	16.0	5.7	2.5	2.4	2.8
1942	4.7	33.6	121.3	115.3	81.6	43.9	134.4	91.3	21.4	10.3	25.6	15.1
1943	50.9	129.1	116.5	69.3	60.3	53.9	24.4	4.5	2.0	1.7	1.3	3.7
1944	5.0	4.5	3.2	9.5	38.4	98.3	60.5	10.5	3.8	1.5	1.2	1.2
1945	1.4	1.6	2.4	5.2	10.1	21.2	19.3	9.1	2.6	1.3	1.2	1.2
1946	1.4	6.3	6.1	14.0	84.1	90.8	43.4	11.1	7.2	5.6	3.9	1.7
1947	2.8	11.5	45.8	72.7	70.0	65.4	40.7	10.8	4.8	1.5	1.2	1.2
1948	2.1	3.1	4.8	6.5	32.4	46.0	24.0	7.4	2.2	1.3	1.3	1.5
1949	2.7	7.4	12.5	23.0	57.5	106.3	67.4	17.7	6.0	4.0	4.1	3.9
1950	2.6	2.5	40.1	97.9	67.8	23.2	8.5	4.4	1.6	1.2	3.1	3.6
1951	4.9	3.1	5.6	50.7	83.4	40.2	15.0	9.8	4.8	2.8	2.4	1.9
1952	1.8	4.8	7.0	23.6	67.7	33.7	6.6	3.1	1.6	1.3	1.5	3.5
1953	4.9	7.7	31.0	54.4	85.2	58.0	18.7	9.6	6.0	3.7	1.4	2.2
1954	11.7	14.8	28.7	130.9	172.3	76.8	22.4	9.2	5.2	2.4	1.3	1.4
1955	1.6	2.6	8.7	12.6	105.9	133.6	60.1	8.5	2.6	1.5	1.4	1.5
1956	3.0	7.2	117.0	146.9	81.9	70.7	46.8	11.7	4.7	1.9	2.8	4.2
1957	40.8	32.9	36.3	69.6	85.9	38.4	24.6	11.5	5.0	1.5	1.2	1.4
1958	1.8	4.2	30.6	69.2	59.2	29.2	10.0	129.9	87.5	9.3	3.9	2.5
1959	3.0	8.0	21.2	19.1	27.7	41.2	34.0	12.1	5.6	1.6	1.3	1.5
1960	1.9	6.0	61.8	44.1	41.5	62.4	95.2	23.4	6.4	3.7	1.7	1.8
1961	1.6	4.0	6.6	42.7	78.1	53.3	18.0	8.2	3.5	1.8	1.8	2.6
1962	1.8	8.6	22.9	111.8	42.6	103.5	28.4	8.8	5.6	10.9	4.1	3.0
1963	4.4	39.9	52.7	96.2	39.7	25.3	9.0	6.2	7.2	4.9	3.3	3.8
1964	6.1	26.7	29.5	55.4	63.9	8.2	5.9	3.2	8.4	5.7	3.7	4.6
1965	7.3	16.3	10.1	79.5	84.5	9.0	5.8	4.7	3.1	2.2	1.6	2.8
1966	1.7	7.4	7.7	35.3	133.8	136.8	105.8	18.3	7.2	5.6	4.1	2.9
1967	1.8	11.7	13.0	17.5	16.7	35.6	27.7	6.2	3.4	2.5	2.9	2.0
1968	1.5	2.4	6.1	2.9	5.1	42.1	36.7	9.3	5.1	3.6	1.9	3.0
1969	6.8	6.2	32.9	33.7	59.1	10.6	4.6	2.9	1.8	1.8	4.2	3.9
1970	31.8	17.9	17.7	21.9	61.0	28.4	20.2	11.3	5.4	4.6	6.6	4.0
1971	8.3	19.8	54.3	94.5	124.9	118.6	29.5	10.9	6.0	4.2	3.4	1.8
1972	2.5	5.2	4.5	4.5	43.2	41.4	73.6	17.8	4.7	2.9	3.1	3.4
1973	5.5	10.0	25.0	137.6	209.9	140.8	72.1	18.8	7.1	5.4	3.9	2.5
1974	2.2	4.2	9.3	83.3	109.0	55.9	20.2	6.5	4.1	3.1	1.9	3.8
1975	3.3	4.4	60.6	197.0	242.9	250.1	85.8	18.2	8.5	6.7	5.1	3.5
1976	21.1	6.9	8.4	39.3	57.4	58.4	28.9	7.8	4.0	3.2	2.0	2.2
1977	3.8	3.5	4.7	59.8	60.2	52.0	36.2	10.9	5.6	3.8	2.5	3.6
1978	6.1	9.6	76.9	29.2	41.8	44.2	11.7	7.8	4.1	4.1	3.8	3.5
1979	2.9	2.5	3.8	6.6	31.5	39.4	6.4	3.1	1.8	1.5	1.3	3.7
1980	4.6	3.0	9.2	58.6	112.1	38.7	5.8	4.0	2.9	1.9	1.7	4.0
1981	2.3	3.2	4.3	5.2	5.0	42.4	11.7	4.1	3.0	2.0	1.5	1.5
1982	1.5	3.1	3.2	3.4	1.8	6.4	5.3	1.6	1.3	1.3	1.3	1.4
1983	2.2	5.5	15.8	45.8	21.9	57.1	47.8	8.5	4.7	3.5	2.1	2.1
1984	2.7	2.9	3.0	15.7	165.4	38.3	6.0	3.4	2.2	1.8	1.3	1.3
1985	4.4	20.8	84.5	71.0	45.9	39.8	9.6	6.1	3.6	2.4	1.7	3.1
1986	4.2	8.8	37.2	39.8	21.3	47.5	11.0	4.5	3.3	3.0	3.8	241.6
1987	211.0	125.8	38.8	32.4	171.3	215.6	54.3	11.6	6.5	5.7	3.8	3.2
1988	2.9	5.0	66.2	97.7	147.8	61.2	16.8	13.0	6.9	4.6	2.8	1.7
1989	1.6	61.6	89.7	29.6	24.8	54.4	52.3	8.6	4.7	3.6	2.9	3.7
1990	3.4	3.1	13.6	67.2	128.4	50.5	12.4	5.8	4.5	3.4	1.8	1.9
1991	5.1	7.5	18.6	30.0	21.8	14.2	5.6	2.1	1.4	1.3	1.2	1.3
1992	1.4	1.9	2.3	3.8	6.5	10.3	8.7	3.8	1.7	1.3	1.3	1.4
1993	5.4	6.2	13.6	101.5	114.3	34.3	7.0	4.0	2.4	2.7	3.3	1.8
1994	2.2	2.2	3.4	8.7	5.6	32.5	26.6	8.9	5.3	3.7	32.8	46.6
1995	24.7	6.1	183.5	200.2	170.3	104.8	26.3	9.7	5.5	32.7	9.6	3.9
1996	4.0	8.9	63.0	117.3	41.9	76.3	37.6	11.4	8.5	10.8	4.6	5.4
1997	4.6	35.4	66.8	64.0	120.9	62.4	23.5	8.5	5.5	3.8	3.3	2.5
1998	1.8	2.7	12.3	41.1	69.3	21.6	5.9	3.4	1.9	1.5	1.3	1.3
1999	3.8	3.7	77.9	144.4	78.7	141.5	71.4	19.2	6.2	4.6	3.3	3.7
2000	3.5	6.9	49.7	60.4	37.1	24.0	31.5	9.6	5.0	3.3	1.8	4.7
2001	6.5	56.5	62.3	44.5	46.3	34.7	7.1	4.4	5.5	8.3	6.5	4.7
2002	3.0	2.4	3.1	9.9	47.2	28.6	18.7	8.3	4.4	2.5	1.4	1.9
2003	1.5	2.7	4.1	9.7	52.3	44.5	9.1	3.6	1.9	2.4	3.0	3.1
2004	4.1	12.0	59.5	79.8	37.7	36.2	25.6	6.1	3.4	2.6	1.6	1.4
2005	1.5	2.0	1.9	8.2	53.1	53.0	23.6	9.8	5.1	3.5	3.4	3.3
2006	8.6	13.0	43.4	23.3	32.9	17.0	7.6	4.1	3.1	4.3	1.7	1.4
2007	4.9	22.6	22.2	46.5	37.6	40.0	26.7	10.2	5.6	3.4	1.6	1.7

2008	1.7	2.9	6.6	10.9	129.8	93.7	26.9	8.2	3.1	1.7	1.8	1.5

Table 7.17 Simulated monthly flows (m^3/s) to the Mkomazi Estuary for Scenario Group D

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1925	10.2	8.7	4.7	11.3	18.5	25.7	12.5	4.2	3.4	2.7	1.4	2.4
1926	6.7	12.5	44.8	52.3	42.3	83.2	48.8	6.1	1.9	1.4	2.4	2.3
1927	5.8	9.8	18.5	100.4	73.9	49.1	24.2	4.7	2.1	1.4	1.5	1.7
1928	5.2	8.5	13.6	27.3	32.2	42.6	27.2	8.3	13.4	15.9	6.4	8.5
1929	12.5	32.0	41.5	70.6	60.8	40.6	19.1	4.5	2.3	1.8	1.9	2.2
1930	4.7	7.3	16.1	55.6	54.4	35.5	19.2	6.0	2.1	3.0	2.7	1.7
1931	1.8	1.8	2.8	6.9	64.0	54.3	12.3	4.1	3.3	2.2	1.3	1.5
1932	4.8	12.1	13.8	4.4	12.9	19.4	10.2	4.2	1.5	1.3	1.3	1.2
1933	1.3	16.7	94.7	143.0	95.9	35.9	24.2	15.2	5.2	3.5	2.7	2.3
1934	5.4	47.7	104.2	55.8	33.6	27.3	17.0	8.3	31.6	19.9	2.8	1.9
1935	1.5	1.6	1.9	6.5	69.0	66.1	25.1	13.0	6.7	3.2	1.5	1.4
1936	4.3	46.5	48.3	37.8	72.5	41.6	9.9	3.3	1.3	1.1	1.0	1.1
1937	1.5	7.5	8.8	19.4	97.0	50.5	28.1	12.7	4.4	2.8	2.6	2.1
1938	6.8	20.7	63.6	56.4	162.3	104.8	24.7	5.5	3.0	1.8	1.6	2.4
1939	6.5	15.2	34.9	41.0	41.7	43.7	24.7	32.4	29.1	9.1	2.7	1.9
1940	5.1	14.6	113.0	96.4	72.9	43.2	17.3	5.6	2.0	1.3	1.2	1.2
1941	3.5	4.4	7.0	25.5	130.9	114.5	58.2	16.1	4.4	2.1	1.9	2.1
1942	5.9	35.8	121.4	115.4	81.7	44.0	134.5	91.4	21.5	10.4	25.6	15.2
1943	51.0	129.2	116.6	69.3	60.4	54.0	24.4	4.2	1.9	1.7	1.3	2.4
1944	6.6	10.2	2.7	5.3	38.5	98.4	60.6	8.7	3.2	1.5	1.2	1.0
1945	1.4	1.5	2.1	4.3	11.6	24.5	19.4	7.5	2.4	1.3	1.0	1.0
1946	1.3	12.3	11.6	11.2	78.0	90.8	43.5	8.6	5.9	3.8	2.6	1.6
1947	4.2	15.3	48.1	72.8	70.0	65.5	40.8	9.2	3.9	1.5	1.1	1.1
1948	3.0	6.0	8.0	7.8	27.4	46.0	24.1	6.0	2.1	1.3	1.2	1.5
1949	4.1	11.4	16.1	16.6	57.6	106.4	67.5	17.8	4.7	3.0	2.8	2.4
1950	4.1	2.4	44.3	97.9	67.9	23.3	8.5	4.1	1.5	1.1	2.3	2.4
1951	6.1	6.8	10.7	43.9	83.5	40.2	15.0	8.0	4.0	2.4	1.9	1.7
1952	2.6	10.6	12.2	16.3	67.8	33.8	5.5	3.1	1.5	1.3	1.5	2.3
1953	6.1	13.4	27.3	54.5	85.3	58.1	18.8	8.0	4.7	2.9	1.5	1.9
1954	11.8	19.4	28.8	131.0	172.4	76.8	22.5	7.8	4.1	2.0	1.3	1.3
1955	1.7	1.9	15.4	10.0	106.0	133.7	60.2	7.3	2.4	1.4	1.3	1.5
1956	4.6	14.1	110.8	146.9	81.9	70.8	46.9	9.8	4.0	1.8	2.0	6.6
1957	42.5	33.0	36.3	69.6	86.0	38.4	24.7	10.4	4.1	1.5	1.2	1.4
1958	2.7	9.2	27.6	69.3	59.2	29.3	10.1	129.9	87.6	9.4	2.6	2.0
1959	4.4	12.4	17.7	19.2	27.7	41.3	34.0	12.2	4.3	1.6	1.3	1.5
1960	2.8	11.7	57.1	44.2	41.6	62.5	95.3	23.5	4.7	2.8	1.6	1.6
1961	1.7	9.1	13.3	34.3	78.2	53.3	18.1	7.2	3.0	1.7	1.6	2.0
1962	2.3	13.6	20.5	111.9	42.7	103.6	28.5	7.5	4.4	13.4	2.8	2.1
1963	5.8	41.4	52.8	96.3	39.7	25.4	9.1	5.3	4.9	3.6	2.4	2.4
1964	6.3	33.8	29.6	55.5	64.0	7.0	5.1	3.1	5.5	4.0	2.7	2.5
1965	9.6	24.5	10.2	79.6	84.6	7.6	4.9	4.3	2.8	1.9	1.6	2.1
1966	2.0	14.0	13.8	27.2	133.9	136.9	105.8	18.4	5.2	3.8	2.8	2.1
1967	2.5	14.1	16.4	17.6	16.8	35.7	27.7	5.3	2.9	2.1	2.2	1.9
1968	1.5	4.6	11.6	2.9	4.3	38.6	36.8	7.6	4.1	2.8	1.7	2.1
1969	7.0	10.5	33.6	33.8	59.2	10.7	4.2	2.7	1.7	1.8	2.8	2.4
1970	35.9	17.9	17.8	22.0	61.0	28.5	20.2	10.2	4.3	3.5	9.6	2.4
1971	10.6	19.9	54.4	94.6	125.0	118.7	29.6	8.6	4.5	3.1	2.4	1.7
1972	4.0	11.1	6.7	3.7	41.1	41.5	73.7	17.9	3.7	2.3	2.4	2.3
1973	6.7	13.8	24.1	137.7	209.9	140.9	72.1	18.9	6.5	3.8	2.7	2.0
1974	3.5	9.5	12.8	77.9	109.1	56.0	20.3	5.6	3.4	2.6	1.7	2.4
1975	4.9	9.9	58.1	197.1	243.0	250.2	85.9	18.2	5.9	5.0	3.1	2.3
1976	21.0	11.8	11.5	39.4	57.5	58.5	29.0	6.8	3.2	2.6	1.7	1.8
1977	5.3	8.1	7.6	54.7	60.3	52.1	36.3	9.3	4.3	2.9	2.0	2.3
1978	6.6	13.4	78.9	29.3	41.9	44.3	11.8	6.7	3.4	3.0	2.6	2.3
1979	4.3	5.1	4.6	9.8	29.2	39.6	5.6	3.1	1.8	1.5	1.3	2.4
1980	5.9	4.3	15.2	53.0	112.2	38.8	5.1	3.9	2.6	1.8	1.6	2.4
1981	3.9	5.4	7.2	4.2	4.3	41.1	11.8	4.0	2.7	1.8	1.5	1.5
1982	1.4	7.0	2.5	3.4	1.7	4.1	4.8	1.5	1.3	1.2	1.3	1.3
1983	3.7	11.3	22.8	35.5	20.2	57.2	47.9	6.8	3.9	2.8	1.8	1.8
1984	3.9	3.7	2.6	18.6	165.4	38.4	5.1	3.4	2.0	1.7	1.3	1.3
1985	5.6	21.4	84.6	71.0	46.0	39.9	9.7	5.1	3.0	2.0	1.6	2.2
1986	5.6	15.6	32.9	39.9	21.4	47.5	11.1	4.1	2.9	2.5	2.7	244.5
1987	211.1	125.9	38.9	32.5	171.4	215.7	54.4	9.0	4.7	6.3	2.7	2.3
1988	4.4	10.8	65.1	97.7	147.8	61.2	16.9	9.2	4.6	3.4	2.2	1.6
1989	1.7	67.1	92.7	29.7	24.9	54.5	52.4	7.4	3.8	2.8	2.2	2.4
1990	4.8	5.5	15.6	66.9	128.5	50.6	12.5	5.2	3.7	2.8	1.7	1.8
1991	6.6	12.4	15.4	30.0	21.9	14.3	4.9	1.9	1.4	1.2	1.1	1.2
1992	1.3	1.7	2.0	3.6	7.8	10.0	9.9	3.6	1.6	1.3	1.3	1.3
1993	6.5	12.3	17.5	94.0	112.5	34.3	6.2	3.9	2.2	2.2	2.4	1.7
1994	3.6	1.8	2.7	14.1	5.0	30.6	26.5	7.0	4.2	2.9	33.1	46.6
1995	24.7	10.6	183.0	200.2	170.4	104.9	26.4	7.9	4.3	35.9	9.7	2.4
1996	5.3	10.8	61.6	117.4	42.0	76.4	37.6	9.2	9.9	11.9	2.9	4.0
1997	5.9	37.6	66.9	64.0	121.0	62.5	23.6	7.3	4.2	2.9	2.4	2.0
1998	2.5	6.0	17.8	37.1	69.4	21.7	5.2	3.4	1.8	1.5	1.3	1.3
1999	5.4	9.7	71.8	144.5	78.8	141.6	71.5	19.3	4.8	3.4	2.4	2.4
2000	5.0	13.1	47.5	60.5	37.2	24.1	31.6	8.2	3.9	2.6	1.6	2.7
2001	6.4	62.5	62.3	44.6	46.3	34.7	6.1	4.0	4.3	6.4	5.5	4.1
2002	4.4	1.9	3.6	15.4	47.3	28.7	18.8	6.4	3.5	2.1	1.4	1.7
2003	1.5	5.2	5.9	15.3	46.2	44.6	9.2	3.7	1.8	2.0	2.3	2.2
2004	5.5	14.6	58.3	79.9	37.8	36.2	25.6	5.2	2.9	2.1	1.6	1.4
2005	1.5	1.8	1.9	13.3	50.6	53.1	23.7	9.4	4.1	2.8	2.5	2.3
2006	9.0	17.4	43.4	23.3	33.0	17.1	7.6	3.9	2.7	3.1	1.6	1.4
2007	6.3	22.5	23.4	46.6	37.7	40.1	26.8	8.7	4.3	2.8	1.6	1.6

2008	1.9	2.1	9.4	13.8	128.7	93.8	26.9	6.9	2.8	1.6	1.6	1.5

Table 7.18 Simulated monthly flows (m^3/s) to the Mkomazi Estuary for Scenario Group E

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1925	9.8	5.2	6.0	12.3	18.1	25.3	12.1	4.2	3.4	2.7	1.4	2.4
1926	3.4	10.2	47.5	51.9	41.9	82.8	48.4	6.1	1.9	1.4	2.4	2.3
1927	3.1	3.2	24.7	100.0	73.5	48.8	23.8	4.7	2.1	1.4	1.5	1.7
1928	2.7	2.8	5.5	40.0	31.9	42.2	26.8	8.3	12.7	15.6	6.1	8.1
1929	12.2	31.6	41.2	70.2	60.4	40.2	18.7	4.5	2.3	1.8	1.9	2.2
1930	2.3	2.6	10.6	64.7	54.0	35.1	18.8	6.0	2.1	3.0	2.7	1.7
1931	1.5	1.8	2.6	4.9	62.7	53.9	11.9	4.1	3.3	2.2	1.3	1.5
1932	2.4	4.4	8.2	14.1	15.2	19.0	9.8	4.2	1.5	1.3	1.3	1.2
1933	1.3	7.6	100.7	142.7	95.5	35.5	23.9	14.9	4.8	3.5	2.7	2.3
1934	2.8	48.4	103.8	55.4	33.2	27.0	16.7	8.3	30.8	19.5	2.8	1.9
1935	1.4	1.6	1.9	4.7	68.2	65.7	24.7	12.6	6.4	3.2	1.5	1.4
1936	2.1	46.9	48.0	37.5	72.1	41.3	9.5	3.3	1.3	1.1	1.0	1.1
1937	1.5	2.6	4.0	20.4	102.4	50.1	27.7	12.3	4.4	2.8	2.6	2.1
1938	3.4	22.0	63.2	56.0	161.9	104.4	24.3	5.5	3.0	1.8	1.6	2.4
1939	3.4	12.2	38.0	40.6	41.3	43.3	24.4	32.0	28.8	8.7	2.7	1.9
1940	2.6	14.3	113.9	96.1	72.6	42.9	17.0	5.6	2.0	1.3	1.2	1.2
1941	1.8	2.2	3.5	29.5	130.5	114.1	57.8	15.8	4.4	2.1	1.9	2.1
1942	3.2	36.4	121.0	115.0	81.3	43.6	134.2	91.1	21.1	10.1	25.3	14.8
1943	50.6	128.9	116.2	69.0	60.0	53.6	24.1	4.2	1.9	1.7	1.3	2.4
1944	3.3	3.3	2.6	12.1	38.1	98.0	60.2	8.6	3.2	1.5	1.2	1.0
1945	1.4	1.5	2.0	4.2	7.3	24.7	19.1	7.5	2.4	1.3	1.0	1.0
1946	1.3	4.6	4.8	16.5	83.9	90.5	43.1	8.6	5.2	3.8	2.6	1.6
1947	2.0	13.4	50.0	72.4	69.7	65.1	40.5	8.8	3.9	1.5	1.1	1.1
1948	1.7	2.4	3.8	5.0	36.7	45.7	23.7	6.0	2.1	1.3	1.2	1.5
1949	2.0	6.9	9.9	25.9	57.2	106.0	67.1	17.4	4.7	3.0	2.8	2.4
1950	2.0	2.0	44.3	97.6	67.5	23.0	8.2	4.1	1.5	1.1	2.3	2.4
1951	3.3	2.5	4.5	53.8	83.1	39.9	14.7	8.0	4.0	2.4	1.9	1.7
1952	1.7	3.5	5.1	28.0	67.4	33.4	5.4	3.1	1.5	1.3	1.5	2.3
1953	3.3	5.2	34.9	54.1	84.9	57.7	18.4	8.0	4.7	2.9	1.5	1.9
1954	11.7	16.9	28.4	130.6	172.0	76.5	22.1	7.8	4.1	2.0	1.3	1.3
1955	1.5	1.9	6.5	15.8	105.6	133.3	59.8	7.3	2.4	1.4	1.3	1.5
1956	2.2	5.3	118.8	146.6	81.6	70.4	46.6	9.4	4.0	1.8	2.0	5.1
1957	42.1	32.6	36.0	69.3	85.6	38.1	24.3	10.0	4.1	1.5	1.2	1.4
1958	1.7	3.0	32.0	68.9	58.9	29.0	9.7	129.6	87.2	9.0	2.6	2.0
1959	2.1	5.6	24.8	18.8	27.4	40.9	33.7	11.8	4.3	1.6	1.3	1.5
1960	1.7	4.2	63.0	43.8	41.2	62.1	95.0	23.1	4.7	2.8	1.6	1.6
1961	1.5	3.0	5.4	45.4	77.9	53.0	17.7	7.2	3.0	1.7	1.6	2.0
1962	1.6	5.6	26.0	111.6	42.3	103.2	28.1	7.5	4.4	12.3	2.8	2.1
1963	3.1	42.7	52.4	95.9	39.4	25.1	8.7	5.3	4.9	3.6	2.4	2.4
1964	3.5	34.2	29.2	55.1	63.6	6.6	5.1	3.1	5.4	4.0	2.7	2.5
1965	7.2	24.1	9.8	79.3	84.2	7.2	4.9	4.3	2.8	1.9	1.6	2.1
1966	1.6	5.3	7.9	38.3	133.5	136.6	105.5	18.1	4.9	3.8	2.8	2.1
1967	1.6	10.3	18.8	17.3	16.5	35.3	27.4	5.3	2.9	2.1	2.2	1.9
1968	1.5	2.1	4.9	2.9	4.3	44.0	36.3	7.6	4.1	2.8	1.7	2.1
1969	4.8	4.9	38.2	33.4	58.8	10.3	4.2	2.7	1.7	1.8	2.8	2.4
1970	33.4	17.6	17.4	21.7	60.7	28.1	19.9	9.8	4.3	3.5	8.5	2.4
1971	9.9	19.5	54.1	94.2	124.6	118.3	29.2	8.6	4.5	3.1	2.4	1.7
1972	1.9	3.7	3.5	3.7	50.8	41.1	73.4	17.5	3.7	2.3	2.4	2.3
1973	3.4	14.0	24.7	137.4	209.6	140.6	71.8	18.5	6.2	3.8	2.7	2.0
1974	1.8	3.1	13.0	83.0	108.7	55.6	19.9	5.6	3.4	2.6	1.7	2.4
1975	2.5	3.2	64.1	196.7	242.6	249.9	85.5	17.9	5.9	5.0	3.1	2.3
1976	21.0	9.4	11.4	39.0	57.1	58.1	28.7	6.8	3.2	2.6	1.7	1.8
1977	2.7	2.7	3.7	63.1	59.9	51.8	35.9	8.9	4.3	2.9	2.0	2.3
1978	3.8	9.7	82.8	29.0	41.5	43.9	11.4	6.7	3.4	3.0	2.6	2.3
1979	2.1	2.2	3.0	9.0	33.5	39.2	5.4	3.1	1.8	1.5	1.3	2.4
1980	3.2	2.2	6.6	63.0	111.8	38.4	5.1	3.9	2.6	1.8	1.6	2.4
1981	1.9	2.3	3.6	4.2	4.3	45.5	11.4	4.0	2.7	1.8	1.5	1.5
1982	1.4	2.6	2.4	3.4	1.7	4.1	4.8	1.5	1.3	1.2	1.3	1.3
1983	1.9	3.9	10.7	52.6	20.7	56.8	47.6	6.8	3.9	2.8	1.8	1.8
1984	1.9	2.1	2.5	19.0	165.1	38.0	5.1	3.4	2.0	1.7	1.3	1.3
1985	3.0	21.1	84.2	70.7	45.6	39.5	9.4	5.1	3.0	2.0	1.6	2.2
1986	3.0	11.2	36.9	39.6	21.0	47.2	10.7	4.1	2.9	2.5	2.7	242.6
1987	210.7	125.5	38.5	32.1	171.0	215.3	54.1	8.6	4.7	5.6	2.7	2.3
1988	2.1	3.6	72.6	97.4	147.5	60.9	16.5	8.9	4.6	3.4	2.2	1.6
1989	1.5	65.1	92.3	29.3	24.5	54.1	52.0	7.4	3.8	2.8	2.2	2.4
1990	2.4	2.3	12.9	71.8	128.2	50.3	12.1	5.2	3.7	2.8	1.7	1.8
1991	3.4	4.7	23.2	29.7	21.5	13.9	4.9	1.9	1.4	1.2	1.1	1.2
1992	1.3	1.7	2.0	3.6	6.0	7.4	7.6	3.6	1.6	1.3	1.3	1.3
1993	3.4	4.6	16.7	102.1	114.1	34.1	5.8	3.9	2.2	2.2	2.4	1.7
1994	1.9	1.8	2.6	7.0	5.9	34.8	26.3	7.0	4.2	2.9	33.0	46.6
1995	24.7	5.4	185.3	199.9	170.0	104.5	26.0	7.9	4.3	34.8	9.3	2.4
1996	2.8	10.8	62.7	117.1	41.6	76.0	37.3	8.9	9.5	11.5	2.9	3.8
1997	3.3	39.1	66.5	63.7	120.6	62.1	23.2	7.3	4.2	2.9	2.4	2.0
1998	1.7	2.3	15.3	40.8	69.1	21.3	5.2	3.4	1.8	1.5	1.3	1.3
1999	2.9	3.1	77.6	144.1	78.4	141.2	71.1	18.9	4.8	3.4	2.4	2.4
2000	2.6	5.1	55.2	60.2	36.8	23.7	31.2	8.2	3.9	2.6	1.6	2.6
2001	3.6	62.9	62.0	44.2	46.0	34.4	5.7	4.0	4.3	6.3	5.4	2.5
2002	2.1	1.9	2.8	16.9	46.9	28.3	18.4	6.4	3.5	2.1	1.4	1.7
2003	1.5	2.2	3.3	11.7	52.3	44.2	8.8	3.7	1.8	2.0	2.3	2.2
2004	2.9	10.5	61.9	79.5	37.4	35.9	25.3	5.2	2.9	2.1	1.6	1.4
2005	1.5	1.8	1.9	6.7	54.2	52.6	23.3	9.0	4.1	2.8	2.5	2.3
2006	7.5	16.7	43.1	23.0	32.6	16.7	7.3	3.9	2.7	3.1	1.6	1.4
2007	3.3	22.3	23.7	46.2	37.3	39.7	26.4	8.7	4.3	2.8	1.6	1.6

2008	1.6	2.0	4.9	13.7	130.3	93.4	26.6	6.9	2.8	1.6	1.6	1.5

6.5 ABIOTIC COMPONENTS

6.5.1 Hydrology

Table 7.13 and Table 7.14 provide a summary of the changes in low flow and floods that have occurred under the different scenarios.

6.5.1.1 Low flows

Table 7.19 Summary of the change in low flow conditions to the Mkomazi Estuary under a range of flow scenarios

Percentile	Monthly flow (m^3/s)						
	Reference	Present	A	B & F	C	D	E
30%ile	*8.5*	*5.0*	*1.2*	*4.0*	*3.6*	*3.2*	*2.7*
20%ile	*6.3*	*3.1*	*1.0*	*3.0*	*2.7*	*2.3*	*2.1*
10%ile	*4.4*	*1.6*	*0.7*	*1.7*	*1.7*	*1.6*	*1.6*
% Similarity in low flows		*47.7*	*15.1*	*44.6*	*41.7*	*37.0*	*34.0*

Confidence: High

6.5.1.2 Flood regime

Table 7.20 Summary of the ten highest simulated monthly volumes to the Mkomazi Estuary under Reference Condition, Present State and a range of flow scenarios

Date	Monthly volume ($x10^6$ m^3/month)						
	Reference	Present	A	B & F	C	D	E
Sep 1987	*747.67*	*688.8*	*634.5*	*629.8*	*626.2*	*633.68*	*628.81*
Mar 1925	*704.19*	*681.1*	*666.0*	*670.7*	*670.0*	*670.2*	*669.22*
Mar 1976	*630.39*	*606.1*	*590.0*	*593.5*	*592.8*	*593.04*	*592.14*
Oct 1987	*620.40*	*591.0*	*573.3*	*578.1*	*577.4*	*577.6*	*576.62*
Feb 1985	*596.34*	*580.5*	*562.3*	*565.8*	*565.1*	*565.35*	*564.37*
Feb 1932	*582.99*	*550.0*	*532.8*	*536.8*	*536.1*	*536.34*	*535.35*
Mar 1988	*580.22*	*542.8*	*524.5*	*528.4*	*527.7*	*527.91*	*526.93*
Apr 1925	*560.76*	*511.8*	*495.6*	*481.5*	*491.4*	*490.24*	*496.43*
Apr 1943	*557.29*	*526.4*	*509.9*	*512.9*	*512.2*	*512.44*	*511.54*
Mar 1927	*468.49*	*436.0*	*420.1*	*421.1*	*420.5*	*420.69*	*419.79*
% Similarity in floods		**94.4**	**91.1**	**91.3**	**91.3**	**91.4**	**91.3**

Confidence: Medium

A summary of the hydrology scores is provided in Table 7.15.

Table 7.21 EHI scores for hydrology under different scenarios

Variable	Scenario Group						
	Present	A	B & F	C	D	E	Conf
a. Similarity in low flows	*48*	*15*	*45*	*42*	*37*	*34*	*M*
b. Similarity floods	*95*	*91*	*91*	*91*	*91*	*91*	*M*
Hydrology score	**66.8**	**45.4**	**63.4**	**61.6**	**58.6**	**56.8**	

6.5.2 Hydrodynamics and mouth condition

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

Present	
Scenario Group A to F	*Mouth closure did not occur the Reference Condition. At present mouth closure occur for about 1% of the time for relatively short periods. Mouth closure is not expected to occur for weeks at a time under Scenario Group B to F, but as flows do decrease below 2.0 m^3/s intermitted closures may occur for short periods (i.e 1- 2 weeks). Mouth closures for weeks to months at a time are a significant feature under Scenario Group A, with flow less than 1.0 m^3/s occurring for about 20% of the time.* *Note: Mouth closure is scored conservatively.*

Table 7.13 provides a summary of the hydrodynamics and mouth condition scores for the Mkomazi Estuary.

Table 7.22 EHI scores for hydrodynamics and mouth condition under different scenarios

Variable	Scenario Group							
	Present	A	B	C	D	E	F	Conf
Hydrodynamics and mouth conditions score	*95*	*75*	*95*	*95*	*95*	*95*	*95*	**M**

6.5.3 Water quality

Table 7.23. Occurrence of the abiotic states under the different scenario groups

Abiotic State	Reference	Present	Scenario Group				
			A	B & F	C	D	E
State 1: Closed mouth	*0*	*1*	*19*	*0*	*0*	*0*	*0*
State 2: Tidal with intermitted mouth closure	*1*	*13*	*27*	*14*	*14*	*16*	*18*
State 3: Tidal	*12*	*17*	*7*	*23*	*27*	*25*	*30*
State 4: Freshwater dominated	*87*	*70*	*47*	*64*	*59*	*59*	*52*

Table 7.24. 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	F
Lower	*0.4*	*4*	*9*	*14*	*11*	*12*	*12*	*13*	*11*
Middle	*0.3*	*3*	*6*	*11*	*7*	*7*	*8*	*9*	*7*
Upper	*0.2*	*1*	*3*	*7*	*3*	*3*	*3*	*4*	*3*
Upper (H)	*0.1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

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	F
Lower	*0.4*	*97*	*207*	*180*	*197*	*189*	*189*	*178*	*505*
Middle	*0.3*	*97*	*222*	*197*	*216*	*209*	*209*	*202*	*820*
Upper	*0.2*	*97*	*230*	*201*	*227*	*223*	*222*	*217*	*996*
Upper (H)	*0.1*	*97*	*237*	*224*	*234*	*230*	*230*	*226*	*1178*

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	F
Lower	*0.4*	*10*	*17*	*15*	*17*	*16*	*16*	*15*	*169*
Middle	*0.3*	*10*	*17*	*15*	*17*	*16*	*16*	*15*	*243*
Upper	*0.2*	*10*	*18*	*15*	*18*	*17*	*17*	*17*	*391*
Upper (H)	*0.1*	*10*	*18*	*15*	*18*	*17*	*17*	*17*	*475*

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	F
Lower	*0.4*	*175*	*143*	*99*	*132*	*122*	*122*	*109*	*132*
Middle	*0.3*	*175*	*143*	*99*	*132*	*122*	*122*	*109*	*132*
Upper	*0.2*	*175*	*143*	*99*	*132*	*122*	*122*	*109*	*132*
Upper (H)	*0.1*	*175*	*143*	*99*	*132*	*122*	*122*	*109*	*132*

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	F
Lower	*0.4*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*
Middle	*0.3*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*
Upper	*0.2*	*6*	*6*	*5*	*6*	*6*	*6*	*6*	*6*
Upper (H)	*0.1*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*

Table 7.25 Summary of water quality changes under different scenarios

Parameter	Summary Of Changes
Changes in longitudinal salinity gradient and vertical stratification	*⇧ due to increase in low flow States 1 and 2*
Inorganic nutrients in estuary	*⇧ due to nutrient enrichment in catchment. Nutrient slightly improve in upper reaches in Future Scenarios as a result of reduction in high flows (State 4) compared with Present State* *⇧⇧ for Scenario B+WWTW as a result of WWTW input at General Limits (0.24 m^3/s)*
Turbidity in estuary	*⇩ due to reduction in high flow state (State 4)*
Dissolved oxygen in estuary	*No marked changes, remains well flushed*
Toxic substances in estuary	*⇧ industrial and urban inputs* *⇧⇧more for Scenario F which include WWTW effluent*

Table 7.26 EHI scores for water quality under different scenarios

Variable		Scenario Group							
		Present	A	B	C	D	E	F	Conf
1	**Salinity**								
	Similarity in salinity	*66*	*45*	*61*	*59*	*58*	*54*	*61*	*M*
2	**General water quality in the estuary**								
A	*N and P concentrations*	*67*	*74*	*69*	*70*	*70*	*72*	*16*	*M/l*
B	*Turbidity*	*90*	*72*	*86*	*82*	*82*	*77*	*77*	*M/L*
C	*Dissolved oxygen*	*99*	*98*	*99*	*100*	*99*	*99*	*99*	*M/L*
D	*Toxic substances*	*75*	*75*	*75*	*75*	*75*	*75*	*60*	*L*
	Water quality score								

* $Score = \frac{0.6*S+0.4*(\min(a\ to\ d)+mean(a\ to\ d))}{2}$

6.5.4 Physical habitats

Table 7.27 Summary of physical habitat changes under different scenarios

Parameter		Scenario Group
1a	*% Similarity in intertidal area exposed*	*Sedimentation processes under Scenario Group A to E are similar to the Present State, with some loss of intertidal habitat due deposition and infilling of the intertidal habitat. There is also a loss of intertidal area above the Sappi Weir.* *Under Scenario A, State 2 increases by 20% reducing exposed intertidal habitat 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 to D. 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, There is also a loss of intertidal area above the Sappi Weir.* *Under the future Scenarios resetting events have been somewhat reduced and infilling is maintaining a more constricted equilibrium state.*

Table 7.28 EHI scores for physical habitat under different scenarios

Variable	Scenario Group							
	Present	A	B	C	D	E	F	Conf
1a. Intertidal areas and sediments	70	50	70	70	70	70	70	*M*
1b.Similarity in sand fraction	80	80	80	80	80	80	80	*M*
2. Subtidal area and sediments	80	75	75	75	75	75	75	*M*
Physical habitat score	78	70	75	75	75	75	75	**M**

6.6 BIOTIC COMPONENT

6.6.1 Microalgae

Table 7.29 Summary of change in microalgae component under different scenarios

Scenario	Summary of Changes
A	*Under this scenario the open water area is increased which will allow more volume in which the microalgae can proliferate. At the same time there is some nutrient enrichment which will result in an increase in both phytoplankton and MPB biomass. This compensates for the loss of intertidal sand and mudflats. There is a big loss of area in reed and swamp vegetation which will have an overall negative effect. The changes in area of forest, mangroves floodplain are not relevant to the microalgae scores. Only small changes in salinity appear and these to levels that will be unlikely to adversely affect microalgae*
B to E	*The changes in these scenarios are so similar to those in A that the end condition is likely to produce a similar effect*
F	*Species richness is expected to increase with increased nutrient loading. Abundance/biomass will increase due to high nutrient loading, but as there is not a significant increase in retention this will be capped during the high flow season. There would eb a shift in community composition to blue-green species as a result of the high nutrients.*

Table 7.30 EHI scores for microalgae component under different scenarios

Variable	Scenario Group							
	Present	A	B	C	D	E	F	CONF
1. Species richness	*95*	*90*	*95*	*95*	*95*	*95*	*80*	*M*
2 Abundance	*90*	*75*	*90*	*90*	*90*	*90*	*60*	*M*
3. Community composition	*95*	*90*	*95*	*95*	*95*	*95*	*60*	*M*
Biotic component score	*90*	*75*	*90*	*90*	*90*	*90*	*60*	*M*

6.6.2 Macrophytes

Table 7.31 Summary of change in macrophyte component under different scenarios

Scenario	Summary of Changes
A	*Worst case scenario where drastically reduced base flow causes the mouth to close. This will result in an increase in open water area thereby reducing area for reeds and sedges to occupy. Higher salinity will reduce reed and sedge growth. Salinity at times will be 30 in Zone A, 20 in Zone B and 10 in Zone C. Reeds, sedges and swamp forest grow best at salinity less than 15. Saline conditions would encourage the growth and expansion of mangroves, with a possible increase from 1 to 2 ha. Some change (15 % lower than present) in species and community composition in response to salinity change expected. The decline in open fresh state (State 4), which was dominant under natural conditions would impact the offshore marine habitats.*
B	*Lower and middle reaches slightly more saline than under present conditions. Some change (5 % lower than present) in species and community composition in response to salinity change expected. Monthly flows 3 % lower than present condition which may increase reed habitat.*

C & D	*Lower and middle reaches more saline. Some change (10 % lower than present) in species and community composition in response to salinity change expected. Reduced base flows and decreased flooding events will lead to infilling of the estuary, creating more habitat for colonisation by reeds and sedges.*
E	*Increased salinity in the lower and middle reaches of the estuary. Some change (10 % lower than present) in species and community composition in response to salinity change expected. Reduced base flows and decreased flooding events will lead to infilling of the estuary, creating more habitat for colonisation by reeds, sedges and grasses.*
F	*Scenario B plus 0.24 $m^3 s^{-1}$ of wastewater input. This causes a significant increase in nutrients and together with low flow will result in a eutrophic estuary particularly during closed mouth conditions. Invasive aquatic plants will increase in abundance and all macrophytes will grow and expand in open sand and mudflat areas. Macroalgal blooms are expected on exposed sand and mudflats.*
Significant negative changes in macrophytes occur in Scenario A due to an increase in salinity and Scenario F due to an increase in nutrients. There is a decrease in low flow conditions for all scenarios and therefore an increase in reed and sedge habitat due to more stable conditions. This replaces some of this habitat lost due to historical disturbance and therefore changes in the scores between scenarios are not large.	

Table 7.6 EHI scores for macrophyte component under different scenarios

Variable	Scenario Group							
	Present	**A**	**B**	**C**	**D**	**E**	**F**	**CONF**
1. Species richness	*80*	*65*	*75*	*70*	*70*	*75*	*60*	*M*
2 Abundance	*21*	*20*	*26*	*31*	*33*	*34*	*15*	*M*
3. Community composition	*51*	*47*	*52*	*54*	*55*	*55*	*45*	*M*
Biotic component score	*21*	*20*	*26*	*31*	*33*	*34*	*15*	*M*

6.6.3 Invertebrates

Table 7.32 Summary of change in invertebrates component under different scenarios

Scenario	Summary of Changes
A	*Increase in mouth closure, especially during winter. Reduced river flows, higher water retention and increased zooplankton and benthic invertebrate community diversity and abundance. Loss of intertidal habitat and intertidal microphytobenthos reduces food availability for some species. Overall numbers of species don't change but total abundance likely to be very reduced, and community composition changes markedly.*
B C D E	*Very similar to present for both species diversity, composition and abundance* *Reduced flows result in an increase of States 2 and 3 and decrease in the dominant (under natural) State 4. Changes in the middle reaches and particularly zone C influence the overall invertebrate community standing stock. Reduction in*
F	*Treated wastewater inputs will increase nutrient levels in the estuary. This will impact the trophic status, and cause low dissolved oxygen concentrations particularly in the middle to upper reaches. The most important benthic productivity area in the estuary is likely to be the most impacted by degraded water quality. This has influences species composition, carry capacity and the relative proportions of species within the system.*

Table 7.33 EHI scores for invertebrates component under different scenarios

Variable	Scenario Group							
	Present	A	B	C	D	E	F	CONF
1. Species richness	*95*	*95*	*95*	*95*	*95*	*95*	*65*	
2. Abundance	*75*	*60*	*75*	*75*	*75*	*75*	*50*	
3. Community composition	*80*	*60*	*75*	*75*	*70*	*70*	*60*	
Biotic component score	**75**	**60**	**75**	**75**	**70**	**70**	**50**	

6.6.4 Fish

Table 7.34 Summary of change in fish component under different scenarios

Scenario	Summary of Changes
A	*Flow reductions cause a significant increase in mouth closure, especially in late winter and early spring. This impacts recruitment of many of the main (and important) estuarine dependent marine fishes. Increased occurrence on State 1 and State 2 might results in depressed oxygen concentrations in Zone C of the estuary, an important nursery area for estuarine dependent marine species. Most of these species will undergo population reductions despite salinities in the estuary being conducive to the use of the whole system. Reduced river flows, higher water retention and increased zooplankton productivity will benefit the estuarine resident component of the fish assemblage. Detritivores are also likely to benefit from lower flows and increased detrital productivity. Loss of intertidal habitat and intertidal microphytobenthos reduces food availability for some mullet species. Overall numbers of species and total fish abundance is likely to be reduced, and community composition changes markedly.*
B	*Flow and habitat changes are unlikely to result in fish assemblages that are different to those under present day conditions.*
C	*Flow and habitat changes are unlikely to result in fish assemblages that are different to those under present day conditions.*
D	*Flow and habitat changes are unlikely to result in fish assemblages that are different to those under present day conditions.*
E	*Increased occurrence of States 2 and 3 occur at the expense of State 4 occurrence. A consequence of this is an increased occurrence of reduced oxygen levels in the lower sections of Zone C of the estuary/ Given the importance of this area for the estuary's fish fauna losses in fish abundance can be expected. Reduced base flows and flooding events will also lead to some infilling of the estuary and consequent loss of fish habitat, causing further loses in fish abundance in the system. Overall numbers of species and total fish abundance is likely to be reduced, and community composition changes.*
F	*Treated wastewater inputs will result in marked changed in nutrient levels in the estuary and a changed trophic base and status, with mullet in particular benefitting. Significant negative consequences also occur. Wastewater nutrients cause depressed oxygen concentrations in Zone C of the system. The most important nursery area in the estuary is likely to be the most impacted by degraded water quality. This will result in losses of some fish species from the estuary as well as losses in fish abundance and an impacted species composition.*

Table 7.35 EHI scores for fish component under different scenarios

Variable	Scenario Group							
	Present	A	B	C	D	E	F	CONF
1. Species richness	*95*	*55*	*95*	*95*	*95*	*85*	*80*	*M*
2. Abundance	*60*	*35*	*60*	*60*	*60*	*55*	*50*	*M*
3. Community composition	*75*	*40*	*75*	*75*	*75*	*75*	*70*	*M*
Biotic component score	**60**	**35**	**60**	**60**	**60**	**55**	**50**	**M**

6.6.5 Birds

Table 7.36 Summary of change in bird component under different scenarios

Scenario	Summary of Changes

A	*This scenario and scenario F are considered to take the system the furthest from reference (and present) state. Mouth closure would increase, with increased back-flooding (which was observed during this study to have positive impacts on the aquatic avifauna). There would be increased salinity in the estuary and the possibility of enhanced development of inter-tidal sandbanks and mudflats to the possible advantage of small invertebrate-feeding waders. Back-flooding and increased salinity would have a negative impact on macrophytes but this would likely have little impact on waterbirds. Low flows would be to the detriment of swimming piscivores, a major component of the relatively impoverished waterbird avifauna, during open-mouth conditions but would be to their benefit during closed-mouth, deeper-water conditions.*
B, C, D & E	*These four scenarios were considered likely to have similar impacts on the waterbird community and only relatively slightly further away from reference than the present state. Expected changes would include reduced base flows (and hence increased mouth closures) and flooding events, increased siltation, salinity and macrophyte growth.*
F	*Reduced base flows and Increased eutrophication through greater waste-water input resulting in spread of macrophytes, including alien species.*

Table 7.37 EHI scores for bird component under different scenarios

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

6.7 ECOLOGICAL CATEGORIES ASSOCIATED WITH SCENARIOS

The REC represents the level of protection assigned to an estuary. The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of importance and level of protection or desired protection of a particular estuary. The PES for the Mkomazi Estuary is a C, but the Estuary is rated as "Very Important" from a biodiversity perspective and should therefore be in a B Category.

In addition, the system also forms part of the core set of priority estuaries in need of protection to achieve biodiversity targets in the National Estuaries Biodiversity Plan for the National Biodiversity Assessment (Turpie et al.,2013). The NBA 2011 (Van Niekerk and Turpie 2012) recommends that the minimum Category for the Mkomazi be a B, that it be a granted full no-take protection, and that 25 % of the estuary margin be undeveloped.

Taking the current conditions (PES=C), the reversibility of the impacts, the ecological impotence and the conservation requirements of the Mkomazi Estuary the REC for the system is a B Category.

Ecological Categories associated with scenarios

The individual EHI scores, as well as the corresponding ecological category under different scenarios are provided below. The estuary is currently in a C Category. Under Scenario Group B (MK21 and 42) and Group C (MK22,23,43) the Mkomazi Estuary will decline slightly in health, as a result of more closed mouth conditions, but is expected to remain in a C Category. While, under Scenario Group A (MK2,4), D (MK31) and E (MK32,33) the estuary will deteriorate further in health by about 14%, 8% and 9% respectively as a result of increase closed mouth conditions.

To test the sensitivity of the estuary to the increased nutrient load associated with a 20 ML/d Waste Water Treatment Works, Scenario Group B was evaluated in more detail. Under this scenario, the

Mkomazi Estuary decline in health by 13%. Similar responses are expected for any of the future scenarios with this high level of nutrient input. (It should be noted that this is a low confidence assessment as no numerical modelling was done to test the tidal effects on a lateral discharges or the effect of entrainment).

Table 7.38 EHI score and corresponding Ecological Categories under the different runoff scenarios

Variable	Weight	Scenario Group									Confidence
		Pres	A (MK2,4)	B (21,42)	C (22,23,43)	D (31)	E (32,33)	F 21,42, + WWTW	G 21, 42 –Ant but +weir	H 21, 42 – Anth & Weir	
Hydrology	*25*	*66.8*	**45**	*63*	*62*	*59*	*57*	*63*	**63**	*63*	*VL*
Hydrodynamics and mouth condition	*25*	*95*	**75**	*95*	*95*	*38*	*38*	*95*	**95**	*97*	*L*
Water quality	*25*	*66.6*	**61**	*66*	*67*	*66*	*67*	*34*	**66**	*66*	*L*
Physical habitat alteration	*25*	*78*	**70**	*75*	*75*	*75*	*75*	*75*	**84**	*90*	*L*
Habitat health score		**76**	**63**	**75**	**75**	**60**	**59**	**67**	**77**	**79**	
Microalgae	*20*	*80*	**65**	*80*	*80*	*80*	*80*	*50*	**80**	*90*	*M*
Macrophytes	*20*	*21*	**20**	*26*	*31*	*33*	*34*	*15*	**46**	*46*	*M*
Invertebrates	*20*	*75*	**60**	*75*	*75*	*70*	*70*	*50*	**85**	*90*	*M*
Fish	*20*	*60*	**35**	*60*	*60*	*60*	*55*	*50*	**70**	*75*	*M*
Birds	*20*	*60*	**50**	*55*	*55*	*55*	*55*	*50*	**57**	*65*	*M*
Biotic health score		**59**	**46**	**59**	**60**	**60**	**59**	**43**	**68**	**73**	*M*
ESTUARY HEALTH SCORE		**68**	**54**	**67**	**67**	**60**	**59**	**55**	**72**	**76**	**M**
ECOLOGICAL STATUS		**C**	**D**	**C**	**C**	**D**	**D**	**D**	**B/C**	**B**	

For the Mkomazi Estuary, none of the scenarios achieved the REC of a B Category. Therefore Scenario H (Group B (MK 21 and MK 42) in conjunction with a number of management interventions) is the recommended ecological flow scenario. Scenario Group C (MK22, 23 and 43) will also achieve the REC. The following management interventions are required to achieve the Mkomasi REC:

- *Remove sandmining from the upper reaches below the Sappi Weir to increase natural function , i.e. restore intertidal area;*
- *Restoration of vegetation upper reaches and along the northern bank, e.g. remove aliens and allow disturbed land to revert to natural land cover (is already on upwards trajectory);*
- *Curb recreational activities in the lower reaches through zonation and improve compliance;*
- *Reduce/remove castnetting in the mouth area through estuary zonation or increase compliance; and*
- *Relocate upstream, or remove, the Sappi Weir to restore upper 15% of the estuary.*

7 RECOMMENDATIONS

7.1 ECOLOGICAL FLOW REQUIREMENTS

The **'recommended Ecological Flow Requirement' scenario,** *is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the recommended Ecological Category.*

Where any component of the health score is less than 40, then modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. The REC for the Mkomazi Estuary should be a Category B

The flow requirements for the estuary are the same as those described for Group B (MK 21 and MK 42) *and are summarised in Table 8—1*

Table 8.1 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	198.0	129.1	174.9	200.2	240.4	247.5	132.3	126.9	82.9	32.4	32.3	226.7
99	78.4	126.7	131.5	197.8	215.7	221.7	110.9	98.2	39.5	22.3	27.0	79.9
90	12.3	32.9	77.8	112.8	133.2	106.1	60.6	18.0	7.2	7.8	4.5	4.1
80	9.5	21.0	55.6	80.7	105.1	76.8	42.1	11.6	6.2	4.7	3.9	3.8
70	8.0	17.8	39.2	68.0	81.9	58.3	28.7	10.6	5.6	4.0	3.4	3.5
60	6.8	14.3	27.1	52.3	69.3	52.0	25.7	9.5	5.1	3.6	3.0	3.1
50	5.7	12.5	20.2	39.9	60.0	44.0	24.1	8.5	4.7	3.0	2.3	2.5
40	4.6	10.5	16.3	29.6	46.7	40.3	19.0	7.1	3.8	2.5	1.7	2.0
30	3.8	8.2	12.0	22.0	41.6	36.4	12.7	5.8	3.1	1.9	1.5	1.7
20	2.8	5.6	8.2	13.9	32.9	28.8	10.0	4.5	2.2	1.5	1.4	1.5
10	1.6	3.1	3.8	8.1	19.6	21.3	6.6	3.5	1.8	1.3	1.3	1.3
1	1.3	1.6	1.9	3.3	4.5	7.9	5.2	2.0	1.4	1.2	1.2	1.2
0.1	1.3	1.6	1.9	2.9	2.1	6.5	4.7	1.6	1.3	1.2	1.2	1.2

7.2 RESOURCE QUALITY OBJECTIVES

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 Mkomazi Estuary, as outlined in Table 8.1 and Table 8.2, are set for the PES and Recommended Ecological Category B

Table 8.2 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 B (i.e. approved flow scenario for the Mkomazi).* • *Monthly river inflow < 1.0 m3/s* • *Monthly river inflow < 2.0 m3/s persists for longer than 3 months in a row* • *Monthly river inflow < 5.0 m3/s for more than 30% 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 September and April*	*Flow reduction*
Water Quality	*Salinity distribution not to cause exceedence of TPCs for fish, invertebrates, macrophytes and microalgae (see above)*	• *0 in the upper reaches (End of Zone C and beginning of Zone D) of the estuary.* • *Salinity values > 20 ppt in middle reaches (above the N2 bridge) during the low flow season* • *Freshwater dominated for 70% of the time*	*Flow reduction*
	System variables (pH, dissolved oxygen and turbidity) not to cause exceedence of TPCs for biota (see above)	*River inflow:* • *7.5 < pH > 8.5 consistently over 2 months* • *DO <6 mg/ℓ* • *Turbidity >15NTU (low flow)* • *Turbidity high flows naturally turbid* *Estuary:* • *Average turbidity >10 NTU (low flow)* • *Turbidity high flow, naturally turbid* • *7.0 < pH > 8.5 in a sampling survey* • *Average DO <6 mg/ℓ in a sampling survey*	• *Agricultural return flow* • *Erosion of agricultural land* • *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 (flows < $5m^3/s$):* • *NO_x-N >150 µg/ℓ over 2 months* • *NH_3-N> 20 µg/ℓ over 2 months* • *PO_4-P > 10 µg/ℓ over 2 months* *River inflow (flows > $5m^3/s$):* • *Average DIN > 200 µg/ℓ* • *Average DIP > 20 µg/ℓ* *Estuary (river flows < $5m^3/s$):* • *Average NO_x-N > 150 µg/ℓ in a sampling survey* • *Average NH_3-N > 20 µg/ℓ in a sampling survey* • *Average PO_4-P > 10 µg/ℓ in a sampling survey* *Estuary (river flows > $5m^3/s$):* • *Average NO_x-N > 300 µg/ℓ in a sampling survey* • *Average NH_3-N > 20 µg/ℓ in a sampling survey* • *Average PO_4-P > 20 µg/ℓ in a sampling survey*	• *Agricultural return flow (nutrients)* • *Municipal wastewater (nutrients)*

Abiotic Component	Ecological Specification	Threshold of Potential Concern	CAUSES
	Presence of toxic substances not to cause exceedence of TPCs for biota (see above)	*River inflow:* • *Trace metals (to be determined)* • *Pesticides/herbicides (to be determined)* *Estuary:* • *Total metal concentrations in estuary waters exceed target values as per SA Water Quality Guidelines for coastal marine waters (DWAF, 1995* • *Total metal concentration in sediment exceeds target values as per WIO Region guidelines (UNEP/Nairobi Convention Secretariat and CSIR, 2009)*	• *Agricultural return flow (e.g. pesticides/herbicides)* • *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).* • *Intertidal and subtidal habitat in Zone C and D are not available for estuarine species (increase by > 20% from present).*	• *Reduced floods* • *Sandmining*
	Changes in sediment grain size distribution patterns not to cause exceedance of TPCs in benthic invertebrates (see above).	• *The median bed sediment diameter deviates by more than a factor of two from levels to be determined as part of baseline studies (Present State 2013).* • *Sand/mud distribution in middle and upper reaches change by more than 20% from Present State (2013).* • *Changes in tidal amplitude at the tidal gauge of more than 20% from Present State (2013)*	• *Reduced floods* • *Sandmining*

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

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
Microalgae	*Maintain current microalgae assemblages, specifically >5 diatom species at a frequency >3% of the total population in saline reaches (i.e. Zone A in low flow)*	• *Medium phytoplankton: > 5µg l-1 for more than 50% of the stations* • *MPB: > 30mg m2 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*

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
Macrophytes	• *Maintain the distribution of macrophyte habitats.* • *Maintain the integrity of the riparian zone particulary in Zone and D where the sandmining no longer occurs* • *No invasive floating aquatic species present in the estuary e.g. water hyacinth.* • *No sugarcane in the EFZ (estuarine functional zone).*	• *Greater than 10 % change in the area covered by different macrophyte habitats.* • *Invasive plants (e.g. syringa berry, Spanish reed, black wattle, Brazilian pepper tree) largely absent from the riparian zone.* • *Die-back of reeds & sedges in the lower reaches.* • *Unvegetated, cleared areas along the banks.* • *Floating invasive aquatics observed in the upper estuary reaches.* • *Sugarcane is present in the estuarine functional zone.*	• *Reduced flow, sedimentation, infilling and spread of reeds, sedges, grasses.* • *Increase in salinity to greater than 20 for 3 months* • *Disturbance* • *Increase in nutrients and possible eutrophication.*
Invertebrates	• *Maintain current levels of zoobenthic abundance (including seasonal variation)* • *Retain an invertebrate community assemblage in the estuary based on species diversity and abundance that includes a variety of indigenous* • *Species diversity (between 15 species in summer - 40 species in winter).* • *Polychaetes, amphipods and tanaeids should numerically dominate during all seasons. However, abundance of all taxon groups should be higher during summer high flow periods and lower during winter low flow period.*	• *Salinities should be <15 in* • *DO's should not drop below 4 ppt in >25% of the estuary* • *Sediment distribution* • *Greater than 20% change in the intertidal and subtidal habitats* • *Occurrence of invertebrate alien species (e.g. Tarebia granifera)* • *Decrease in abundance of zooplankton by >20% in terms of numbers per m-2 over entire estuarine area (3 sample sites) over 3 years* • *Decrease in abundance of benthic macroinvertebrates* • *No occurrence of Paratylodiplax blephariskios in annual sample*	• *Nutrient enrichment* • *Loss of baseflows* • *Mouth closure*
Fish	• *Zone C in its entirety acts as a nursery to a diversity of EDC2 species (EDC2a especially).* • *A good trophic basis exists for predatory estuarine dependant marine species (e.g. Agyrosomus japonicus, Carynx spp.).* • *Estuarine residents species represented by core group (Glossogobius spp., Oligolepis spp. Ambassis spp. and Gilchistella aestuaria). Zone D is used by these species as well.* • *Oreochromis mossambicus limited to the upper reaches of Zone C in the low flow period.* • *Species assemblage comprises indigenous species only.* • *Connectivity to a healthy transitional marine-estuary waters is maintained. Connectivity down the full length of the*	• *An abundance (to be defined as an average with prediction limits) of EDC2a species as young juveniles in spring and early summer (Solea bleekeri, Acanthopagrus vagus, Ponmadasys comerssonnii, Rhabdosargus holubi).* • *Mullet occur throughout the system represented by a full array of size classes.* • *Any one of these species does not occur in the estuary in two consecutive years (to include occurrence in Zone D).* • *Oreochromis mossambicus distribution extend into Zone B for more than two consecutive years* • *Alien fish species occur* • *A decline in nearshore linefsh catches (Agyrosomus japonicus) (not related to gear changes or bag limit restrictions). Estuarine species occur in Zone D.*	• *Hydrological (flow and mouth condition related) and habitat (sediment dynamics) changes. Sand mining impacts* • *Water quality changes (toxic impacts, persistent low oxygen levels (< 4 mg/L) or intermittent fish kills (* • *Changes salinity gradients resulting from flow and/or mouth condition changes* • *Water quality impacts, primarily changes in salinity gradient and mouth closure* • *Translocations (IBT) and poor water quality (often coincident with higher nutrient levels, eutrophication)* • *Loss of trophic bases (prey*

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
	historic estuary and into the marine enviornemnt is restored.		*fish), loss of transitional marine-estuary waters. Loss of connectivity with upper estuary (tidal freshwaters)*
Birds	*The most characteristic component of the avifaunal waterbird community is the piscivores and it is this group that would be the most valuable for monitoring*	• *Resident pair of African Fish Eagle disappears or fails to breed successfully* • *Pied Kingfishers, White-breasted Cormorants or Reed Cormorants fail to be recorded on more than three consecutive counts spanning a period of 18 months or more* • *Numbers of waterbird species drop below 10 for 2 consecutive counts*	*Decrease in food availability – fish*

7.3 MONITORING REQUIREMENTS

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

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

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

- ***Baseline surveys (or studies)**, the purpose of which is to collect data and information to characterize and understand the ecosystem functioning of a specific system. The baseline studies that are carried out for an Ecological Reserve determination study at Comprehensive level may be considered as the baseline data against which the long-term monitoring is carried out on estuaries. If less than the recommended baseline studies for a comprehensive assessment was carried out, due to the Ecological Reserve study being carried out at a rapid or intermediate level as was the case for the Great Brak Estuary, additional 'baseline' work will definitely be required to produce sufficient baseline data against which future long-term monitoring can take place.*

- ***Long-term (or compliance) monitoring programmes** to assess (or audit) whether the management objectives are being achieved. The purpose of long-term monitoring programmes, in this context, is to assess (or audit) whether the Ecological Specifications (defined as part of the Ecological Reserve determination process) are being complied with after implementation of the Reserve. In addition, these programmes can also be used to improve and refine the Ecological Reserve measures (including the Resource Quality Objectives), in the longer-term through an iterative process (Taljaard et al., 2003). Although baseline studies and long-term monitoring programmes have different purposes, it is extremely important that long-term monitoring programmes follow on from similarly structured baseline studies. In essence, the monitoring activities selected for the long-term monitoring programme should be derived from the monitoring activities conducted as part of the baseline studies, but implemented on less intensive spatial and/or temporal scales (Taljaard et al., 2003).*

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

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

- *River inflow (i.e. flow gauging);*
- *Continuous water level recording at the estuary mouth (recording the state of the mouth, a*

key driver for most biotic components);

- *Water quality of river inflow;*
- *Water quality and flow rate of effluent discharges into the estuary; and*
- *Salinity distribution patterns under different river flow ranges.*

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

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

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

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

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

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

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

- *Biotic indicators should include economic important indicators where relevant.*

Recommended minimum monitoring requirements to ascertain impacts of changes in freshwater flow to the estuary and any improvement or reductions therein are listed in below.

Table 8.4 Recommended baseline monitoring requirements

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Hydrodynamics	*Record water levels*	*Continuous*	*At bridge*
	Measure freshwater inflow into the estuary	*Continuous*	*Above the estuary*
	Aerial photographs of estuary (spring low tide)	*Every 3 years*	*Entire estuary*
Sediment dynamics	• *Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detailed in the mouth (every 100m). The vertical accuracy should be about 5 cm.*	*Every 3 years*	*Entire estuary*
	• *Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)*	*Every 3 years (with invert sampling)*	*Entire estuary (6 stns)*

Water quality	*Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary, where considered an issue (must also include sediment grain size analysis of samples).*	*Every 3-6 years*	*Focus on sheltered, depositional areas*
Microalgae	• *Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae* • *Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. HPLC* • *Intertidal and subtidal benthic chlorophyll-a measurements*	*Monthly sampling for 2 years (seasonal trends)*	*Entire estuary (5 stns)*
Invertebrates	• *Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary;* • *Record benthic invertebrate species and abundance, based on subtidal and intertidal core samples at a series of stations up the estuary, and counts of hole densities;* • *Measures of sediment characteristics at each station*	*Summer and winter survey for 3 years*	*Entire estuary (6 stns) if weir is removed add upper station*
Fish	*Record species and abundance of fish, based on seine net and gill net sampling. The data will establish Zone specific baselines and provide a measure of natural variability. They should be based on replicate sampling of stations and wet and dry seasons.*	*Late spring, summer and two winter survey every year for 3 years*	*Entire estuary (9 stns) (increase to 12 to include Zone D)*
Birds	*Undertake counts of all water associated birds, identified to species level.*	*A series of monthly counts for a yea,*	*Entire estuary (3 sections)*

Table 8.5 Recommended long term monitoring requirements

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Hydrodynamics	*Record water levels*	*Continuous*	*At bridge*
	Measure freshwater inflow into the estuary	*Continuous*	*Above the estuary*
	Aerial photographs of estuary (spring low tide)	*Every 3 years*	*Entire estuary*
Sediment dynamics	*Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detailed in the mouth (every 100m). The vertical accuracy should be about 5 cm.*	*Every 3 years*	*Entire estuary*
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	*Every 3 years (with invert sampling)*	*Entire estuary (6 stns)*
Water quality	*Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary*	*Monthly continuous*	*DWA WQ monitoring station(U1H006)*
	Longitudinal salinity and temperature profiles ((and any other in situ measurements possible e.g. pH, DO, turbidity) collected during high and low tide at: • *end of low flow season (i.e. period of maximum seawater intrusion/closed mouth)* • *peak of high flow season (i.e. period of maximum flushing by river water)*	*Seasonally every year*	*Entire estuary (9 stations)*
	Water quality parameters (i.e. system variables, and inorganic nutrients) taken along the length of the estuary (at least surface and bottom samples)	*Coinciding with biotic surveys or when significant change in quality expected*	*Entire estuary (9 stations)*

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
	Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary, where considered an issue (must also include sediment grain size analysis of samples).	*Every 3-6 years*	*Focus on sheltered, depositional areas*
Microalgae	• *Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae* • *Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. HPLC, fluoroprobe* • *Intertidal and subtidal benthic chlorophyll-a measurements,*	*Summer and winter survey every 3 years*	*Entire estuary (5 stns)*
Macrophytes	• *Map the area covered by the different macrophyte habitats during a field survey.* • *Compile a species list and check for expansion of invasive plants, reed, sedge and grass areas.*	*Summer survey every 3 years*	*Entire estuary*
Invertebrates	• *Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary;* • *Record benthic invertebrate species and abundance, based on subtidal and intertidal core samples at a series of stations up the estuary, and counts of hole densities;* • *Measures of sediment characteristics at each station*	*Winter/low flow survey every year.*	*Entire estuary (6 stns) include extra upper station if weir removed*
Fish	*Record species and abundance of fish, based on seine net and gill net sampling.*	*Late spring/ summer and winter survey every year. Repeated within season if any ecospecification is not met.*	*Entire estuary (9 stns) (increase to 12 to include Zone D)*
Birds	*Undertake counts of all water associated birds, identified to species level.*	*Winter and summer surveys every year (CWAC)*	*Entire estuary*

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