P WMA 12/T30/00/5212/7

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

DIRECTORATE: OPTIONS ANALYSIS

FEASIBILITY STUDY FOR THE MZIMVUBU WATER PROJECT

RESERVE DETERMINATION

VOLUME 2: ESTUARY

OCTOBER 2014

FEASIBILITY STUDY FOR THE MZIMVUBU WATER PROJECT

APPROVAL

Report title:	***Reserve Determination: Volume 2: Estuary***
Authors:	N.T. Forbes, J.B. Adams, A.T. Forbes, C.M. McLean, B. McKelvey, G. Snow, S. Taljaard, A. Theron, J.K. Turpie & L van Niekerk
Project name:	***Feasibility Study for the Mzimvubu Water Project***
DWS Report Number:	*P WMA 12/T30/00/5212/7*
PSP project reference number:	*002819*
Status of report:	*Final*
First Issue:	*December 2013*
Final issue:	*October 2014*

CONSULTANTS: JEFFARES & GREEN
Approved for Consultants:

S Johnson
Deputy Study Leader

A Pepperell
Study Leader

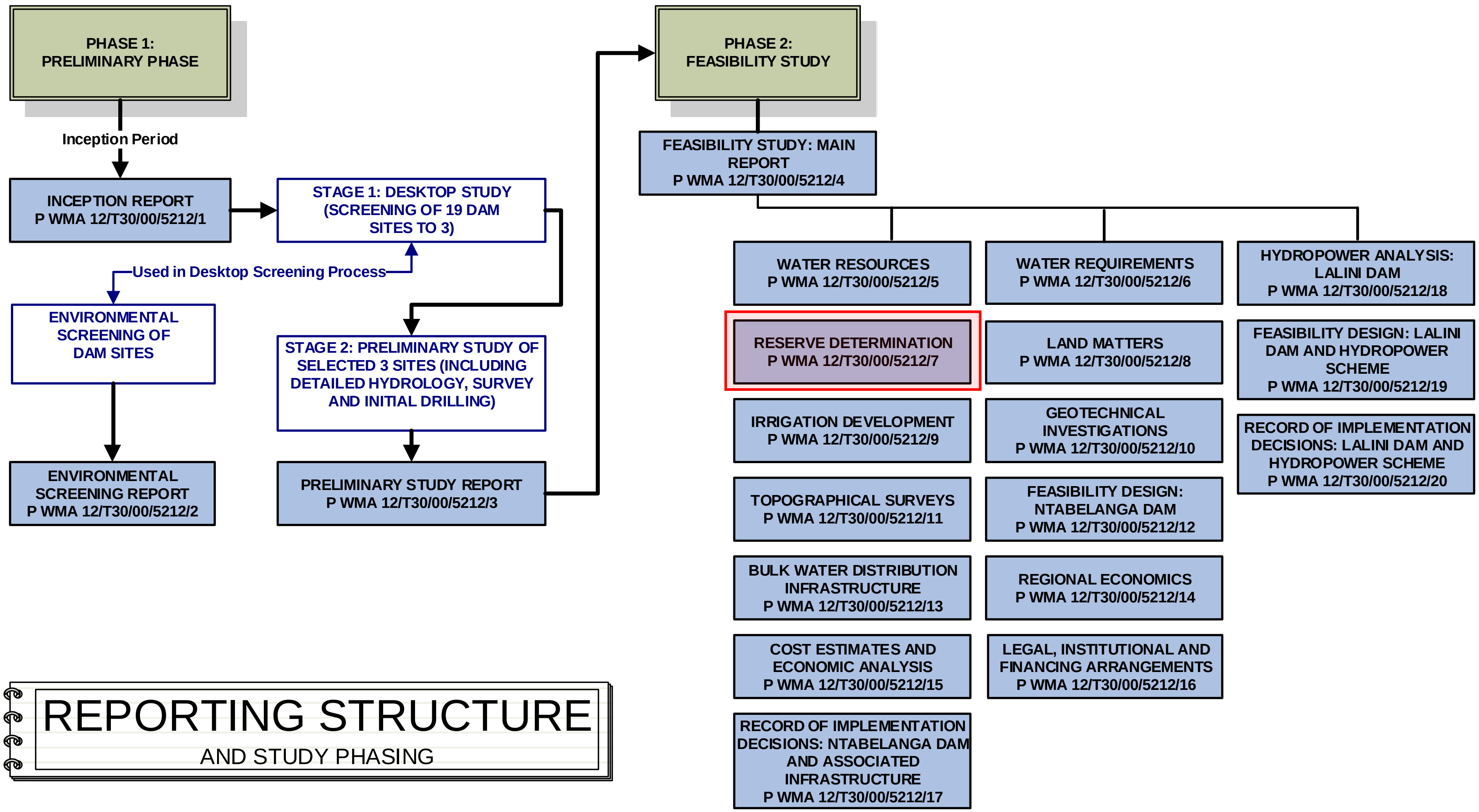
DEPARTMENT OF WATER AND SANITATION (DWS)
Directorate: Options Analysis
Approved for DWS:

M Mugumo
Chief Engineer: Options Analysis (South)

L S Mabuda
Chief Director: Integrated Water Resource Planning

LIST OF REPORTS

REPORT TITLE	DWS REPORT NUMBER
Inception Report	P WMA 12/T30/00/5212/1
Environmental Screening	P WMA 12/T30/00/5212/2
Preliminary Study	P WMA 12/T30/00/5212/3
Feasibility Study: Main Report	P WMA 12/T30/00/5212/4
Volume 1: Report	
Volume 2: Book of Drawings	
FEASIBILITY STUDY: SUPPORTING REPORTS:	
Water Resources	P WMA 12/T30/00/5212/5
Water Requirements	P WMA 12/T30/00/5212/6
Reserve Determination	**P WMA 12/T30/00/5212/7**
Volume 1: River	
Volume 2: Estuary: Report	
Volume 3 :Estuary: Appendices	
Land Matters	P WMA 12/T30/00/5212/8
Irrigation Development	P WMA 12/T30/00/5212/9
Geotechnical Investigations	P WMA 12/T30/00/5212/10
Volume 1: Ntabelanga, Somabadi and Thabeng Dam Sites: Report	
Volume 2: Ntabelanga, Somabadi and Thabeng Dam Sites: Appendices	
Volume 3: Lalini Dam and Hydropower Scheme: Report	
Volume 4: Lalini Dam and Hydropower Scheme: Appendices	
Topographical Surveys	P WMA 12/T30/00/5212/11
Feasibility Design: Ntabelanga Dam	P WMA 12/T30/00/5212/12
Bulk Water Distribution Infrastructure	P WMA 12/T30/00/5212/13
Regional Economics	P WMA 12/T30/00/5212/14
Cost Estimates and Economic Analysis	P WMA 12/T30/00/5212/15
Legal, Institutional and Financing Arrangements	P WMA 12/T30/00/5212/16
Record of Implementation Decisions: Ntabelanga Dam and Associated Infrastructure	P WMA 12/T30/00/5212/17
Hydropower Analysis: Lalini Dam	P WMA 12/T30/00/5212/18
Feasibility Design: Lalini Dam and Hydropower Scheme	P WMA 12/T30/00/5212/19
Record of Implementation Decisions: Lalini Dam and Hydropower Scheme	P WMA 12/T30/00/5212/20


PHASE 1: PRELIMINARY PHASE
Inception Period
INCEPTION REPORT P WMA 12/T30/00/5212/1
STAGE 1: DESKTOP STUDY (SCREENING OF 19 DAM SITES TO 3)
Used in Desktop Screening Process
ENVIRONMENTAL SCREENING OF DAM SITES
STAGE 2: PRELIMINARY STUDY OF SELECTED 3 SITES (INCLUDING DETAILED HYDROLOGY, SURVEY AND INITIAL DRILLING)
ENVIRONMENTAL SCREENING REPORT P WMA 12/T30/00/5212/2
PRELIMINARY STUDY REPORT P WMA 12/T30/00/5212/3
PHASE 2: FEASIBILITY STUDY
FEASIBILITY STUDY: MAIN REPORT P WMA 12/T30/00/5212/4
WATER RESOURCES P WMA 12/T30/00/5212/5
WATER REQUIREMENTS P WMA 12/T30/00/5212/6
HYDROPOWER ANALYSIS: LALINI DAM P WMA 12/T30/00/5212/18
RESERVE DETERMINATION P WMA 12/T30/00/5212/7
LAND MATTERS P WMA 12/T30/00/5212/8
FEASIBILITY DESIGN: LALINI DAM AND HYDROPOWER SCHEME P WMA 12/T30/00/5212/19
IRRIGATION DEVELOPMENT P WMA 12/T30/00/5212/9
GEOTECHNICAL INVESTIGATIONS P WMA 12/T30/00/5212/10
RECORD OF IMPLEMENTATION DECISIONS: LALINI DAM AND HYDROPOWER SCHEME P WMA 12/T30/00/5212/20
TOPOGRAPHICAL SURVEYS P WMA 12/T30/00/5212/11
FEASIBILITY DESIGN: NTABELANGA DAM P WMA 12/T30/00/5212/12
BULK WATER DISTRIBUTION INFRASTRUCTURE P WMA 12/T30/00/5212/13
REGIONAL ECONOMICS P WMA 12/T30/00/5212/14
COST ESTIMATES AND ECONOMIC ANALYSIS P WMA 12/T30/00/5212/15
LEGAL, INSTITUTIONAL AND FINANCING ARRANGEMENTS P WMA 12/T30/00/5212/16
RECORD OF IMPLEMENTATION DECISIONS: NTABELANGA DAM AND ASSOCIATED INFRASTRUCTURE P WMA 12/T30/00/5212/17
REPORTING STRUCTURE
AND STUDY PHASING

FEASIBILITY STUDY FOR THE MZIMVUBU WATER PROJECT

REFERENCE

This report is to be referred to in bibliographies as:

Department of Water and Sanitation, South Africa (2014). ***Feasibility Study for the Mzimvubu Water Project Reserve Determination: Volume 2: Estuary***

DWS Report No: P WMA 12/T30/00/5212/7

Prepared for: Directorate – Options Analysis

Prepared by: Jeffares & Green (Pty) Ltd, P O Box 794, Hilton, 3245
Tel: 033 343 6700, Fax: 033 343 6701
Contact: Mr A Pepperell
Email: pepperella@jgi.co.za

Note on Departmental Name Change:

In 2014, the Department of Water Affairs changed its name to the Department of Water and Sanitation, which happened during the course of this study. In some cases this was after some of the study reports had been finalized. The reader should therefore kindly note that references to the Department of Water Affairs and the Department of Water and Sanitation herein should be considered to be one and the same.

Note on Spelling of Laleni:

The settlement named Laleni on maps issued by the Surveyor General is locally known as Lalini and both names therefore refer to the same settlement.

EXECUTIVE SUMMARY

INTRODUCTION AND PURPOSE OF THIS REPORT

This report is a summary of the findings of the Reserve Determination for the Mzimvubu Estuary, prepared in support of the broader feasibility study for the Mzimvubu Water Project. The assessment has followed the methods supported in Version 2 of the Reserve Determination methods outlined by the Department of Water Affairs.

Summer and winter sampling of the abiotic and biotic features of the estuary were undertaken to provide supporting information for the study in determining the Present Ecological Status of the estuary, as well as assessing a series of future water use scenarios and the likely impact these may have on the estuary, and to Recommend an Ecological Management class (REC) for the estuary that would take optimum use in consideration without impacting negatively on the health integrity of the Mzimvubu.

INTRODUCTION AND PURPOSE OF THIS REPORT

The brief was undertaken based on the following assumptions:

- *It is assumed that the simulated run-off scenarios, representative of river inflow at the head of the Mzimvubu Estuary provided are correct. These scenarios included the reference condition, the present state and a range of additional scenarios as agreed between the Jeffares and Green and DWA;*

- *The accuracy and confidence of an Estuarine Ecological Water Requirements study is strongly dependant on the quality of the hydrology. The overall confidence in the hydrology supplied to the estuarine study team was considered to be low as there are no measured flow data records available on this system – at least not close to the head of the estuary.*

- *The findings of this study only pertain to the water use scenarios (1-4) described in this report. A number of different water use scenarios are included as part of the hydrology report and the riverine EWR but these were not assessed for impact to the estuary (ecological consequences).*

PRESENT ECOLOGICAL STATE

The Present Ecological Status of the Mzimvubu Estuary was determined to be a B (as the estuary has an Estuarine Health Index Score of 83, (i.e. 83% similarity to natural condition)), meaning that the estuary is “largely natural with few modifications”.

ESTUARY IMPORTANCE

The Estuary Importance Score (EIS) for the estuary takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account, and the overall score was 82, which corresponds to a rating of “Highly important”. In addition, the estuary is identified as a desired protected area in the Biodiversity Plan for the National Biodiversity Assessment.

A number of features contributed to the high importance score of the estuary, including that:

- *Significantly, this is the only Water Management Area not linked to another Water Management Area through cross-catchment transfers and is largely unregulated;*

- *This catchment has been identified as supplying high levels of ecological services nationally, and SANBI is currently undertaking an assessment of the economic importance of the system;*

- *The confirmed use of the estuary by Zambezi sharks (Carcharhinus leucas), White steenbras (Lithognathus lithognathus) and Dusky kob (Argyrosomus japonicus) species as a pupping/nursery ground, given that these are species of conservation and fisheries concern, and that available nursery habitat for these species is highly limited in South Africa;*

- *The significant role that this estuary plays in the delivery of sediments and nutrients/detritus to the marine environment, elevating the importance of this estuary in geological terms to the local beaches and marine environments.*

Given that the PES for the Mzimvubu is a B, and that the estuary is rated as "Highly important", the Recommended Ecological Category for the estuary is and ***A or Best Attainable State.***

ASSESSMENT OF FUTURE WATER USE SCENARIOS

Four potential future water use scenarios were assessed as part of the Reserve Determination for the estuary (note that these are different from those assessed for the riverine EWR)

1. *A small dam (0.1 MAR) at Ntabelanga;*
2. *A medium dam (0.5 MAR) at Ntabelanga;*
3. *A large dam (1.5 MAR[1]) at Ntabelanga;*
4. *A 40% naturalised MAR scenario.*

The scenario assessments determined that water use scenarios 1 – 3 would likely retain the Mzimvubu Estuary in its Present Ecological Status of a B ("largely natural with few modifications"), although Scenario 3 would be likely to bring this into a low-scoring B. Scenario 4 would likely lower the Estuarine Health Index Score to drop the estuary into a PES of a D ("largely modified").

MANAGEMENT RECOMMENDATIONS

The study resulted in a series of recommendations for the future management of the estuary aimed at maintaining and/or improving the estuarine health of the Mzimvubu. These recommendations addressed the key abiotic and biotic conditions that have resulted in a PES that is lowered from the reference state of the estuary. These recommendations included:

- *Returning some variability to the mouth dynamics through removal of the access road behind the area formerly known as "First Beach", which has effectively entrained the estuary mouth;*

- *Reinstating local sediment dynamics (also through the removal of the abovementioned access road), given the realistic possibility that the loss of "First Beach" may be reversed, potentially re-establishing this once-popular recreational beach for the town of Port St John's;*

- *Land-use management regulation within the estuarine functional zone that focuses on restricting the loss of further habitat within this zone and the estuary floodplain up to the 10 m contour (or 10 m above mean sea level);*

- *The rehabilitation of disturbed areas of the estuary floodplain/functional zone where impacts are reversible, and rehabilitation would significantly enhance the functional integrity and importance of the estuary as a whole;*

[1] *The 1.5 MAR reference throughout this report stemmed from the Phase 1 investigations. After review of the hydrology of the Tsitsa River in Phase 2, this same dam capacity was redesignated as a 1.18 MAR_{PD} capacity dam. MAR_{PD} refers to the Present Day Mean Annual Runoff value.*

- *The establishment of a programme for Invasive Alien Plant management within the estuary floodplain, which would make a significant contribution towards addressing this and enhancing the functional importance of the floodplain as a feature of the estuary;*

- *The management of fishing pressure in the estuary through the possible partial closure of the estuary to fishing in order to protect important fish stocks and sensitive habitats;*

- *Addressing possible point source pollution risks from the canalised creek that flows from the town of Port St John's, as the study has suggested that this canal may be compromising water quality to some extent.*

CONCLUSION

The fact that the Ntabelanga Dam site is located on the tributary Tsitsa River some 200 km above the Mzimvubu River mouth, controls just 10% of the total Mzimvubu catchment area, and would ultimately reduce the total Mzimvubu River MAR by just 2%, it follows, prima face, that the Ntabelanga Dam's impact and influence on the Mzimvubu Estuary ecology and hydraulics would not be a fatal flaw in its implementation.

Given that the PES for the Mzimvubu is a B, in order for the Mzimvubu Estuary to be maintained in an A or Best Attainable State, it would be preferred that the water use scenario presented in Scenario 2 (a medium dam of 0.5 MAR at Ntabelanga) is implemented.

However the likely scenario 3 (implementing the larger 1.5 MAR capacity Ntabelanga Dam) will still result in an ecological state of B albeit with a lower score.

Please note that a further reserve determination study has been undertaken of the Tsitsa River at the proposed Lalini hydroelectric scheme site below the Tsitsa Falls. This additional study was undertaken following this Ntabelanga Dam site study under the separate EIA PSP contract.

The findings and EWR recommendations of that additional study may be found in DWS Report: Rapid Reserve Determination: Tsitsa River at Lalini No. P WMA 12/T30/00/5314/17.

The addition of hydropower plants at both Ntabelanga and Lalini dams are non-consumptive, and will follow an operational regime that will mimic naturalized environmental flows. This should therefore not change this ecological state at the estuary locality.

The development scenario would need to be implemented in combination with the additional land-use recommendations outlined above in order to address the key issues that are leading to the lowered PES of the estuary.

TABLE OF CONTENTS

APPENDIX TO THIS VOLUME

SEE ALSO SEPARATE VOLUME 3 FOR APPENDICES B TO F

LIST OF APPENDICES IN VOLUME 3

LIST OF TABLES

LIST OF FIGURES

GLOSSARY AND SCIENTIFIC TERMS

Anthropogenic	Having to do with people, or caused by humans.
Biodiversity	The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems.
Benthic invertebrates	Invertebrate organisms living in or on sediments of aquatic habitats and typically retained by a 500 micron sieve.
Catchment	In relation to a watercourse or watercourses or part of a watercourse, this term means the area from which any rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points.
Community	Assemblage of organisms characterised by a distinctive combination of species that occupy a common environment and interact with one another.
Community	All taxa, plants and animals, present in a community composition.
Cumulative impact	Impact on the environment which results from the incremental or combined effects of one or more developmental activities in a specified area over a particular time period, which may occur simultaneously, sequentially, or in an interactive manner.
Dilution	The reduction in concentration of a substance due to mixing with water.
DO	Dissolved Oxygen.
EHI	Estuarine Health Index.
Habitat	The natural home of an organism or community of organisms (this also includes the surrounding area).
Intertidal	Area of the shore between the highest and lowest tides.
Invasive species	A species that does not naturally occur in a specific area and whose introduction does or is likely to cause economic or environmental harm or harm to human health.
PES	Present Ecological Status.
REI	River Estuarine Interface.
Runoff	Runoff is the water yield from an individual catchment – the sub-catchment plus the runoff from all upstream sub-catchments. Runoff includes any seepage, environmental flow releases and overflows from the reservoirs in a catchment, if they are present - which is not the case in any of the simulations in this project in which baseline catchment conditions are assumed.
Storm water run-off	Storm water run-off from paved areas, including parking lots, streets, residential subdivisions, of buildings, roofs, highways, etc.
Sub-tidal	The area of the estuary bottom that is always covered by water and is never exposed at low tides.
Wastewater	Water containing solid, suspended or dissolved material (including sediment) in such volumes, composition or manner that, if spilled or deposited in the natural environment, will cause, or is reasonably likely to cause, a negative impact.

LIST OF ACRONYMS AND ABBREVIATIONS

AsgiSA-EC	Accelerated and Shared Growth Initiative for South Africa – Eastern Cape
CAPEX	Capital Expenditure
CFRD	Concrete-faced rockfill dam
CMA	Catchment Management Agency
CTC	Cost of Company
DAFF	Department of Agriculture, Forestry and Fisheries
DBSA	Development Bank of Southern Africa
DEA	Department of Environment Affairs
DM	District Municipality
DME	Department of Minerals and Energy
DoE	Department of Energy
DRDAR	Department of Rural Development and Agrarian Reform
DRDLR	Department of Rural Development and Land Reform
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EA	Environmental Authorisation
EAP	Environmental Assessment Practitioner
EC	Eastern Cape
ECRD	Earth core rockfill dam
EF	Earthfill (dam)
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EPWP	Expanded Public Works Programme
ESIA	Environmental and Social Impact Assessment
EWR	Environmental Water Requirements
FSL	Full Supply Level
GERCC	Grout enriched RCC
GIS	Geographic Information System
GN	Government Notices
GW	Gigawatt
GWh/a	Gigawatt hour per annum
IB	Irrigation Board
IFC	International Finance Corporation
IPP	Independent Power Producer
IRR	Internal Rate of Return
IVRCC	Internally vibrated RCC
ISO	International Standards Organisation
kW	Kilowatt
LM	Local Municipality
ℓ/s	Litres per second
MAR	Mean Annual Runoff
MEC	Member of the Executive Council
MIG	Municipal Infrastructure Grant
million m^3	Million cubic metres
MW	Megawatt

NEMA	National Environmental Management Act
NERSA	National Energy Regulator of South Africa
NHRA	National Heritage Resources Act
NOCL	Non-overspill crest level
NWA	National Water Act
NWPR	National Water Policy Review
NWRMS	National Water Resources Management Strategy
O&M	Operations and Maintenance
OPEX	Operational Expenditure
PICC	Presidential Infrastructure Co-Ordinating Committee
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PSC	Project Steering Committee
PSP	Professional Services Provider
RBIG	Regional Bulk Infrastructure Grant
RCC	Roller-compacted concrete
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RWI	Regional Water Institution
RWU	Regional Water Utilities
SEZ	Special Economic Zone
SIP	Strategic Integrated Project
SMC	Study Management Committee
SPV	Special Purpose Vehicle
TCTA	Trans Caledon Tunnel Authority
ToR	Terms of Reference
UOS	Use of System
URV	Unit Reference Value
WEF	Water Energy Food
WRYM	Water Resources Yield Model
WSA	Water Services Authority
WSP	Water Services Provider
WTE	Water Trade Entity
WUA	Water User Association

LIST OF UNITS

Description	Standard unit
Elevation	m a.s.l.
Height	m
Distance	m, km
Dimension	mm, m
Area	m^2 , ha or km^2
Volume (storage)	m^3
Yield, Mean Annual Runoff	m^3/a
Rotational speed	rpm
Head of Water	m
Pressure	Pa
Diameter	mm or m
Temperature	ºC

Description	Standard unit
Velocity, speed	m/s, km/hr
Discharge	m^3/s
Mass	kg, tonne
Force, weight	N
Gradient (V:H)	%
Slope (H:V) or (V:H)	1:5 (H:V) or 5:1 (V:H)
Volt	V
Power	W
Energy used	kWh
Acceleration	m/s^2
Density	kg/m^3
Frequency	Hz

1. INTRODUCTION

The Mzimvubu River catchment in the Eastern Cape Province of South Africa is situated in one of the poorest and least developed regions of the country. Development of the area to accelerate the social and economic upliftment of the people was therefore identified as one of the priority initiatives of the Eastern Cape Provincial Government.

Harnessing the water resources of the Mzimvubu River, the only major river in the country which is still largely unutilised, is considered by the Eastern Cape Provincial Government as offering one of the best opportunities in the Province to achieve such development. In 2007, a special-purpose vehicle (SPV) called ASGISA-Eastem Cape (Pty) Ltd (ASGISA-EC) was formed in terms of the Companies Act to initiate planning and to facilitate and drive the Mzimvubu River Water Resources Development.

The five pillars on which the Eastern Cape Provincial Government and ASGISA-EC proposed to model the Mzimvubu River Water Resources Development are:

- Forestry;
- Irrigation;
- Hydropower;
- Water transfer; and
- Tourism.

The Department of Water and Sanitation (DWS) commissioned the Mzimvubu Water Project with the overarching aim of developing water resources schemes (dams) that can be multi-purpose reservoirs in order to provide benefits to the surrounding communities and to provide a stimulus for the regional economy, in terms of irrigation, forestry, domestic water supply and the potential for hydropower generation amongst others.

1.1 Study Locality

The Mzimvubu River Catchment is situated in the Eastern Cape (EC) Province of South Africa which consists of six District Municipalities (DM) and two Metropolitan Municipalities (Buffalo City and Nelson Mandela Bay). These include Cacadu DM in the west across to the Alfred Nzo DM in the east with the two Metropolitan Areas being located around the two major centres of the province, East London and Port Elizabeth, both of which border the Indian Ocean.

The Mzimvubu River Catchment is situated within three of the DM's namely the Joe Gqabi DM in the north-west, the OR Tambo DM in the South and the Alfred Nzo DM in the east and north east. A locality map of the whole catchment area and its position in relation to the DM's in the area is provided in Figure 1-1 overleaf.

1.2 Study Stages

The study commenced in January 2012 and was completed by October 2014 in three stages as follows:

- Inception;
- Phase 1 – Preliminary Study; and
- Phase 2 – Feasibility Study.

The purpose of the study was not to repeat or restate the research and analyses undertaken on the several key previous studies described below, but to make use of that information previously collected, to update and add to this information, and to undertake more focussed and detailed investigations and feasibility level analyses for the dam site options identified as being the most promising and cost beneficial.

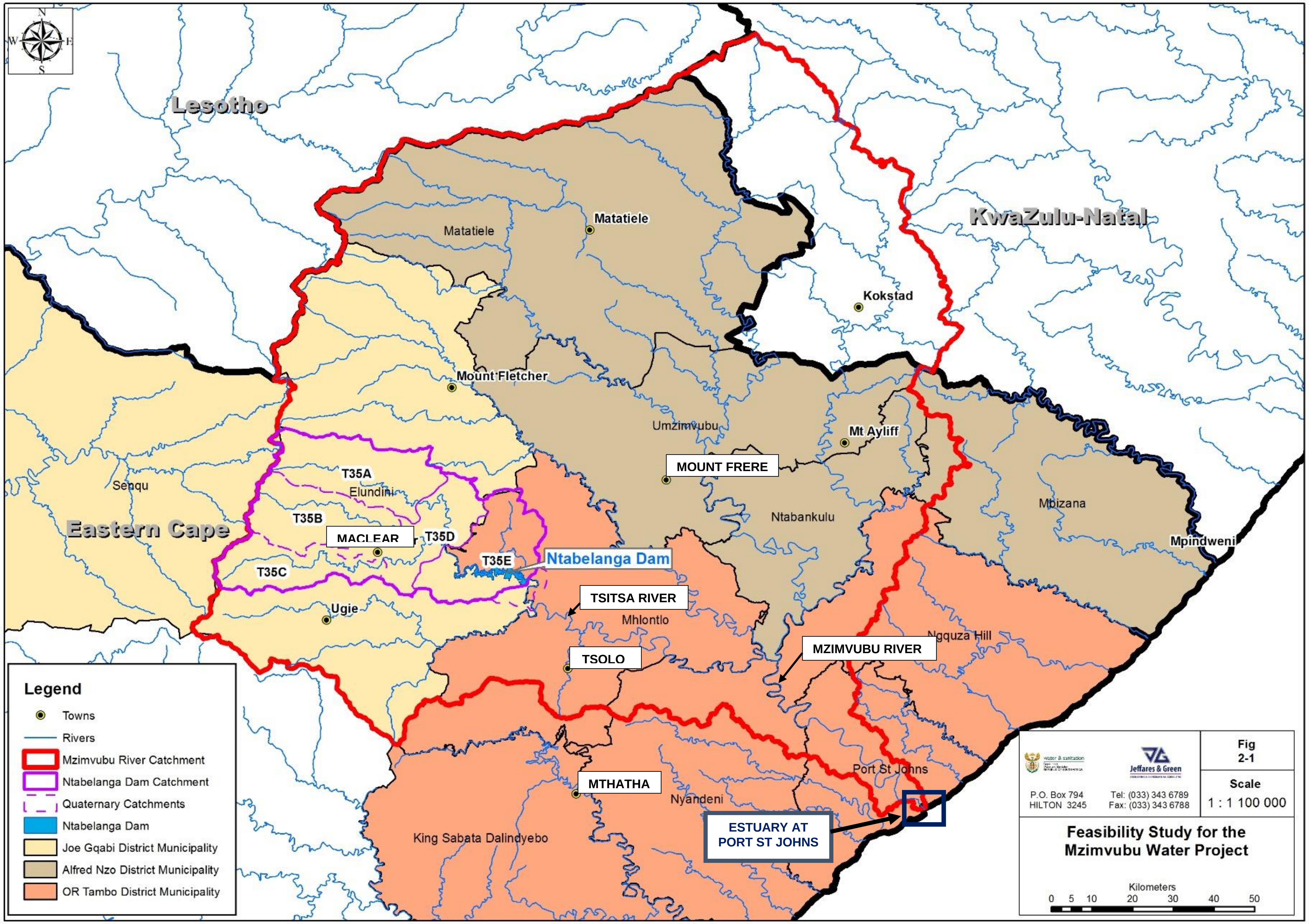


Figure 1-1: Locality Map of Mzimvubu Catchment

1.2.1 *Inception Phase*

The aim of the inception phase was to finalise the Terms of Reference (TOR) as well as to include, *inter alia*, the following:

- A detailed review of all the data and information sources available for the assignment;
- A revised study methodology and scope of work;
- A detailed review of the proposed project schedule, work plan and work breakdown structure indicating major milestones;
- Provision of an updated organogram and human resources schedule; and
- Provision of an updated project budget and monthly cash flow projections.

The inception phase has been completed and culminated in the production of an inception report (DWS Report Number P WMA 12/T30/00/5212/1) which also constitutes the final TOR for the study.

1.2.2 *Preliminary Study Phase*

The preliminary report describes the activities undertaken during the preliminary study phase, summarizes the findings and conclusions, and provides recommendations for the way forward and scope of work to be undertaken during the feasibility study phase.

The Preliminary Study Phase was divided into two stages:

- Desktop Study; and
- Preliminary Study.

The aim of the desktop study was, through a process of desktop review, analyses of existing reports and data, and screening, to determine the three best development options from the pre-identified 19 development options (from the previous investigation). This process is described in Section 2 of this report.

The aim of the preliminary study was to gather more information with regard to the three selected development options as well as to involve the Eastern Cape Provincial Government and key stakeholders in the process of selecting the single best development option to be taken forward into Phase 2 of the study.

The main activities undertaken during of the second stage of Phase 1 were as follows:

- Stakeholder involvement;
- Environmental screening;
- Water requirements (including domestic water supply, irrigation and hydropower);
- Hydrological investigations;
- Geotechnical investigations;
- Topographical survey investigations, and
- Selection process.

1.2.3 Phase 2 – Feasibility Study

The preliminary study recommended a preferred dam site and scheme development to be taken forward to Feasibility Study level.

The key activities undertaken during the Feasibility Study are as follows:

- Detailed hydrology (over and above that undertaken during the Preliminary Study);
- Reserve determination;
- Water requirements investigation (including agricultural and domestic water supply investigations);
- Topographical survey (over and above that undertaken during the Preliminary Study);
- Geotechnical investigation (more detailed investigations than during the Preliminary Study);
- Dam design;
- Land matters;
- Public participation;
- Regional economics; and
- Legal, institutional and financial arrangements.

An Environmental Impact Assessment was undertaken in a separate study that ran in parallel to this one;

1.2.4 Additional Detailed Investigations for Lalini Dam and Hydropower Scheme

Further detailed investigations were undertaken for a second dam on the Tsitsa at Lalini (just above the Tsitsa Falls) which would be operated conjunctively with the Ntabelanga Dam to generate significant hydropower for supply into the national grid. The feasibility design of the Lalini Dam and hydropower scheme is described in Report No. P WMA 12/T30/00/5212/19.

1.3 Purpose of Report

This report summarizes the estuary-focused reserve determination component which forms part of the broader Feasibility Study for the Mzimvubu Water Project which is investigating the potential impacts of future water resource developments being considered by the Department of Water and Sanitation.

1.4 Terms of Reference and Scope of Study

This study investigates the freshwater requirements of the estuary and addresses the implications of different development scenarios affecting river flows into the Mzimvubu Estuary. In determining estuarine water requirements (EWR), a scenario-based approach was used that was based on the baseline description of the estuary, its predicted reference, states present state and the predicted state under a range of scenarios.

1.5 Approach and Assumptions / Limitations for this Study

The brief was undertaken based on the following assumptions:

- It was assumed that the simulated run-off scenarios, representative of river inflow at the head of the Mzimvubu Estuary provided are correct. These scenarios included the reference condition, the present state, and a range of additional scenarios as agreed between Jeffares and Green and DWA;

- The accuracy and confidence of an Estuarine Ecological Water Requirements study is strongly dependant on the quality of the hydrology. The overall confidence in the hydrology supplied to the estuarine study team was considered to be medium as there are no measured flow data records available on this system – at least not close to the head of the estuary; and

- The findings of this study only pertain to the water use scenarios (1-4) described in this report. A number of different water use scenarios are included as part of the hydrology report and the riverine EWR but these were not assessed for impact to the estuary.

1.6 Confidence Levels and this Study

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 recognized in the past in terms of the effort expended during the assessment – rapid, intermediate and comprehensive. In this study, effort lay somewhere between a rapid and intermediate study, in that some field data collection was carried out. Nevertheless, the paucity of historical data on the system 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 shown in Table 1-1. Confidence levels related to level of a Reserve Study.

Table 1-1: Confidence levels for an Estuarine EWR study

Confidence level	Situation	Expressed as percentage
Very Low	No data available for the estuary or similar estuaries	less than 40% certain
Low	Limited data available	40 - 60% certainty
Medium	Reasonable data available	60 – 80% certainty
High	Good data available	> 80% certainty

1.7 Estuary Specialist Team

The estuarine scientists working on this environmental water requirements study, their expertise and affiliations are listed in Table 1-2.

Table 1-2: Estuary specialists on this project

<table>
<tr><th colspan="2">Personnel</th><th colspan="2">Expertise</th><th>Affiliation</th></tr>
<tr><td colspan="2">Ms Nicolette Forbes (NTF)</td><td colspan="2">Study Leader</td><td>MER</td></tr>
<tr><td colspan="2">Ms Lara van Niekerk</td><td colspan="2">Hydrodynamics</td><td>CSIR</td></tr>
<tr><td colspan="2">Mr Andre Theron</td><td colspan="2">Sediments</td><td>CSIR</td></tr>
<tr><td colspan="2">Dr Susan Taljaard</td><td colspan="2">Water quality</td><td>CSIR</td></tr>
<tr><td colspan="2">Dr Gavin Snow</td><td colspan="2">Microalgae</td><td>Nelson Mandela Metropolitan University</td></tr>
<tr><td colspan="2">Prof Janine Adams</td><td colspan="2">Macrophytes</td><td>Nelson Mandela Metropolitan University</td></tr>
<tr><td colspan="2">Dr Alan Connell</td><td colspan="2">Zooplankton</td><td>Private</td></tr>
<tr><td colspan="2">Prof Anthony Forbes (ATF)</td><td colspan="2">Invertebrates</td><td>MER</td></tr>
<tr><td colspan="2">Mr Cameron McLean</td><td colspan="2">Fish</td><td>MER</td></tr>
<tr><td colspan="2">Dr Jane Turpie</td><td colspan="2">Birds</td><td>Anchor Environmental</td></tr>
<tr><th>Student / HDI Participation</th><th colspan="2">Component</th><th>Affiliation</th><th>Role</th></tr>
<tr><td>Mr Junior Gabela</td><td colspan="2">Invertebrates</td><td>MER</td><td>Laboratory sorting of benthic samples and species identification training</td></tr>
<tr><td>Not named</td><td colspan="2">Macrophytes</td><td>NMMU</td><td>M.Sc student</td></tr>
<tr><td>Not named</td><td colspan="2">Macrophytes</td><td>NMMU</td><td>M.Sc student</td></tr>
</table>

2. STUDY AREA

2.1 Location of the Mzimvubu Estuary

The Mzimvubu Estuary (31°37'52” S, 29°32'59” E) is situated on the subtropical coast of South Africa, with its mouth opening into the Indian Ocean at Port St. Johns (DWAF, 2008; van Niekerk & Turpie, 2012).

Figure 2-1: Mzimvubu Estuary at Port St Johns

2.2 Delineation and Geographical Boundaries

The boundary of South Africa’s estuaries incorporates an area known as the estuarine functional zone (SANBI 2011). The estuarine functional zone is defined by the 5 m topographical contour (as indicative of 5 m above mean sea level). The estuarine functional zone includes:

- Open water area;
- Estuarine habitat (sand and mudflats, rock and plant communities); and
- Floodplain area.

The 5 m contour boundary has been set to allow the inclusion of estuarine linked areas and biodiversity components dependent on estuarine processes and has a number of planning advantages. It allows dynamic areas to be protected as these are areas responsible for the key physical processes that drive biodiversity in estuaries and along the SA coastline. In most cases, the 5 m contour also allows for the inclusion of a buffer zone of terrestrial vegetation that represents the transition between terrestrial and coastal ecosystems.

The original boundary of the Mzimvubu Estuary as per the national requirement is indicated in Figure 2—2. Historical references (Day, 1981) suggest an upper boundary of the estuary about 14.5 km upstream from the mouth. It should be noted that the Mzimvubu Estuary mouth may be prone to closure if the river inflow decreases below ~ 1.0 m^3/s.

Therefore, the 5 m contour should be adhered to as a development setback line.

However, given the conditions (freshwater dominated and minimal saline intrusion) within the system during the survey, the upper limit 5 m contour was not applied.

Instead, a modified boundary of the system was applied for the purposes of this assessment which encompasses the major estuarine habitats and estuarine support habitats which are found within the estuarine functional zone (Figure 2-2) and is closely aligned with the historical references.

Figure 2-2 shows the delineation of the modified boundary of the Mzimvubu Estuary (blue) and the extent of upstream areas below the 5 m.a.s.l. contour as included in the national delineation (green)

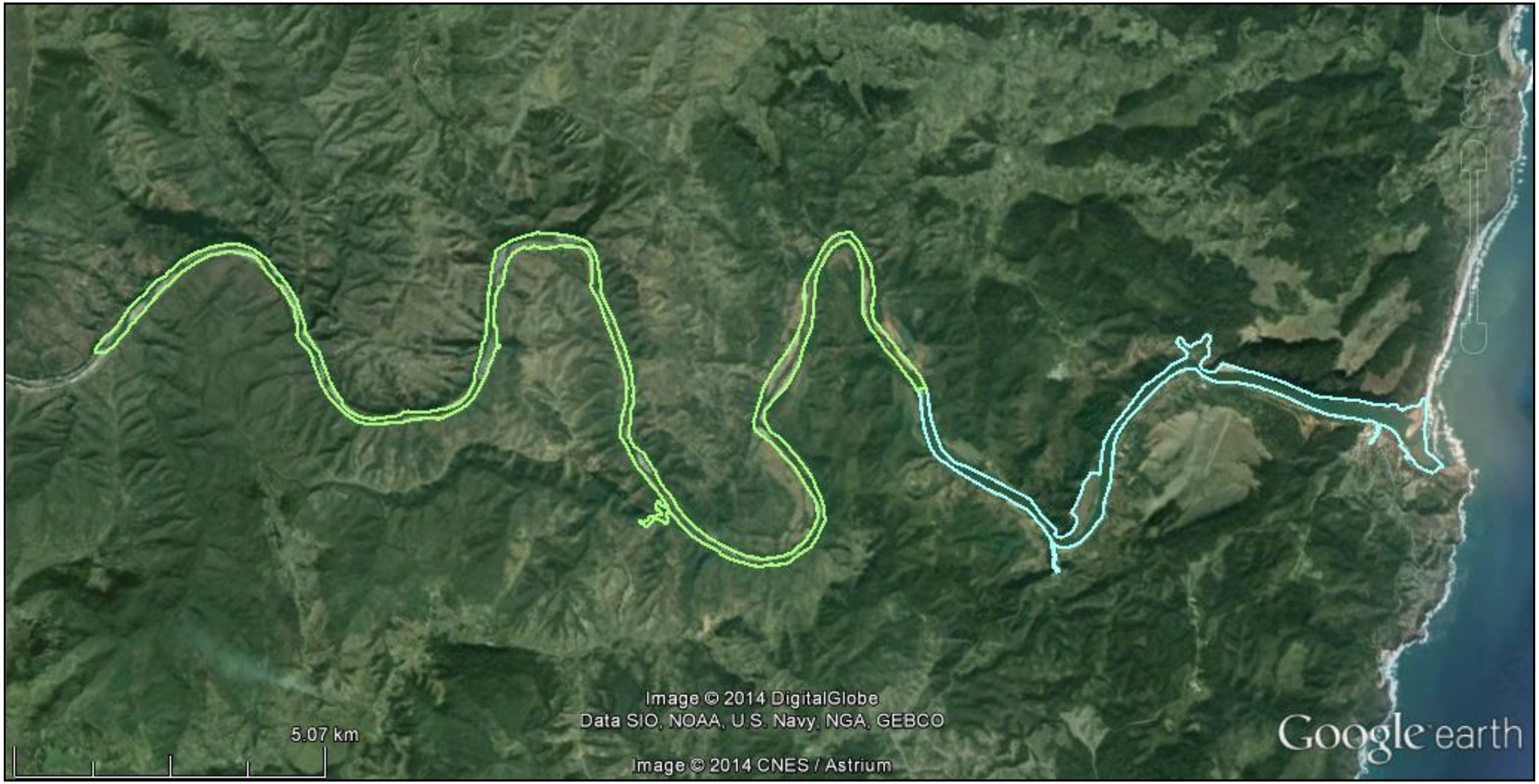


Figure 2-2: Delineation of the Mzimvubu Estuary

3. DESCRIPTION AND ASSESSMENT OF THE MZIMVUBU ESTUARY

The river has its source in the northern region of the Eastern Cape, in the area of Matatiele and Mount Fletcher near the Lesotho border. The Mzimvubu flows with many meanders generally in a southeastern direction and flows into the Indian Ocean through an impressive gorge known as the "Gates of St John" into an estuary located at Port St. Johns.

It is approximately 400 km long and has a large catchment area (19 853 km^2) (DWAF, 2008).

This river and estuary falls within the Mzimvubu to Keiskamma Water Management Area, and the estuary is classified as a river mouth (note that this is a particular type of estuary).

The total surface area of the estuary is 150.99 ha (van Niekerk & Turpie, 2012). With a mean annual run-off (MAR) of 2 893.8 million m^3/a, the system contributes 7% of the total MAR in South Africa (van Niekerk & Turpie, 2012).

Day (1981) defined the estuary as extending 6-9 km from the mouth. Within this area the estuary is about 200 m wide and was then (1950) about 2 m deep along most of its length, widening to about 400 m near the mouth, which featured a prominent sandbar. The estuary is crossed by a road bridge about 4.2 km from the mouth.

The estuarine health state of the Mzimvubu Estuary has been rated in the past as FAIR (i.e. habitat state/abiotic = good; biological state = fair), and has a desktop Present Ecological Status and Recommended Ecological Category of C (*i.e.* moderate) (van Niekerk & Turpie, 2012).

In addition to this, the estuary is ranked as the 35th out of 265 most important estuary in terms of conservation importance (Turpie & Clark, 2007). The most prevalent pressures cited in that assessment include moderate levels of pollution as a result of poor catchment management, as well as high levels of fishing and bait collection (van Niekerk & Turpie, 2012).

Based on its physico-chemical and physical characteristics (i.e. river-dominated) the Mzimvubu Estuary is known as an important nursery area for species such as the white steenbras, dusky kob and the Zambezi shark (van Niekerk & Turpie, 2012).

Field surveys were conducted in August 2012 and January 2013 to assess the present ecological health and to document the distribution and species composition of the various habitats in relation to determining Reserve Assessing environmental factors. The data will then be used to determine the ecological water requirements of the estuary. A broad habitat map for the present conditions was produced from the field surveys.

The system has a number of different habitat types and these include:

a) Open water which includes shallow sub-tidal sand and mud;
b) Intertidal sand flats;
c) Deeper sub-tidal;
d) Sedge and Reedbeds;
e) Swamp forest; and
f) Mangroves.

3.1 Catchment Characteristics

The Mzimvubu estuary is one of the largest on the Wild Coast. The river system rises in the Drakensberg and has a catchment area of about 19 925 km^2 which is located in a summer rainfall area. Much of the catchment lies in communal land areas of the former Transkei, and has been historically overgrazed, such that summer floods carry heavy loads of silt. The lower part of the estuary runs through a gorge of Table Mountain sandstone which is vegetated with indigenous forest.

3.2 Hydrology

According to the hydrological data provided for this study, under the Present State the MAR into the Mzimvubu Estuary is 2 552 million m^3. This is a slightly reduced MAR from the reference condition which is 2 666 million m^3.

3.2.1 Scenario Modelling

The hydrological information used in this study (i.e. for the entire Mzimvubu catchment feeding into the estuary) was based on a multi-level rainfall-runoff modelling exercise. The simulated natural stream flow was modelled at a detailed level up until and including Quaternary Catchment T35L on the Tsitsa River as a part of the detailed hydrology and yield assessment of the Ntabelanga Dam (see Report P WMA 12/T30/00/5212/5 for the details regarding the configuration and calibration of the rainfall-runoff model).

The naturalised stream flow values for the remainder of the Mzimvubu catchment were obtained from the Water Resources of South Africa 2005 study (WRC, 2009), which has WRSM2000 configurations for the entire catchment.

In order to simulate the impact of the proposed Ntabelanga Dam, the water resources yield model was used to assess various dam size scenarios. The outputs from these scenarios at the outlet of the Ntabelanga Dam were combined with the incremental and accumulated stream flow values from the detailed rainfall-runoff modelling (i.e. incremental T35E – T35L) and the WR2005 generated stream flow results for the remaining Quaternary Catchments in the Mzimvubu catchment.

These results were used to generate monthly stream flow time-series for several scenarios. These scenarios were assessed by the various specialists in the project team. The scenarios provided were as follows:

- Natural Flows;
- Present Day Flows;
- Impacts of including a 0.1 MAR Ntabelanga Dam;
- Impacts of including a 0.5 MAR Ntabelanga Dam;
- Impacts of including a 1.5[2] MAR Ntabelanga Dam; and
- 40 % of Natural Flows (extreme example).

[2] *The 1.5 MAR reference throughout this report stemmed from the Phase 1 investigations. After review of the hydrology of the Tsitsa River in Phase 2, this same dam capacity was redesignated as a 1.18 MAR_{PD} capacity dam. MAR_{PD} refers to the Present Day Mean Annual Runoff value.*

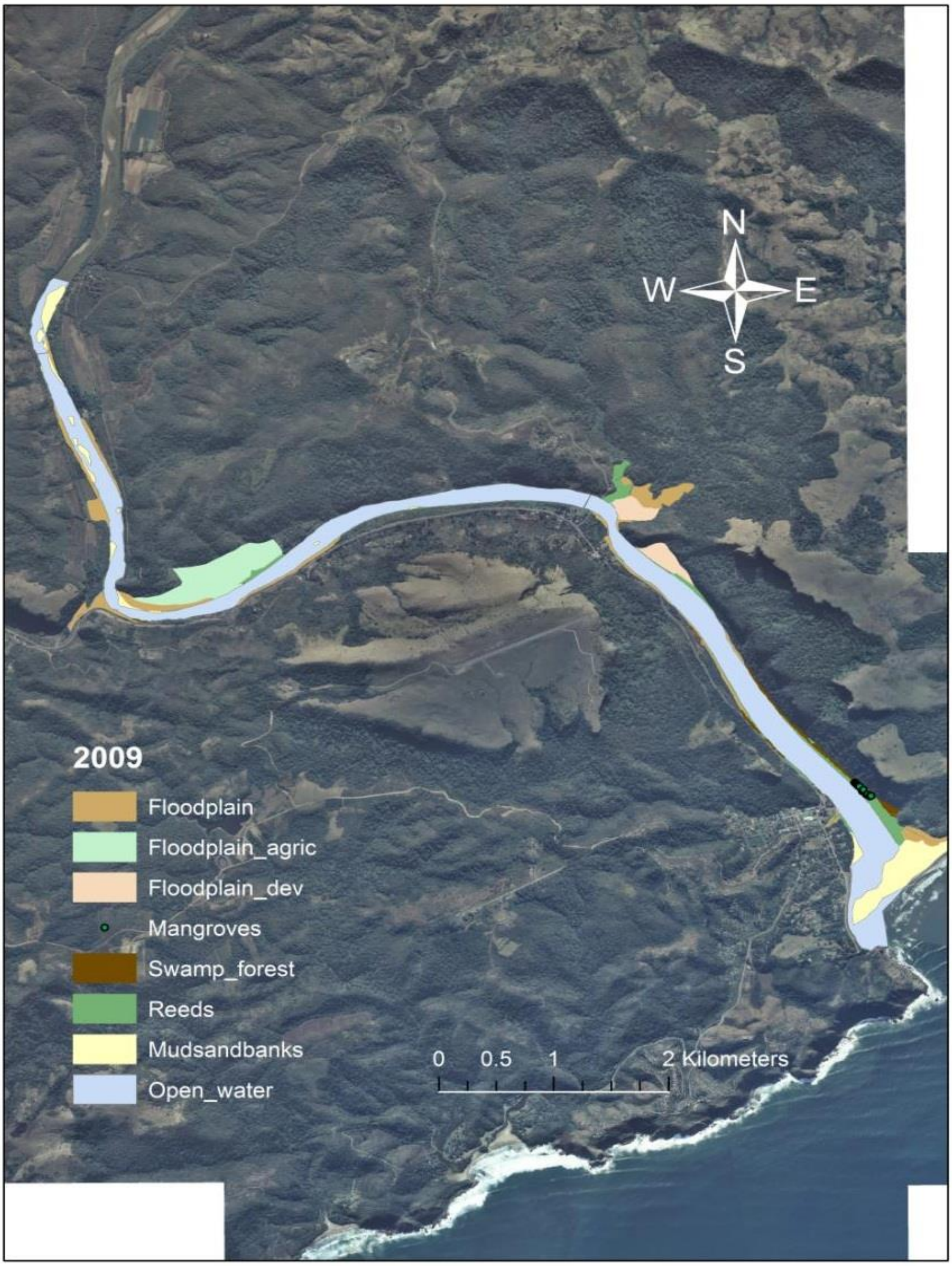


Figure 3-1: Major habitats identified within the delineated Mzimvubu Estuary boundary

3.2.2 Floods

The fact that the Ntabelanga Dam site is located on the tributary Tsitsa River some 200 km above the Mzimvubu River mouth, controls just 10% of the total Mzimvubu catchment area, and would ultimately reduce the total Mzimvubu River MAR by just 2%, it follows, prima face, that the Ntabelanga Dam's impact and influence on the Mzimvubu Estuary ecology and hydraulics would not be of major significance.

The role of floods in the estuary is very important in eroding accumulated sediment and temporarily deepening the estuary channel, while river flow is also critical to the maintenance of an open mouth.

As a still unregulated river, the Mzimvubu is subject to occasional rainfall driven floods (some very large), but there are no discernible trends in flood regime. As such, the present MAR is estimated at 96% of natural, and the magnitude and frequency of virtually all categories of floods are considered to be very similar to reference, with probably only a slight overall reduction. Thus, from the perspective of river flow influence on estuarine sediment dynamics and morphology, only a very small change from reference to present is expected, after the implementation of the proposed dams in the Tsitsa River.

3.2.3 Low Flows

Low flows (also called base flows) were taken as the flow range that is exceeded for 70% or more of the time. The average change in the 10, 20 and 30 percentile was taken as change in the low flows to the estuary.

3.2.4 Present Hydrological Health

This score is calculated based on the extent to which current inflow patterns resemble those of the "Reference" state estimated from two parameters, as in Table 3-1. These are (a) general inflow patterns, highlighting the changes in low flows, and (b) the frequency and magnitude of flood events.

The relative weighting of these two parameters (60:40) is set according to their assumed importance as drivers of the estuarine system. This may alter *a priori* for particular systems, with justification.

Table 3-1: Calculation of the hydrological health score

Variable		Score	Motivation	Confidence
a.	% Similarity in period of low flows	91	Average change in low flows (derived from the 30, 20 and 10 percentile) from present to that of the reference condition.	M
b.	% Similarity in mean annual frequency of floods	95	Very little water resource development has occurred in this catchment. Most change is due to land-use and small dam development	M
Hydrology score		**Category A**		

3.3 Physical Characteristics

3.3.1 Available Information on Bathymetry and Sediments

Drivers of the abiotic estuarine morphology and geophysical sediment characteristics, from the marine side, such as the wave regime, tides (and other currents), coastal sediment supply and transports, and to a small extend local winds, are considered to be unchanged from reference conditions.

It is evident that, while data are equivocal as to whether erosion in the Mzimvubu catchment, and sedimentation in the estuary are accelerating beyond natural levels or not, there is consensus that the system is naturally turbid and muddy. However, erosion and degradation of vegetation cover in the catchment suggest that sediment transport levels are higher than those that existed prior to degradation in the 20th century.

Small changes in riverine sediment load are probably linked to increased development pressures; anthropogenic activities in the catchment have probably increased the sediment load very slightly, and thus also turbidity levels and deposition of muddy sediments in the estuary.

Overall, all parts of the (geo-physical) estuarine morphology (sub-, inter- and supra-tidal) are considered to be still very similar to reference. In conjunction, the surficial/bottom sediments (as well as suspended) sediment characteristics (type and relative composition) within each estuarine zone (sub-, inter- and supra-tidal within the lower, middle and upper areas) are also considered to be virtually the same as reference.

The noticeable yet still small changes to the estuarine habitat (geo-physical morphology), are mainly due to local small scale anthropogenic interventions such as the bridge across the estuary, the road along the bank, and limited infilling.

3.3.2 Physical Habitat Health

Table 3-2: Calculation of the score and adjusted score (net of non-flow impacts)

Variable		Change from natural	Score	Confidence
1.	Resemblance in intertidal sediment structure and distribution			
a	% similarity in intertidal area exposed	Very similar to Reference. Some loss of supratidal area due to the road and infilling around the bridge.	95	M
b	% similarity in sand fraction relative to total sand and mud	Very similar to Reference. Probably very slightly more muddy from Reference. Slight loss of intertidal area due to the road and infilling around the bridge.	95	M
2.	Resemblance of sub-tidal area to ref. (depth, bed, channel)		95	M
Physical habitat score[1]			95	
% of impact due to non-flow factors			90	
Adjusted score			99.5	

1 Score = mean ((mean (a to d), means (a to d))
Supratidal: Pertaining to the shore area immediately marginal to and above the high-tide level.

3.4 Hydrodynamics and Abiotic States

3.4.1 Mouth Condition

The Mzimvubu is typed as a river mouth. There is no record of it ever closing, although at times it can become very constricted. However, it should be noted that river inflow is the driving factor in the maintenance of an open mouth and closure is very probable at flow ranges less than 1.0 m^3/s.

3.4.2 Typical Abiotic States

Based on available literature, four distinct ‘states’ can be identified for the Mzimvubu Estuary, i.e. those related to mouth condition, tidal exchange, salinity distribution and water quality (Table 3-3). The latter are primarily determined by river inflow patterns, state of the tide and wave conditions. The transition between the different states may not always take place gradually and may occur within a few hours.

Table 3-3: Summary of abiotic states, and associated hydrodynamic characteristics

PARAMETER	STATE 1: Significant saline penetration	STATE 2: Intermediate saline penetration	STATE 3: Limited saline penetration	STATE 4: Freshwater dominated
Flow range (m^3/s)	1 - 3[3]	3 – 10	10 – 30	>30.0
Mouth condition	Open, but constricted	Open	Open	Wide open
Water level	None	None	None	Extensive during floods
Tidal range	less than 1.0 m	1.5 m	1.5 m	2.0 m
Dominant circulation process	Tide	Tide and Fluvial	Fluvial	Fluvial
Retention	2 – 4 weeks	1 – 2 weeks	1 – 5 days	less than 1 day
Stratification	Relatively well mixed	Strong stratification in middle and lower reaches	Strong stratification in lower reaches	Limited in mouth area

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

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

3.4.3 *Present Distribution of Abiotic States*

The occurrences of flow distributions (mean monthly flows in m^3/s) for the present state of the Mzimvubu Estuary, derived from the 85-year simulated data set, are provided in Table 3-4.

A graphic representation of the occurrence of the various abiotic states is presented in Figure 3-2.

The 85-year series of simulated monthly runoff data for the present state is provided in Table 3-5.

Colour coding in Table 3-4:

STATE 1: Significant saline penetration	STATE 2: Intermediate saline penetration	STATE 3: Limited saline penetration

State 1	**1-3 m^3/s**	**State 2**	**3-10 m^3/s**	**State 3**	**10-30 m^3/s**	**State 4**	**>30 m^3/s**

[3] *This estuary is classified as a river mouth, but under extended periods of very low base flows this system can close. The actual cut-off flows for closure is unknown due to a lack of data, but for the purposes of this study it is assumed to be base flows less than 1 m^3/s. Based on the scenarios provided, such a severe reduction in base flows are not expected in future and for this reason the close state has not been included as a typical Abiotic State for this permanently open estuary, at least not at this stage.*

Table 3-4: Summary of the monthly flow (in m³/s) distribution under the present state

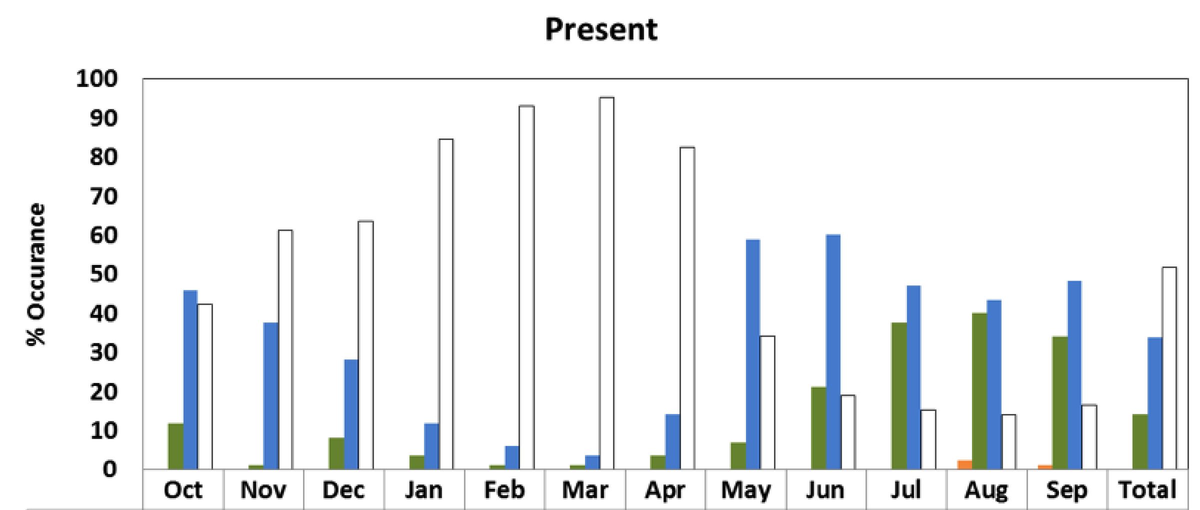
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	315.1	456.0	428.2	606.6	662.5	728.9	370.6	212.3	310.5	265.4	145.1	315.6
90%ile	112.1	216.4	259.2	322.5	514.7	386.4	154.2	67.9	50.1	36.4	43.7	70.0
80%ile	68.4	112.2	183.9	199.0	288.3	263.6	113.3	50.4	27.9	27.2	23.3	27.1
70%ile	45.8	79.4	151.0	139.9	213.1	222.5	99.8	33.7	20.1	20.3	16.7	21.2
60%ile	30.5	56.8	75.1	110.9	154.6	172.0	70.6	22.4	17.2	16.6	13.0	17.0
50%ile	21.9	38.8	52.5	85.4	127.5	138.5	62.5	20.5	14.2	12.0	11.3	14.0
40%ile	18.1	31.7	32.7	65.8	91.8	112.4	41.9	18.7	12.0	10.1	9.6	11.4
30%ile	15.7	22.8	24.2	50.0	68.1	78.5	35.7	14.7	10.8	9.4	8.7	8.2
20%ile	12.6	18.1	18.8	39.9	51.0	54.6	32.0	12.2	9.9	8.3	7.3	7.5
10%ile	9.9	14.2	11.2	21.6	37.0	45.2	19.4	10.8	8.0	7.0	6.4	6.4
1%ile	5.8	10.2	5.2	8.3	15.1	14.0	8.9	6.6	5.8	4.2	2.9	3.1

Table 3-5: Simulated monthly flows (m³/s) under present state

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	15.6	14.8	19.2	21.8	128.5	224.2	131.6	43.1	16.9	10.2	7.2	11.8
1921	18.6	287.9	249.7	68.9	21.3	14.8	9.1	84.0	77.3	37.0	43.2	27.1
1922	65.0	190.2	82.7	223.4	529.5	273.7	62.5	12.1	11.4	246.8	101.2	14.2
1923	10.2	8.7	18.3	94.7	136.4	91.7	31.7	11.9	10.5	8.1	8.9	15.2
1924	14.8	21.9	372.0	140.4	46.7	573.3	340.5	73.0	15.7	10.2	7.5	11.1
1925	12.1	22.9	19.4	63.7	38.2	295.7	114.6	18.8	26.3	18.7	9.8	27.4
1926	37.4	31.9	54.2	35.0	36.5	678.2	244.6	14.6	9.0	9.9	11.5	9.9
1927	30.4	22.0	105.9	293.5	168.7	84.7	32.0	12.2	10.5	8.4	14.0	12.7
1928	15.8	24.2	54.8	40.1	45.0	255.0	96.1	16.8	50.4	52.5	26.9	103.8
1929	95.3	87.7	130.9	131.7	48.1	86.7	56.5	20.5	18.2	16.5	44.0	33.7
1930	22.4	13.8	30.3	321.7	315.5	287.1	110.0	22.1	10.7	362.8	138.8	13.1
1931	18.0	22.8	92.4	41.6	289.2	115.5	21.5	15.2	16.7	20.4	14.6	57.2
1932	49.1	222.8	183.3	47.7	17.1	53.5	31.7	11.3	8.0	8.4	7.3	6.2
1933	5.2	351.1	368.2	579.5	211.7	140.7	63.7	16.4	12.0	27.5	18.1	8.4
1934	30.3	77.5	173.0	72.4	27.9	66.3	122.6	93.9	82.8	35.6	30.2	20.1
1935	12.8	11.3	5.9	10.9	279.0	161.3	40.7	68.2	40.4	18.4	10.6	8.9
1936	28.5	518.7	181.4	65.4	493.0	202.5	35.5	10.4	8.6	7.8	6.5	7.5
1937	11.6	12.8	36.5	120.0	267.0	89.3	120.7	53.7	21.7	24.6	22.0	14.0
1938	17.7	38.8	263.5	234.7	704.3	215.8	22.3	18.6	16.0	20.6	18.6	135.4
1939	85.5	56.6	33.3	24.1	435.9	230.9	60.1	126.8	63.4	16.8	9.5	25.5
1940	21.9	25.2	74.9	108.0	128.8	61.6	42.4	20.8	10.8	10.4	9.7	7.8
1941	20.4	16.4	7.0	61.1	330.2	256.4	95.9	40.2	18.7	9.8	12.5	18.0
1942	44.7	300.9	384.8	187.9	51.1	158.9	204.8	77.5	34.8	25.6	178.1	85.2
1943	77.5	353.0	288.7	120.6	102.6	137.6	52.5	12.1	20.2	20.0	10.8	202.4
1944	90.8	17.7	5.4	45.5	220.3	233.9	74.3	13.6	10.4	8.0	6.1	5.2
1945	36.9	19.3	10.6	123.7	98.9	149.2	68.2	24.6	15.0	10.5	7.5	6.4
1946	9.9	35.4	43.5	94.2	145.4	196.0	85.2	19.0	49.5	33.3	12.9	13.8
1947	18.2	339.9	229.5	162.9	288.1	259.3	91.0	20.7	11.4	8.4	6.4	5.2
1948	17.6	15.2	10.6	41.7	60.6	51.4	35.3	18.8	10.2	8.8	7.5	7.5
1949	8.6	15.3	22.2	28.7	259.6	401.0	134.2	49.3	27.1	17.6	58.5	34.6
1950	24.6	18.2	210.7	100.1	121.5	62.8	23.8	12.3	9.2	7.4	12.8	24.5
1951	53.1	22.7	6.7	39.2	198.4	85.3	32.3	20.0	14.2	12.5	9.1	15.4

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1952	15.9	23.5	75.4	50.0	50.6	38.7	38.3	20.9	9.7	6.9	7.9	25.9
1953	55.4	58.8	52.5	40.2	60.4	107.7	49.7	67.5	53.4	24.1	10.8	12.3
1954	47.1	38.7	23.4	530.2	536.3	131.5	38.8	21.8	20.4	14.5	7.7	10.2
1955	16.5	35.5	23.3	14.5	164.0	290.1	103.1	19.9	17.7	12.0	7.8	10.7
1956	21.3	98.7	420.6	323.0	150.3	252.9	109.3	22.9	14.1	12.1	18.8	87.2
1957	75.1	33.4	34.7	201.7	121.9	37.5	63.4	36.8	14.2	9.9	7.4	7.3
1958	7.5	128.5	224.1	77.2	74.1	48.8	62.8	428.9	160.9	32.0	31.0	19.2
1959	15.7	26.4	31.9	53.5	44.4	37.6	36.2	23.2	12.5	8.6	10.5	18.1
1960	17.8	54.2	160.7	78.3	56.0	125.8	137.9	53.4	16.8	10.1	9.2	8.1
1961	5.9	74.2	53.8	45.2	213.3	189.0	63.8	16.7	10.8	7.5	8.6	7.0
1962	12.3	111.0	69.8	391.2	212.4	526.0	198.3	24.7	12.2	37.1	22.8	7.7
1963	126.6	173.0	68.1	137.3	67.2	138.5	102.2	32.2	308.8	121.1	16.8	15.3
1964	100.9	43.6	16.9	37.8	90.3	36.0	14.4	15.4	195.3	105.7	56.7	30.0
1965	73.5	94.0	30.0	260.5	128.1	17.1	9.4	50.1	32.1	11.9	13.5	17.0
1966	12.7	11.3	29.4	187.5	152.4	464.7	258.0	62.0	27.6	29.4	17.6	7.6
1967	11.4	18.6	15.1	14.6	25.1	49.3	32.2	12.8	7.4	6.9	9.6	14.1
1968	12.9	14.9	12.1	8.6	57.5	229.4	93.0	33.7	19.4	11.0	8.8	6.9
1969	33.7	23.0	28.9	21.5	59.1	26.7	7.7	9.5	15.3	11.3	72.2	65.6
1970	119.6	55.2	18.9	94.8	84.7	44.2	32.5	51.7	30.9	28.4	46.0	24.7
1971	177.0	81.1	27.0	131.6	459.3	261.3	65.5	15.5	11.9	9.2	6.8	6.6
1972	9.9	93.9	40.0	17.2	280.6	175.6	64.1	20.5	9.9	9.4	11.3	14.6
1973	14.5	59.5	37.1	400.9	428.2	499.1	165.1	62.2	37.7	18.2	11.1	6.6
1974	7.5	73.6	56.8	35.3	46.0	55.0	33.0	13.0	7.7	6.5	6.2	65.4
1975	30.5	19.6	468.4	569.5	529.2	995.0	326.0	66.0	33.2	14.6	9.2	21.7
1976	313.3	116.7	13.3	66.1	120.3	79.1	36.3	14.5	11.1	9.9	8.8	21.5
1977	58.1	41.3	67.7	62.3	52.6	169.8	529.0	171.1	18.9	9.5	11.4	29.3
1978	67.2	57.6	172.2	64.5	87.5	47.7	28.2	20.1	12.6	29.8	27.1	26.8
1979	17.8	11.2	13.0	85.4	127.5	53.5	18.0	9.7	7.3	7.2	4.8	103.4
1980	48.1	44.2	22.6	115.1	211.9	68.4	15.6	23.5	19.3	10.0	19.1	17.7
1981	10.0	14.9	24.0	55.0	85.5	273.0	113.0	19.9	18.5	20.7	11.4	11.4
1982	76.5	37.8	4.4	6.8	4.3	9.7	15.0	10.1	7.4	21.0	11.1	11.4
1983	18.6	96.0	194.2	105.6	77.0	130.2	101.4	33.9	17.6	25.0	15.2	7.2
1984	33.6	44.9	16.4	165.8	618.9	177.8	12.3	6.8	5.8	5.0	2.9	3.5
1985	273.7	135.5	127.0	213.2	108.7	54.8	27.2	10.1	8.5	7.4	16.2	22.0
1986	130.4	127.7	41.9	25.3	35.2	65.8	33.6	9.7	10.6	8.0	25.4	910.0
1987	324.9	56.5	30.1	50.1	549.8	364.7	100.1	36.6	23.1	17.7	13.2	11.8
1988	14.1	57.1	186.4	103.0	537.7	183.8	133.5	57.5	16.0	13.0	6.6	3.0
1989	35.3	444.0	172.2	70.7	29.8	303.7	135.5	22.1	12.4	9.6	13.8	7.3
1990	18.8	10.5	37.9	137.9	157.8	52.7	11.0	5.5	6.1	4.6	2.7	7.5
1991	246.1	118.3	161.7	69.6	81.7	46.6	25.9	11.6	6.1	4.3	6.4	6.4
1992	7.1	16.1	8.2	9.5	53.8	118.5	52.7	11.7	5.6	3.6	5.5	19.8
1993	140.9	79.8	153.3	203.9	247.7	320.5	103.7	9.9	8.1	13.8	14.2	5.8
1994	6.5	18.3	21.8	73.9	37.7	175.2	111.9	31.8	25.5	17.8	7.3	7.8
1995	21.6	31.4	369.9	613.3	535.8	162.7	40.3	14.5	11.3	27.2	16.8	8.1
1996	13.9	206.7	220.4	327.8	172.0	117.4	98.6	40.7	319.6	130.8	26.6	12.1
1997	18.3	37.8	17.7	106.3	654.5	414.1	97.9	20.8	12.0	9.2	11.7	8.9
1998	8.4	87.5	156.8	146.9	236.2	130.8	41.3	13.2	8.5	6.9	4.5	3.2

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1999	28.7	25.6	321.6	605.3	442.3	638.6	288.3	74.5	28.9	12.6	7.1	17.0
2000	28.2	38.3	77.2	162.9	130.8	96.5	53.6	20.8	11.9	11.7	11.7	14.3
2001	42.7	371.0	252.8	154.8	92.8	148.5	59.4	33.5	24.6	44.2	105.9	72.9
2002	25.6	11.8	25.2	49.2	35.1	66.3	38.0	16.2	12.0	8.4	7.3	17.9
2003	12.1	10.7	6.9	19.0	71.9	159.4	65.3	13.1	10.1	35.1	27.8	96.6
2004	46.1	64.6	141.8	198.3	99.7	78.4	35.6	11.5	8.6	6.6	6.3	4.4



	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	2	1	0
State 2	12	1	8	4	1	1	4	7	21	38	40	34	14
State 3	46	38	28	12	6	4	14	59	60	47	44	48	34
State 4	42	61	64	85	93	95	82	34	19	15	14	16	52

Figure 3-2: Percentage occurrence of the various abiotic states under present conditions

3.4.4 Abiotic States under the Reference Condition

According to the hydrological data provided for this study, under the Reference condition the natural MAR into the Mzimvubu Estuary was 2 665.6 million m^3.

The flow distributions (mean monthly flows in m^3/s) under the Reference condition, derived from an 85-year simulated data set are provided in Table 3-6).

A graphic representation of the percentage occurrence of the various abiotic states is presented in Figure 3-3.

The 85-years of simulated monthly runoff data under the Reference condition are provided in Table 3-7.

Table 3-6: Summary of the monthly flow (in m³/s) distribution

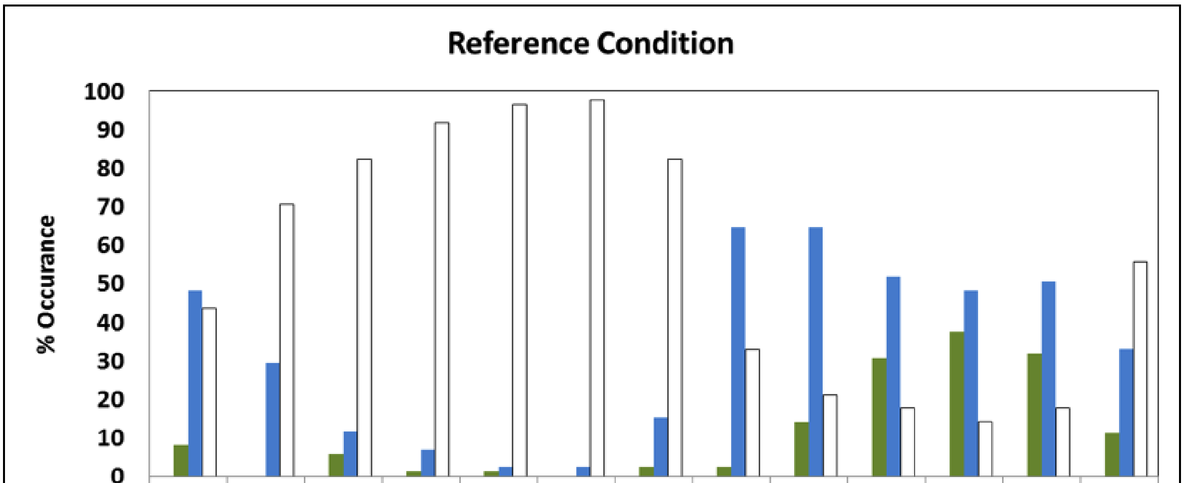
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	316.0	460.9	414.2	602.1	636.4	690.4	405.5	239.4	253.1	254.0	129.0	291.1
90%ile	117.2	241.5	258.6	324.8	501.7	387.9	171.5	69.4	49.8	36.3	37.7	57.4
80%ile	67.3	125.7	201.0	204.0	315.1	267.2	126.0	58.3	30.4	26.3	21.5	27.2
70%ile	44.7	80.8	162.4	154.3	236.0	209.9	109.3	35.0	20.8	19.9	17.0	20.5
60%ile	36.9	64.2	88.4	124.8	171.2	189.2	82.5	25.2	18.4	17.3	13.6	15.7
50%ile	25.5	51.1	61.0	99.9	127.5	150.5	64.2	21.9	15.1	12.7	11.7	14.1
40%ile	20.5	39.8	48.7	74.6	103.2	109.4	51.8	19.2	12.8	11.0	10.5	11.9
30%ile	17.5	30.7	35.5	63.5	75.3	83.5	41.5	16.5	11.5	10.1	9.1	9.7
20%ile	14.2	20.4	30.6	50.3	60.0	62.8	33.2	13.4	10.7	8.9	8.3	8.3
10%ile	10.8	14.2	17.4	41.7	45.7	45.7	23.1	12.6	8.9	7.7	7.1	7.0
1%ile	6.6	11.2	5.8	11.0	18.6	14.8	9.1	8.4	7.2	5.6	4.4	4.7

Table 3-7: Simulated monthly flows (m³/s) under Reference Condition

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	25.5	21.3	35.2	41.5	77.4	171.7	105.9	36.7	16.7	10.9	7.8	10.7
1921	23.9	247.9	243.6	74.5	24.5	14.9	8.7	95.5	83.4	38.3	38.6	24.3
1922	40.8	213.6	88.0	231.0	488.9	266.3	63.2	13.2	11.4	239.6	103.4	15.3
1923	10.3	10.2	32.2	75.7	141.5	83.3	25.9	12.8	11.5	8.7	9.4	14.1
1924	17.4	37.8	355.2	144.6	51.1	559.9	340.6	70.2	17.4	11.2	8.2	11.1
1925	11.7	44.2	30.7	48.5	51.4	251.4	111.1	19.8	26.8	19.3	10.3	23.8
1926	36.6	36.0	68.2	52.0	40.5	632.3	258.4	20.2	10.3	9.9	11.7	10.7
1927	26.6	17.4	136.5	315.0	187.0	80.3	30.7	13.5	11.4	8.9	13.7	11.7
1928	14.4	28.9	70.2	38.3	69.5	270.8	114.9	18.0	47.3	51.8	26.9	58.6
1929	121.3	101.4	134.9	162.9	60.0	90.1	60.4	21.4	18.8	16.9	36.2	31.6
1930	26.0	13.4	30.4	335.5	339.5	287.7	113.7	24.9	11.9	329.6	125.1	13.3
1931	21.0	26.3	61.0	42.1	283.6	129.6	23.4	16.1	16.6	20.0	15.1	55.6
1932	53.1	254.2	219.3	63.9	20.9	77.4	41.5	12.1	8.5	8.1	7.1	6.5
1933	5.8	321.3	383.2	659.0	292.2	176.9	73.5	16.7	12.8	32.2	18.9	8.6
1934	24.8	57.5	207.4	99.9	31.8	68.8	120.6	94.7	88.8	37.1	30.7	19.6
1935	13.2	11.4	5.4	21.0	323.7	187.9	42.3	72.3	46.9	19.8	11.4	9.7
1936	44.2	514.1	198.8	87.0	513.2	240.9	48.8	12.6	9.5	8.4	7.1	8.6
1937	14.6	12.2	55.7	159.3	247.6	89.1	135.0	59.2	20.9	23.2	21.1	13.0
1938	20.4	39.8	200.3	248.5	700.1	230.8	26.4	19.5	17.0	21.0	18.6	149.8
1939	100.0	64.6	46.3	47.8	372.8	209.9	60.9	97.9	63.6	18.5	10.6	15.5
1940	27.2	38.1	80.4	110.0	121.1	66.7	41.8	18.7	11.5	10.5	9.7	7.8
1941	15.8	16.7	8.7	72.9	327.5	275.3	128.7	61.6	21.7	10.8	12.7	15.9
1942	62.8	271.3	372.1	215.8	59.9	164.7	197.1	76.2	35.6	25.9	149.5	94.0
1943	83.7	269.3	315.6	155.4	108.9	147.4	56.4	13.2	19.2	19.7	11.1	190.2
1944	94.6	19.9	5.8	49.1	213.1	249.9	95.0	17.3	11.4	8.6	6.6	5.8
1945	44.2	20.5	15.5	125.0	107.3	156.1	74.9	26.5	14.6	10.7	8.0	6.7
1946	11.0	51.0	58.1	111.1	140.5	193.0	106.3	25.6	52.2	33.2	13.5	14.0
1947	17.9	322.2	258.5	201.2	312.9	243.4	93.9	21.9	12.1	9.2	7.1	5.9
1948	28.0	19.4	18.1	46.6	104.9	81.8	46.5	19.4	11.1	9.6	8.4	8.7
1949	9.6	18.9	34.5	56.6	250.5	393.2	152.9	48.8	26.2	17.8	52.4	36.3
1950	29.2	20.0	236.8	140.5	127.5	68.5	24.1	13.0	9.8	7.8	12.6	23.8
1951	77.3	32.8	9.2	52.7	222.8	114.7	40.2	21.1	14.8	12.8	9.2	13.4
1952	15.7	29.9	76.5	67.4	83.1	54.6	53.8	24.3	10.5	7.6	8.5	27.6
1953	52.7	66.0	80.6	68.9	80.7	128.8	57.5	58.1	51.5	24.2	11.7	13.8
1954	65.8	52.4	34.4	516.5	565.2	167.7	51.6	22.7	20.5	14.9	8.4	10.3
1955	22.5	50.8	33.7	24.7	136.0	300.0	116.2	22.8	19.1	12.7	8.4	10.7
1956	17.1	139.2	406.6	331.3	156.6	283.1	129.1	26.5	15.1	12.9	18.9	65.3
1957	86.1	47.0	46.5	214.8	145.5	47.4	65.3	35.2	14.4	10.6	8.0	7.6
1958	7.8	133.1	198.8	92.5	71.3	53.1	64.6	382.5	164.0	33.1	28.8	20.6
1959	16.4	38.1	50.2	45.5	56.5	38.6	42.6	24.7	12.7	9.4	10.8	20.6
1960	17.9	62.3	174.3	105.4	69.6	120.2	146.3	62.1	18.2	10.8	9.5	8.8
1961	6.8	63.9	89.1	73.2	210.0	193.1	74.5	18.9	11.7	8.2	8.9	7.5
1962	18.6	116.6	100.2	404.8	253.2	521.8	201.5	26.2	12.8	35.2	21.4	8.3

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1963	105.4	196.2	89.6	150.2	81.7	149.1	116.9	35.6	237.2	101.4	18.6	17.1
1964	111.1	51.1	41.9	50.6	105.2	35.2	14.0	13.0	199.8	107.6	59.7	31.2
1965	73.4	124.5	41.0	174.1	166.3	38.0	10.4	59.3	34.5	12.5	13.1	17.2
1966	13.4	13.7	30.2	120.1	238.0	533.0	284.3	66.6	31.0	32.4	18.6	8.8
1967	12.7	31.8	21.6	20.3	40.6	44.1	38.7	15.5	8.1	7.1	9.7	14.1
1968	15.4	24.3	17.0	11.4	57.3	245.3	109.4	34.0	19.6	11.8	9.3	7.9
1969	40.3	30.4	54.1	46.1	79.7	35.2	9.2	10.6	16.7	11.8	68.3	49.2
1970	138.1	66.0	32.0	104.0	115.8	54.9	33.2	50.3	30.5	26.4	51.0	27.1
1971	174.5	83.5	34.7	124.7	448.2	245.8	64.2	17.3	13.1	10.0	7.3	6.7
1972	10.7	130.2	57.9	29.6	270.5	192.9	67.4	21.4	10.9	9.8	11.8	14.6
1973	20.5	66.6	54.0	392.3	407.6	510.3	183.9	68.3	39.4	19.3	11.6	7.3
1974	7.4	75.1	90.1	74.7	50.8	59.4	37.4	13.6	8.6	7.3	6.4	73.5
1975	35.1	34.5	454.3	591.3	576.0	995.3	359.4	67.8	32.5	15.6	10.4	22.2
1976	307.9	123.9	16.1	63.4	110.0	86.2	45.8	16.4	11.3	11.3	10.8	28.8
1977	52.0	53.1	64.0	92.3	71.0	150.5	648.0	212.1	21.7	11.0	11.7	21.1
1978	64.3	57.7	151.5	75.5	61.3	44.6	29.4	17.0	10.8	30.0	25.7	16.8
1979	18.2	13.1	19.2	54.0	97.1	58.8	22.8	11.5	8.5	7.5	5.7	82.2
1980	40.2	61.4	37.9	95.2	228.1	87.8	19.1	24.4	19.4	10.8	17.2	17.2
1981	11.8	23.3	52.2	61.3	60.4	299.5	137.0	24.3	18.6	20.5	12.1	14.0
1982	37.4	45.7	14.1	8.7	6.8	14.1	17.9	11.1	7.6	19.5	11.1	12.0
1983	20.3	100.5	192.0	147.9	110.3	160.6	108.9	33.5	19.3	26.2	15.9	9.0
1984	44.8	64.5	24.7	179.3	624.3	200.4	17.6	8.6	7.2	6.3	4.5	4.6
1985	214.6	183.6	179.1	230.2	178.5	91.3	35.9	12.1	9.9	8.9	16.1	24.0
1986	146.9	174.1	59.7	45.7	47.1	73.6	40.7	11.7	11.8	9.3	21.8	821.0
1987	358.4	79.7	38.2	52.1	515.2	379.9	112.5	39.8	25.4	19.9	16.1	14.5
1988	19.3	73.4	217.0	125.0	510.3	191.1	143.8	61.1	18.2	16.2	9.1	4.8
1989	40.5	450.7	211.8	102.0	44.8	203.2	104.2	23.4	14.6	10.5	16.0	10.0
1990	21.6	12.4	37.0	95.1	100.5	42.8	12.8	7.7	7.6	5.9	4.1	13.5
1991	200.2	111.2	165.7	66.3	74.8	52.7	25.7	12.6	7.7	5.8	6.7	8.3
1992	8.0	17.1	9.1	13.8	38.4	63.7	36.0	13.2	6.9	4.9	5.9	14.5
1993	138.8	81.0	165.2	190.7	268.0	314.2	100.3	12.5	10.1	14.5	15.7	7.6
1994	8.3	14.9	33.3	74.3	55.6	209.8	138.9	36.0	28.3	19.8	9.0	8.2
1995	19.2	29.7	358.6	588.9	569.7	196.6	47.2	16.5	11.8	26.2	17.3	9.5
1996	17.0	231.9	204.0	299.3	178.7	101.4	106.7	48.1	336.6	147.0	32.1	15.5
1997	22.7	40.9	20.5	131.2	603.2	463.2	125.3	28.3	15.6	12.6	14.1	11.2
1998	11.5	105.0	183.5	137.8	215.1	146.6	51.9	15.1	10.3	8.5	6.1	4.7
1999	43.2	39.8	258.7	544.4	416.9	547.4	269.3	79.1	30.4	14.4	8.7	17.2
2000	30.7	50.5	85.0	161.1	140.1	97.6	56.2	21.9	12.8	11.7	11.5	14.9
2001	52.4	363.6	279.8	155.9	68.3	134.7	74.0	25.8	22.6	39.2	71.2	53.4
2002	22.6	13.4	39.7	59.8	37.3	57.0	32.9	17.3	13.6	9.6	8.5	20.1
2003	12.0	12.5	18.1	110.1	82.4	169.5	70.9	14.3	10.9	28.7	25.1	109.4
2004	49.9	57.5	135.6	269.1	136.6	84.1	39.5	14.9	10.1	7.6	8.0	6.4

State 1	**1-3 m^3/s**	**State 2**	**3-10 m^3/s**	**State 3**	**10-30 m^3/s**	**State 4**	**>30 m^3/s**



	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	8	0	6	1	1	0	2	2	14	31	38	32	11
State 3	48	29	12	7	2	2	15	65	65	52	48	51	33
State 4	44	71	82	92	96	98	82	33	21	18	14	18	56

Figure 3-3: Monthly occurrences of the various abiotic states under the Reference condition

3.5 Hydrodynamic Health

Table 3-8 summarises the hydrodynamic health scoring undertaken by the specialist team.

Table 3-8: Calculation of the hydrodynamics score

Variable	Motivation	Score	Confidence
Mouth condition and abiotic states	No change from reference condition	100	M
Hydrodynamics and mouth conditions score	The first score was considered an adequate representation of all of the above	100	H

3.6 Water Quality

3.6.1 Baseline Description and Reference Condition

The water quality assessment considered the following variables:

- System variables - salinity, temperature, pH, dissolved oxygen and suspended solids/turbidity (and secchi depth);
- Dissolved inorganic nutrients - dissolved inorganic nitrogen, dissolved inorganic phosphate and dissolved reactive silicate;
- Organic matter as represented by Total phosphorus; Kjeldahl nitrogen[4] and Particulate organic carbon (limited data only).

[4] *The Kjeldahl method or Kjeldahl digestion in analytical chemistry is a method for the quantitative determination of nitrogen in chemical substances developed by Johan Kjeldahl in 1883.*

Figure 3-4: Location of sampling station during Aug '12 (top) and Jan '13 (bottom) surveys

No data were collected for toxic substances, as this was not considered a serious issue in this catchment. Available literature therefore was assessed. Sampling station for the 2012/13 surveys are indicated in Figure 3-4.

During these surveys the estuary was completely fresh further upstream of the bridge.

For the purposes of this study, the Mzimvubu Estuary was sub-divided into three distinct zones primarily based on bathymetry (Figure 3-5):

- Lower Zone: From mouth to 4 km upstream (34% of volume);
- Middle Zone: From 4 - 10 km upstream (33% of volume); and
- Upper zone: From 10 - 14 km upstream (33 % of volume).

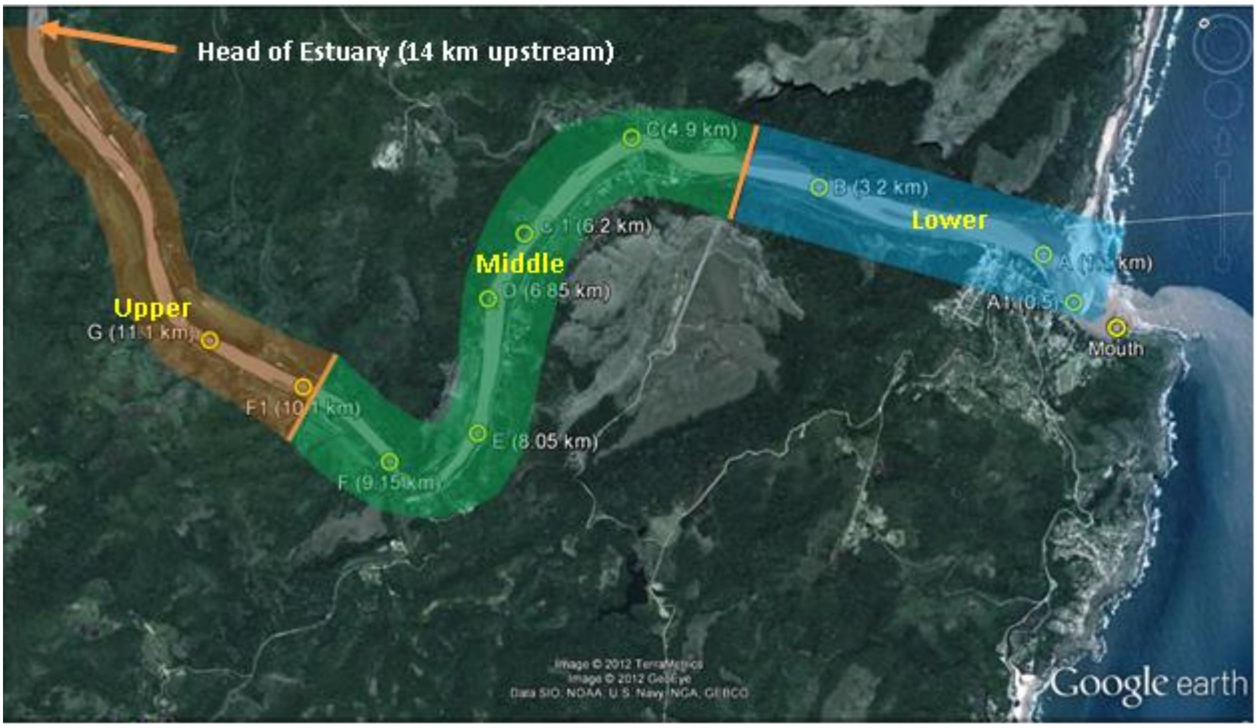


Figure 3-5: Zones identified in the Mzimvubu Estuary

A detailed assessment of the water quality characteristics of the Mzimvubu Estuary is presented in the Abiotic specialist reports attached as an Appendix to this report.

A summary of the typical water quality characteristics of different abiotic states in the Mzimvubu Estuary is provided in Table 3-9.

Table 3-9: Water Quality Characteristics in Different Zones under the Four Abiotic States

PARAMETER		STATE 1: Significant saline penetration			STATE 2: Intermediate saline penetration			STATE 3: Limited saline penetration			STATE 4: Freshwater dominated		
Salinity		30	20	10	25	15	0	20	0	0	5	0	0
Temperature (°C)	Summer	24	24	24	24	24	24	24	24	24	24	24	24
	Winter	18	19	19	18	18	19	18	18	18	18	18	18
pH		8	8	8	8	8	8	8	8	8	8	8	8
DO (mgl/l)		>8	>8	7	>8	>8	>8	>8	>8	9	>8	>8	>8
Turbidity (NTU)	Reference	30	30	50	30	40	60	80	150	150	230	230	230
	Present and Future	40	40	60	40	50	70	90	160	160	250	250	250
DIN (µg/l)	Reference	100	100	80	100	80	80	80	80	80	100	100	100
	Present and Future	100	130	150	120	140	180	130	180	180	180	180	180
DIP (µg/l)	Reference	10	10	10	10	10	10	10	10	10	15	15	15
	Present and Future	10	15	25	15	20	30	15	30	30	30	30	30
DRS (µg/l)		1500	3000	4500	2000	3500	6000	3000	6000	6000	6000	6000	6000

NOTE: *Differences between reference condition and present/future scenarios – due to anthropogenic influences other than flow - are indicated)*
For the purposes of this assessment the estuary was sub-divided into three zones representing from left to right: Lower, Middle and Upper Zones (see Figure 3-5).

3.6.2 *Reference versus present water quality*

Overall changes in water quality parameters are estimated in Table 3-10.

Table 3-10: Summary of Average changes in each of the Three Zones

Parameter	Description of change from Reference to Present	Zone	Reference	Present
Salinity	Salinities have increased slightly from reference due to decrease in baseflows.	Lower	12	13
		Middle	2	2
		Upper	0	0
DIN (µg/ℓ)	Due to increased nutrient input from diffuse sources in the catchment, mainly settlements and cattle herds, concentrations in the estuary increased under Present state (and future scenarios) compared with reference.	Lower	93	154
		Middle	91	174
		Upper	91	180
DIP (µg/ℓ)	Due to increased nutrient input from diffuse sources in the catchment, mainly settlements and cattle herds, concentrations in the estuary increased under Present state (and future scenarios) compared with reference.	Lower	13	23
		Middle	13	29
		Upper	13	30
Turbidity (NTU)	Due to some erosion as a result of catchment practices turbidity in the estuary increased. However, it should be noted that this catchment has naturally and historically introduced turbid waters to the estuary	Lower	158	166
		Middle	182	191
		Upper	184	194
DO (mg/ℓ)	No marked shifts occurred in the dissolved oxygen conditions in the estuary from Reference to Present	Lower	8	8
		Middle	8	8
		Upper	8	8
Toxic substances	Urban development along the banks of the estuary introduced some toxic substances (*e.g.* trace metals) Assume similarity to reference as 90% for present and all future scenarios.	90% similarity between Reference and Present		

3.6.3 *Scoring Present Water Quality*

The similarity in each parameter (*e.g.* dissolved oxygen) to reference condition was scored as follows (Table 3-11):

- 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 = 0.43; Middle = 0.32; Upper = 0.32);
- 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; and
- 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; and
- 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 3-11: Summary of changes and calculation of the water quality health score

	Variable	Motivation	Score	Confidence
1	**Salinity**			
	Similarity in salinity	Increased due to decrease in flow	95	L
2	**General water quality in the estuary**			
a	N and P concentrations	Increased due to nutrient enrichment from diffuse sources	68	
b	Water clarity (measured as suspended solids/turbidity/transparency)	Slight increase associated with erosion in catchment	98	
c	Dissolved oxygen (mg/l) concentrations	No marked changes	100	
d	Toxic substances	Increased accumulation	90	L
Water quality health score[2]			**79**	
% of impact due to non-flow factors				
Adjusted score				

1 Net of non-flow impacts

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

3.7 Microalgae

3.7.1 Microalgal Groups

Two groupings of microalgae were considered in this study (Table 3-12).

Table 3-12: Groupings of microalgae considered in this study with their defining features

Microalgal groups	Defining features, typical/dominant species
Benthic microalgae	There are no large sand or mud flats associated with this estuary so their abundance will be limited in this permanently open river mouth. The MPB community generally consists of euglenophytes, cyanophytes and bacillariophytes (diatoms). Benthic diatoms, typically those living in mud (epipelics), are the most useful indicators of ecosystem health.
Phytoplankton	The phytoplankton can consist of cells from the following groups: flagellates, diatoms, dinoflagellates, cyanophytes, chlorophytes, euglenophytes and coccolithophorids. Flagellates, diatoms, chlorophytes and dinoflagellates were the only groups recorded during the August 2012 and January 2013 sampling session.

MPB: Methane Producing Bacteria

3.7.2 Description of Factors Influencing Microalgae

The factors influencing the different microalgal groups are summarised in Table 3-13. Based on these considerations, the expected influence of the different abiotic states on microalgae is described in Table 3-14.

Table 3-13: Effect of abiotic characteristics and processes on microalgae groupings

	Phytoplankton					MPB
	Cyanophytes	**Dinoflagellates**	**Chlorophytes**	**Diatoms**	**Flagellates**	
Temperature	-	-	-	-	-	-
% Fines: < 63 µm	-	-	-	-	-	⇧ in epipelic diatoms
Salinity	-	-	-	-	-	-
External P input	⇧	⇧	⇧	⇧	⇧	⇧
Grazing	⇩	⇩	⇩	⇩	⇩	⇩
Oxygen	⇧ as O_2 ⇩	-	-	-	-	-
Stratification	-	⇧ in middle reaches	-	-	-	-
External N input	⇧	⇧	⇧	⇧	⇧	⇧
Turbidity	-	-	-	-	-	-
Organic content	⇧	-	-	-	-	-

⇧	Increased concentration
⇩	Decreased concentration

Table 3-14: Summary of phytoplankton biomass of different abiotic states

STATE	Predicted water column chlorophyll *a*
1 – (1-3 m^3/s)	High chlorophyll *a* in response to long residence time and elevated nutrients.
2 – (3-10 m^3/s)	High chlorophyll *a* in response to long residence time and elevated nutrients. Well-developed River Estuarine Interface (REI) with dinoflagellates in response to vertical stratification in the mid and lower reaches.
3 – (10-30 m^3/s)	Elevated chlorophyll *a* in response to nutrients but limited by short residence time. Slight stratification in lower reaches could support low density of dinoflagellates.
4 – (>30 m^3/s)	Slightly elevated chlorophyll *a* in response to nutrients but limited by short residence time.

3.7.3 Survey Method

Seven sampling sites were included for phytoplankton measurements in August 2012 (Figure 3-4), six more in January 2013, and six sampling sites for benthic microalgae were taken in both sampling sessions. Phytoplankton was collected from the mouth to the site where there was no evidence of saline intrusion. Benthic microalgae were collected at sites where there was a clear intertidal zone and were accessible by boat, from the mouth to 6.4 km.

Phytoplankton chlorophyll a: Water samples filtered through GF/C filters then stored in the dark in a cooler box until they could be frozen. Chlorophyll *a* was extracted in 95% ethanol for 24 hours then measured using a spectrophotometer.

Phytoplankton identification: Water samples for phytoplankton enumeration were collected at the surface, 0.5 m, 1.0 m and then at 1.0 m intervals to the bottom. The water samples were fixed with glutaraldehyde solution, placed in 60 ml settling chambers, allowed to settle for 24 hours and then counted using an inverted microscope. Functional and dominant groups were categorised into flagellates, dinoflagellates, chlorophytes (greens), cyanophytes (blue-greens), diatoms and euglenoids.

Benthic chlorophyll a: Replicate intertidal benthic samples were collected from premarked locations (20 mm internal diameter circle) at low tide from each site by scraping a known area of surface sediment (less than 2 mm depth) just above the estuarine water level. Subtidal samples were collected from each site using a 20 mm internal diameter corer attached to an extension pole and the surface sediment was scraped from the core. Both intertidal and subtidal samples were stored in the dark in a cooler box until they could be frozen. The chlorophyll *a* was extracted for 24 hours using 95% ethanol then analysed using a spectrophotometer.

Benthic diatom collection and identification: Samples were taken using a length of PVC piping (~15 mm I.D.) that was drawn across the sediment and allowed to fill with a mixture of surface sediment and water. On the same day the mixture was allowed to settle in a Petri dish.

The following day a sheet of lens tissue paper was placed on top of the wet sediment and ca. 6 hours later the lens tissue was carefully removed with as little sediment as possible. In this way only living cells that had attached to the lens tissue were sampled. The lens tissue from each sample was transported to the laboratory and the diatoms digested using a mixture of saturated $KMnO_4$, concentrated HCl and heat.

The acid cleaned samples were rinsed using distilled water and mounted onto glass slides. Diatom frustules were counted under a light microscope at 1000x magnification and images of the taxa were captured; at least one of every taxon was made into a digital image. All the images were then printed and used in the counting procedure.

3.7.4 Phytoplankton Chlorophyll a and Community Composition

30 August 2012: Average phytoplankton chlorophyll a showed no distinct trend with distance from the estuary mouth, ranging from 3.51 ± 1.41 µg/l at the mouth and 4.58 ± 1.46 µg/l 3.2 km upstream (Figure 3-4).

A single sample was measured for chlorophyll a in the shallow (less than 0.5 m) upper reaches, 10.6 km from the mouth, which had a chlorophyll a content of 10.18 µg/l. Phytoplankton chlorophyll a is usually highest near the surface but this was not the case in the Mzimvubu Estuary where concentrations that are typical of oligotrophic to mesotrophic conditions (less than 10 µg/l) were measured throughout the water column.

The flagellates and diatoms increased in cell density with distance from the estuary mouth suggesting the river was the primary source of these phytoplankton groups. Flagellates increased from 475 ± 243 cells/ml (1.1 km) to a maximum of 3424 ± 216 cells/ml (4.9 km), and diatoms from 4893 ± 683 cells/ml (0.5 km) to 14591 ± 1436 cells/ml (4.9 km). Dinoflagellates were present but in low density at sites in the lower and middle reaches (up to 629 ± 481 cells/ml at 1.1 km).

Chlorophytes were present throughout the estuary with highest densities in the middle and upper reaches (up to 1 295 ± 511 cells/ml at 4.4 km). Total phytoplankton cells was strongly influenced by the high density of diatoms in the estuary, increasing with distance from the mouth. There was a poor association between phytoplankton community structure and chlorophyll *a*; cell density was >10 000 cells/ml from 3.3 km to the head of the estuary, typical of phytoplankton blooms, but chlorophyll *a* was considerably lower than 20 µg/l, the threshold for blooms.

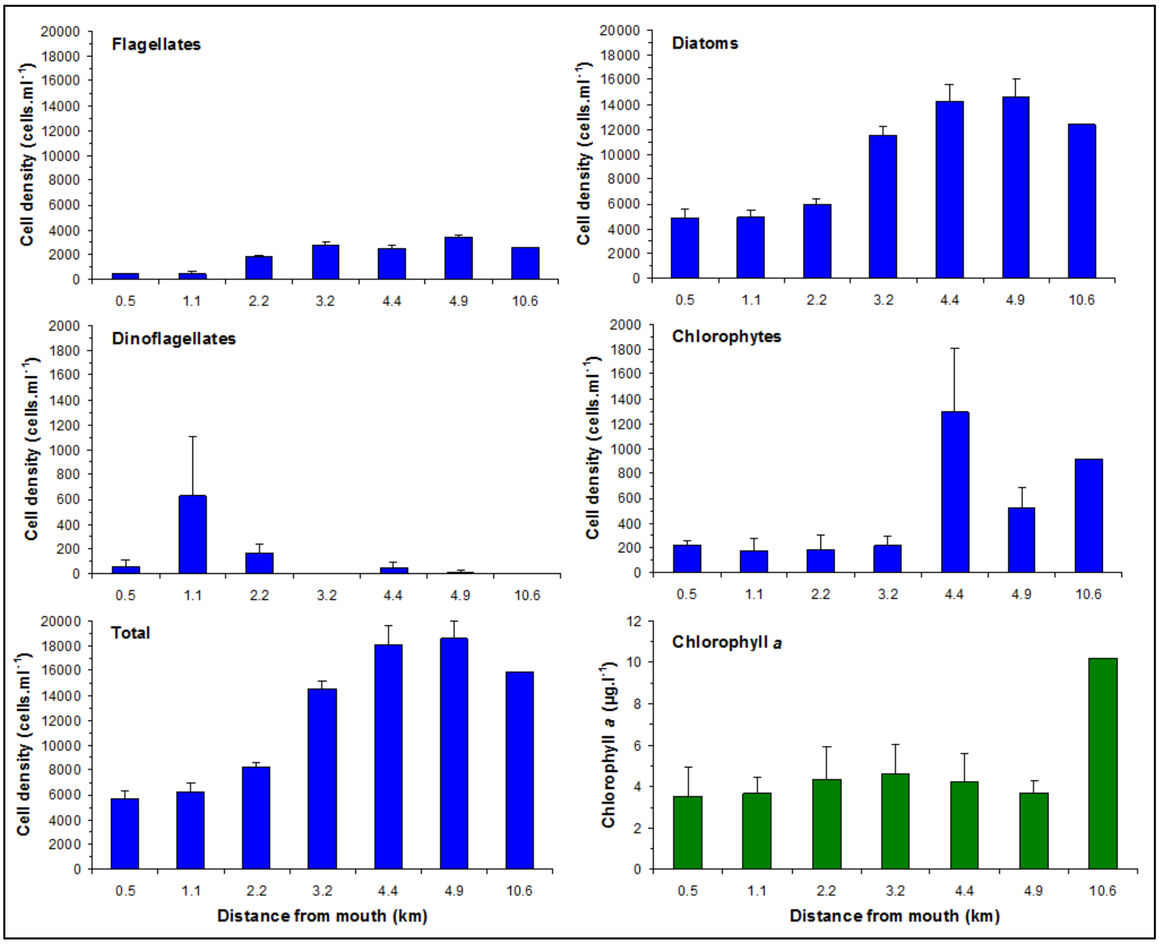


Figure 3-6: Avg phytoplankton community composition and chlorophyll a, 30 Aug '12

30 January 2013: Chlorophyll a was highest (>7 µg/l) in the surface water at the mouth (0.5 and 0.8 km from mouth) and averaged 4.14 ± 0.34 µg/l (3.2 km) to 7.79 µg/l (0.5 km; shallow and well mixed) (Figure 3-7). There were no discernible trends in chlorophyll a with distance from the mouth and with depth, excluding the elevated biomass at the mouth.

All phytoplankton groups had low density (less than 1000 cells/ml) in the turbid, fast flowing waters. The highest density of flagellates were present in the surface water (606 cells.ml^{-1}) 3.2 km from the mouth, with no cells recorded near the mouth. Diatoms were highest at the mouth (711 cells/ml) and gradually decreased in density with distance upstream. Dinoflagellates were present but at low density (less than 100 cells/ml) in the lower 2 km of estuary. There were no chlorophytes recorded. Chlorophyll *a* was highest at the mouth where diatom density was highest but the association between chlorophyll *a* and cell density was poor throughout the rest of the estuary.

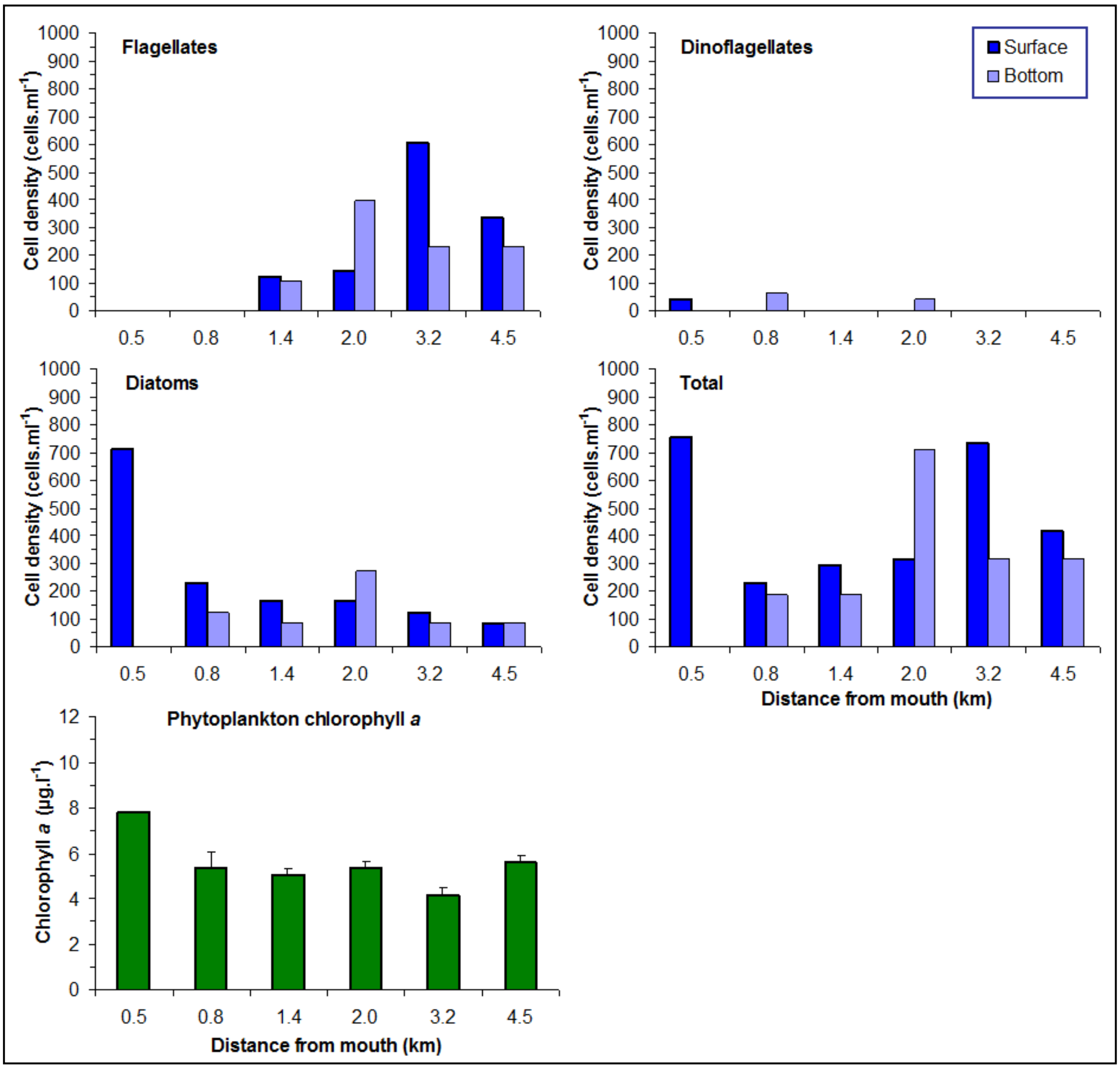


Figure 3-7: Phytoplankton community composition and average chlorophyll a, 30 Jan '13

3.7.5 Benthic Chlorophyll a and Diatom Community Structure

30 August 2012: Average benthic chlorophyll *a* in the intertidal zone ranged from 1.75 ± 0.58 mg/m^2 (0.7 km) to 13.43 ± 0.58 mg/m^2 (1.7 km) (Figure 3-8), and from 1.17 ± 0 mg/m^2 (0.7 km) to 5.26 ± 1.75 mg/m^2 (3.8 km) subtidally. Average benthic chlorophyll *a* content was 6.03 ± 1.41 mg/m^2 (intertidal) and 3.50 ± 0.72 mg/m^2 (subtidal).

The benthic diatoms in the Mzimvubu Estuary were dominated (greater than10% relative abundance at a particular site) by *Navicula gregaria, Nitzschia palea, Encyonopsis minuta* and *Fragilaria fasciculata*. All of these species are cosmopolitan, found in water with elevated electrolyte content and have a broad ecological range; *i.e*. are found in oligotrophic to eutrophic environments making them poor indicators of ecological health.

30 January 2013: Average benthic chlorophyll *a* ranged from 2.74 ± 0.83 mg/m^2 (3.0 km) to 14.21 ± 0.57 mg/m^2 (1.7 km) in the intertidal zone (Figure 3-8), and from 7.41 ± 1.79 mg/m^2 (3.0 km) to 16.44 ± 2.56 mg/m^2 (1.7 km) in the subtidal zone. Average content was 6.78 ± 0.86 mg/m^2 (intertidal) and 10.33 ± 1.00 mg/m^2 (subtidal).

The dominant diatoms included *Navicula cryptocephala, Navicula gregaria, Nitzschia palea, Cocconeis placentula, Denticula kuetzingii, Gyrosigma scalproides, Navicula vandamii, Achnanthes minutissima, Tryblionella calida, Navicula erifuga, Navicula rostellata* and *Cymbella kappii*. Almost all of the species are found in electrolyte-rich environments (excl. *A. minutissima* that favours clean, fresh water). *Cocconeis placentula* is typically found in *meso- to eutrophic* conditions, whereas *N. vandamii*, *T. calida* and *N. erifuga* are found in eutrophic conditions.

The general community composition in the estuary indicates that the estuary was brackish or electrolyte-rich for a period of time leading up to sampling. The species composition is comprised of taxa typically found in oligotrophic environments as well as a number found in eutrophic conditions. However, unlike the Orange River estuary where the vast majority of the 70-plus taxa are indicators of eutrophic conditions, the diatoms in the Mzimvubu Estuary show a broad range of tolerances. This may be representative of drainage from the large catchment, as well as the variability within the estuary itself; relatively undisturbed in the upper reaches and more urbanised near Port St. Johns.

The median content in the intertidal zone was 4.09 mg/m^2 (August 2012) and 5.89 mg/m^2 (January 2013), which is regarded as low (less than 11 mg/m^2) based on the classification scheme of Snow (2008).

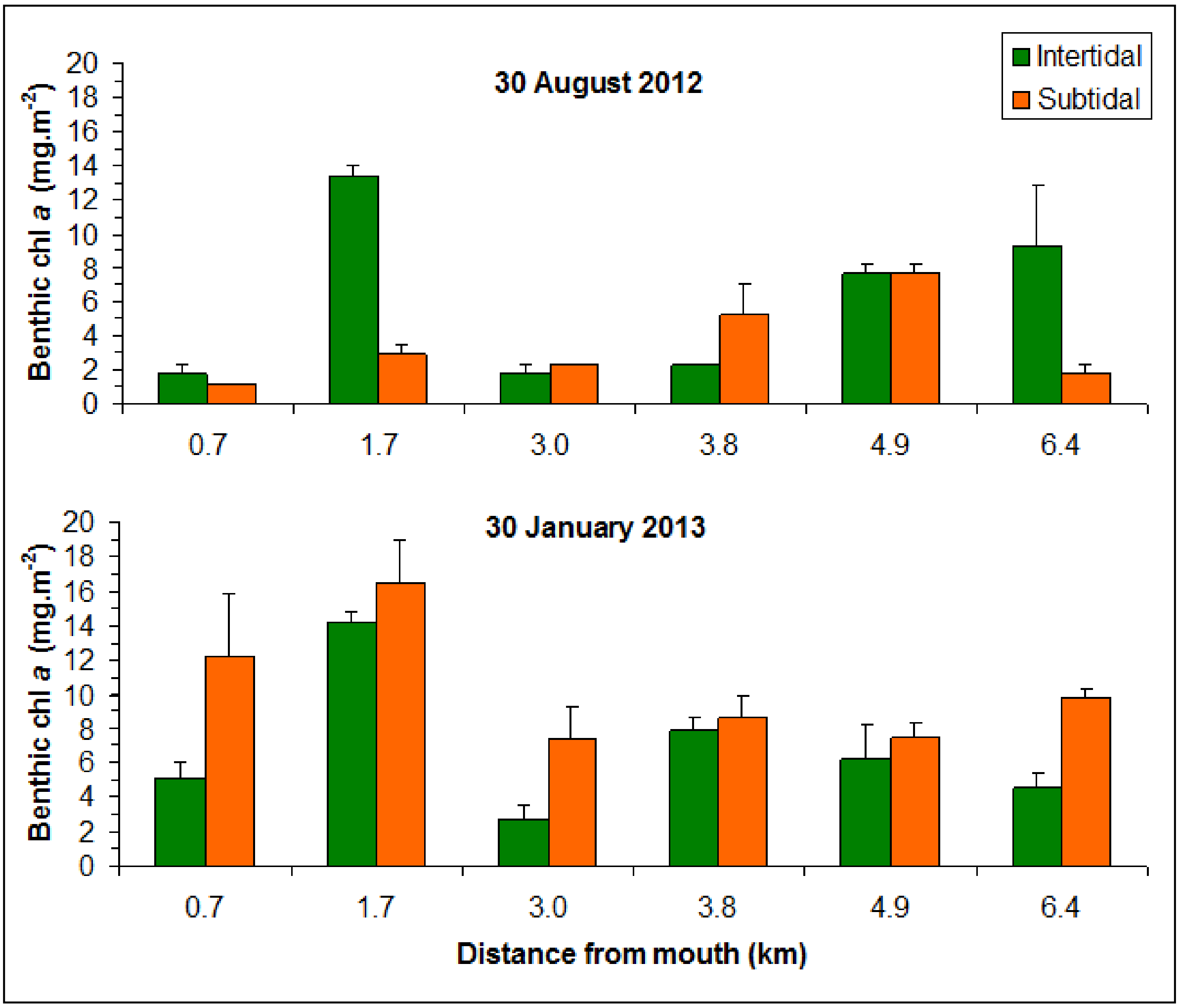


Figure 3-8: Intertidal and Subtidal Benthic Chlorophyll *a*

3.7.6 Reference versus Present: Microalgae

Under reference conditions, the river flow would have been slightly stronger and nutrient concentrations lower resulting in the water having a low residence time, and the benthos would have been a more unstable environment (frequent deposition and scouring events). This would have prevented the establishment of microalgal communities, limiting chlorophyll *a* in the water column to less than 5.0 µg/l and on the benthos to less than 15 mg/m^2. A slight increase in the lower reaches would have been expected during extended periods (greater than2 weeks) of low flow (states 1 and 2). The phytoplankton community would have been dominated by diatoms with fewer chlorophytes and dinoflagellates.

The slight decrease in river flow (~4%), increase in turbidity (~5%) and increase in nutrient concentrations (DIN 54% and DIP 48%) has seen microalgal biomass increase throughout the estuary. Phytoplankton chlorophyll *a* at present is ~5 µg/l during high flows (states 3 and 4) and is likely to increase as residence time and vertical salinity stratification increases (5 to 20 µg/l). As river flow decreases (states 1 and 2) dinoflagellates should become more established in the developing river-estuary interface zone (responding to vertical salinity stratification and nutrients) and the relative abundance of chlorophytes has increased in the river water in response to nutrients.

Benthic chlorophyll *a* has increased slightly in response to slightly lower flows, reduction in floods (~5%), elevated nutrients (particularly in the vicinity of Port St. Johns), and the slight increase in muddiness (~5%), which favours the establishment of epipelic taxa. In addition, ~15% of taxa in the lower estuary at present are typically found in eutrophic conditions. A further reduction in river flow is likely to favour an increase in biomass, a shift in community to epipelic taxa, and an increase in taxa that can tolerate more eutrophic conditions.

Table 3-15: Summary of how the microalgae have changed

Drivers	Changes
River flow	Low residence time limits microalgal growth.
Nutrients	An increase in nutrients (DIN and DIP) favours an increase in microalgal biomass.
Turbidity	An increase in turbidity limits microalgal productivity at depth. Strong turbulence enhances mixing, negating this effect at high flows.

3.7.7 Health of the Microalgae Component

A similar scoring technique was used to estimate the change in phytoplankton and benthic microalgal biomass as used for water quality. Phytoplankton chlorophyll *a* was categorized into low (less than 3 µg/l), medium (3 to < 10 µg/l), high (10 to < 25 µg/l), and very high (>/= 25 µg/l). Similarly, benthic chlorophyll a was categorized into low (less than 10 mg/m^2), medium (10 - < 25 mg/m^2), high (25 to 50 mg/m^2), and very high (>/= 50).

Health scores are summarised in Table 3-16. Ten percent (10%) of the impact on microalgae was thought to be flow related.

Table 3-16: Similarity Scores of Phytoplankton

Variable	Motivation	Score	Confidence
Phytoplankton			
1. Species richness	It is likely that the reduction in river flow and increase in nutrients has increased the chlorophytes and flagellates to similar density as the diatoms. Conditions also favour some dinoflagellates becoming established. As a result, there has been an estimated 40% increase in species richness (based on evenness of phytoplankton groups).	70	M
2. Abundance	Based on the scoring technique used for water quality, it was calculated there would have been a 38% increase in biomass from the reference state. The intrusion of nutrient-rich seawater would have supported a medium level of biomass in the deeper waters in the lower reaches of the estuary.	72	M
3. Community composition	The phytoplankton at present was dominated by flagellates, diatoms and chlorophytes with a few dinoflagellates at normal flow. Cell density would have been much lower during the reference condition and dominated by diatoms with very few cells from the other groups. It is likely that flagellates, diatoms and chlorophytes were present during the reference condition, but conditions favouring the establishment of an REI zone, with associated dinoflagellates would not have occurred as frequently as at present. Expect a 20% change from reference.	65	M
Benthic microalgae			
1. Species richness	There has been only a slight decrease in river flow and flood events so it is unlikely that there was a change in species richness associated with river flow. The slight increase in muddiness and elevated nutrients favours the growth of epipelic taxa (those growing on fines), particularly those adapted to more eutrophic conditions (15% increase).	85	M
2. Abundance	The muddiness of the estuary has increased slightly (5%) and nutrients – particularly in the lower reaches near Port St. Johns – have increased (DIN 54% & DIP 48%) supporting an increase in biomass. However, river flow and the frequency of floods have only decreased slightly from natural (4% and 5% respectively); the benthos is an unstable environment limiting microalgal growth.	83	M
3. Community composition	There has been only a slight decrease in river flow and flood events so it is unlikely that there was a change in species richness associated with river flow. The slight increase in muddiness and elevated nutrients favours the growth of epipelic taxa (those growing on fines), particularly those adapted to more eutrophic conditions (15% increase).	85	M
Microalgal health score		**65**	**M**
% non-flow related impacts; Microalgal growth has been supported through the reduction in river flow as well as elevated nutrients and fine sediment (elevated turbidity through erosion) in river water. The contribution change through non-flow related impacts is probably ~90%.		90	M
Adjusted score		**97**	

3.8 Macrophytes

3.8.1 Macrophyte Groups

The main habitats and macrophytes groups present in the Mzimvubu Estuary are described in Table 3-17.

Table 3-17: Macrophyte Habitats and Functional Groups recorded in the Estuary

Habitat type	Defining features, typical/dominant species	Area (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	345
Intertidal sand and mudflats	Intertidal zone consists of sand/mud banks that are regularly flooded by freshwater inflows. This habitat provides a possible area for microphytobenthos to occur/inhabit. Peripheral species present include the grass species: *Cynodon dactylon* and *Stenotaphrum secundatum.*	26
Swamp forest	Species present include lagoon hibiscus, *Hibiscus tiliaceus*.	5
Mangroves	The following species are present and belong to the Rhizophoraceae family: *Rhizophora mucronata* and *Bruguiera gymnorrhiza*.	0.03
Reeds and sedges	The following species have been recorded, and belong to the families Cyperaceae, Juncaceae & Poaceae: *Bolboschoenus maritimus*, *Schoenoplectus scirpoides, Juncus kraussii, Phragmites mauritianus* and *Phragmites australis.*	16

Note: Species examples in italics.

3.8.2 Species Diversity, Richness and Rarity

The Mzimbuvu Estuary supports mainly reeds and sedges with smaller areas of swamp forest and mangrove habitat. Some salt marsh species are present and these include *Triglochin striata* Ruiz & Pav., *Stenotaphrum secundatum* (H. Walter) Kuntze, *Sporobulus virginicus* (L.) Kunth, *Cynodon dactylon* (L.) Pers, *Juncus effusus* L., *Juncus kraussii* Hochst subsp. *kraussii,* and *Juncus littoralis* C.A Mey*.* The dominant reed and sedge species were *Phragmites australis* (Cav.) Steud and *Bolboschoenus maritimus* (L.) Palla. Swamp forest was represented by lagoon hibiscus *Hibiscus tiliaceous* L. Alien invasive species such as *Lantana camara* L., *Sesbania punicea* (Cav.) Benth. and *Arundo donax* L. were abundant.

The mangroves are probably an opportunistic, temporary habitat. They were recorded in the estuary in 1999 (Adams et al., 2004). This and other habitats in the Mzimvubu estuary are likely very dynamic and change in response to bank scouring by floods and salinity variations. A healthy population of mangroves was found in this study and included *Rhizophora mucronata* Lam., and *Bruguiera gymnorrhiza* (L.). Lam. Beyond the estuarine fringe is lush coastal forest which extends to watersheds up to 60 km from the coast (DWAF 2005). According to DWAF (2005) the coastal vegetation consists of coastal grasslands, valley bushveld, coastal forests and dune forest. On the landward side, this coastal forest is replaced by patches of thicket and bushveld dominated by *Acacia karroo* (Kulukwa et al. 2008).

3.8.3 Description of Factors influencing Macrophytes

The factors influencing the different macrophyte habitats are summarised in Table 3-18. Based on these considerations, the expected influence of the different abiotic states on macrophytes is described in Table 3-19.

Table 3-18: Effect of Abiotic Characteristics and Processes

Process	**Effect on macrophytes**
Mouth condition (provide temporal implications where applicable)	The mouth of the Mzimvubu Estuary is not expected to close, if this were to happen, shallow and fresh conditions would encourage expansion of reeds and sedges. Macroalgae would also grow in response to the calm sheltered nutrient rich conditions. Additionally, lack of tidal exchange would result in a loss of mangroves. The configuration of the mouth influences the distribution of the macrophytes. There is a currently a large reed and sedge area on the northern bank together with some mangroves. In early aerial photographs when the mouth was open to the north this area bare indicating the dynamic nature of the macrophyte habitats and mouth area. High flow prevents the establishment of submerged macrophytes such as *Stuckenia pectinata* (pondweed). Open mouth and saline conditions allow for the growth of mangroves which appear to have colonized during one large event as the older trees are similar in height.
Retention times of water masses	Greater water retention time would provide better opportunities for nutrient uptake by macrophytes thereby favouring their abundance. High flow and frequent flooding currently prevents the establishment of submerged macrophytes and macroalgae which is typical of a river mouth.
Flow velocities (e.g. tidal velocities or river inflow velocities)	Low flow velocities would encourage the growth of macroalgae and reeds and sedges. Fringing reeds and sedges are removed by floods which scour the banks and deposit sediments.
Total volume and/or estimated volume of different salinity ranges	The estuary is mostly fresh or less than 15 ppt and therefore colonized by reeds and sedges. Some mangrove trees (*Bruguiera gymnorrhiza*, black mangrove) have established on the west bank of the estuary near the mouth among the reeds (0.03 ha). There are a number of seedlings but the long term survival of these salt tolerant trees is unknown.
Floods	Floods are important for resetting the estuary and removing accumulated sediment and macrophyte growth. Reduced flooding will result in reed encroachment. Floods would also deposit rich organic mud in the estuary thus having an important nitrifying effect.
Salinity	*Phragmites* spp and lagoon hibiscus *Hibiscus tiliaceus;* the dominant species are indicative of low salinity water and representative of river mouth conditions. The vegetation of the estuary is typical of a low salinity system where salinity is mostly less than 15 ppt.
Turbidity	The Mzimvubu is a high flow naturally turbid system; these conditions prevent the growth of submerged macrophytes.
Dissolved oxygen	Thick mud layers in the lower reaches on the south bank of the estuary were anoxic.
Nutrients	Catchment and surrounding land use changes have introduced nutrients to the estuary. This would encourage macrophyte growth; however the high flow conditions possibly restricts nutrient uptake.
Sediment characteristics (including sedimentation)	Increased sedimentation and a reduction in water depth would increase macrophyte growth.
Other biotic components	No signs of grazing, browsing or disturbance by animals.

Table 3-19: Response of Macrophytes to different Abiotic States

State 1: Significant saline penetration	State 2: Intermediate saline penetration	State 3: Limited saline penetration	State 4: Freshwater dominated
If this state persisted then there would be die-back of reeds and sedges. They will persist where salinity is less than 15 ppt.	Representative of current conditions where reeds, sedges and swamp forest are dominant.	Representative of current conditions where reeds, sedges and swamp forest are dominant.	High flow and water level conditions could limit macrophyte growth.

3.8.4 Reference Condition: Macrophytes

Table 3-20 indicates the percentage change in the abundance (area cover) of the macrophyte habitats in response to the various abiotic changes. The final abundance score is a measure of the similarity in overall abundance for the present state compared to that in the reference state.

The reed and sedge habitat (16 ha) extends along the length of the estuary. There have been localised losses of reeds due to development of property and the removal of reeds to make access to the river easier. However there has been an overall increase in reed and sedge habitat due to colonisation of sand banks on the west bank near the mouth.

The area covered by all macrophyte habitats would be dynamic changing in response to floods. Reeds and sedges would increase in cover in response to reduced flows and stable sediment conditions. The increase in nutrients from reference conditions has probably also encouraged growth as well as the input of sediments from the catchment. Further catchment degradation and an increase in the deposition of fine sediments could lead to the expansion of reeds and sedges.

Riparian vegetation within the 5 m contour of the estuary has been disturbed by human activities with roads running parallel to both banks. Vegetation has been removed to provide views and access to the water channel by numerous resorts along the length of the system. Invasive plant species are prevalent, gum trees occur above the bridge, Spanish reed is found along the banks particularly in the middle to upper reaches. These exotic weeds would have been absent under reference conditions and thus community composition has changed.

There is some macroalgal growth on the rocks possibly indicating nutrient input. They are not abundant in the water column or as epiphytes because of the high river inflow. Sites of point source run-off were observed.

If floodplain area occupies approximately 66 ha, 10 ha are now developed and 26 ha have been transformed as a result of agriculture then this represents a loss of 55% of floodplain habitat. Reeds and sedges have increased from the 1938 aerial photograph from 10 to 16 ha. This represents a 38% increase in this habitat but should be interpreted with caution as a large percentage of this change is due to an increase in area on the east bank of the mouth due to sediment deposition as a result in a change in mouth configuration.

This area could easily be eroded by the next large flood. Swamp forest (5 ha) was difficult to identify from the 1938 aerial photograph and no changes over time were indicated. In the reference condition macrophytes would cover 81 ha, now they cover 51 ha which represents an overall 37% loss of habitat. The 51 ha is composed of 30 ha floodplain vegetation, 16 ha reeds and sedges, 5 ha swamp forest and 0.03 ha mangroves. Approximately 30% of the changes are due to non-flow related impacts with 7% attributed to flow related impacts.

The health of the macrophytes was assessed in terms of species richness, abundance and community composition. 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*present area cover / reference area cover. Macrophytes currently cover 51 ha compared to 81 ha in reference conditions.

Change in community composition was assessed using a similarity index which is based on estimates of the area cover of each macrophyte habitat in the reference and present state. (Czekanowski's similarity index: $\underline{\sum(\min(ref,pres)\ /(}\sum ref + \sum pres)/2$). Alien plants were included as a subgroup for the present state.

Salt marsh was included as an additional macrophyte habitat for Scenario 4 when salinity would increase. The similarity score for the present state (66%) and for Scenario 4 (64 %) did not differ by much because of the small area occupied by these habitats relative to the floodplain area. The index was not sensitive to the two new habitats gained i.e. salt marsh and invasive plants.

Table 3-20: Macrophyte Habitats and Calc. of the similarity in Community Composition

Macrophyte habitat	Reference area cover (ha)	Present area cover (ha)	Minimum
Floodplain	66	30	30
Reeds & sedges	10	16	10
Swamp forest	5	5	5
Mangroves	0	0.03	0
Alien plants	0	5	0
% similarity	Sum min / (sum ref + present) /2	45/(137.03)/2 = 66%	

Table 3-21: Factors influencing Changes from Reference to Present condition

Drivers	Changes
⇩ floods, ⇧low flow conditions, ⇧ nutrient rich sediments	⇧ reeds & sedges, ⇧ swamp forest (disturbance has led to an equivalent loss of habitat)
Development & agriculture	⇩ macrophyte habitat, mostly floodplain
Overall change	⇧ 5% Reeds & sedges ⇧ 5%, swamp forest ⇩55% floodplain

Table 3-22: Similarity scores in the Present condition relative to the Reference condition

Variable	Motivation	Score	Confidence
1. Species richness	Invasive species potentially displaced some species. Species have been lost because of the less dynamic environment.	85	M
2. Abundance	There has also been a loss of reed, sedge and floodplain habitat due to development and disturbance. In the reference condition macrophytes would cover 81 ha, now they cover 51 ha which represents a 37% loss of habitat. There has been a 6 ha gain in reeds and sedges since reference conditions due to change in mouth configuration, sediment and nutrient input.	63	M
3. Community composition	Invasive species have altered the community composition.	66	M
Macrophyte health score		**63**	
% of impact non-flow related -		**30**	
Adjusted score		**93**	

3.9 Invertebrates

Invertebrate species occurring in estuaries typically utilise and depend on a particular suite of biotic and abiotic parameters which determine their relative abundance and distribution throughout the system. In order to predict a response in the invertebrate community structure to changes in these parameters, the estuarine invertebrate macrofauna needs to be classified according to their relative dependence on these parameters.

The classification used in this study is shown in Table 3-23 where the parameters influencing each category are shown. Table 3-24 provides a summary of the invertebrate groupings responses to various abiotic and biotic processes.

Table 3-23: Classification of South African estuarine invertebrate fauna

#	Description	Influencing factors/requirements
1	Polychaetes - estuarine resident (*e.g. Ceratoneries keiskamma*)	Medium to fine sediments; detritus; other edible invertebrates
2	Polychaetes - marine (*e.g. Arenicola*)	Med to coarse sediments; detritus; open mouth; saline water
3	Amphipods	Finer sand/mud; shelter; detritus; POM; reduced salinity
4	Isopods	Coarse sediments; higher salinity; dead matter
5	Gastropods - marine dominated species (detritivores, scavengers & predators *e.g.* Bullia spp.)	Detritus; open mouth; MPB; higher salinity
6	Gastropods - resident sediment living grazers, detritivores & predators (*e.g. Hydrobia sp.*; Assiminea spp.,*Natica sp.*)	Shelter; submerged macrophytes; MPB; detritus
7	Gastropods - grazers associated with macrophytes (*e.g Neritina spp., Cerithidea decollate)*	Shelter; submerged macrophytes; MPB
8	Bivalves - estuarine residents (*e.g. Dosinia hepatica)*	Med-fine sediments; submerged macrophytes; POM
9	Bivalves - marine (e.g. *Donax spp./Tellina spp.*)	Med-coarse sediments; open mouth; POM
10	Crabs - resident estuarine (e.g. *Spiroplax spiralis, Hymenosoma spp.)*	Med-fine sediments; (presence of burrowing prawns for *S. spiralis*)
11	Crabs - marine migrants (e.g. *Scylla serrata*)	Open mouth; favours finer sediments and turbid conditions.
12	Caridean shrimps - marine (e.g. *Palaemon peringueyi*)	Medium-fine sediments; detritus; open mouth; high salinity; submerged macrophytes
13	Carid shrimps - resident (e.g. *Betaeus jucundus*)	Medium-fine sediments; detritus
14	Saltmarsh intertidal invertebrates, *e.g.* marsh crabs	Saltmarsh
15	Insect larvae (*e.g.* Chironomidae, Ceratopogonidae)	Lower salinities
16	Thalassinid mudprawns (e.g. *Upogebia africana*)	Fine sand/mud; open mouth; POM
17	Thalassinid sandprawns (e.g. *Callianassa kraussi*)	Sand; not extended fresh water conditions (>17 to breed); POM
18	Zooplankton - marine	Phytoplankton; open mouth
19	Zooplankton – estuarine resident	Phytoplankton; extended residence time

Note: POM = particulate organic matter, MPB = Microphytobenthos

3.9.1 Baseline Description

Very little research on the invertebrate community of the Mzimvubu Estuary has been undertaken in the past and almost no quantitative data exist. Day (1980) provided a brief account of the benthic invertebrates found during the January 1950 surveys and reported the presence of the following twelve species: on the sands at the mouth the soldier crab *Dotilla fenestrata* and the ghost crab *Ocypode kuhlii,* on the mudbanks the amphipods *Grandidierella bonneroides, G. lignorum* and the thalassinid mudprawn *Upogebia africana;* in the saltmarsh vegetation at high tide the small gastropod *Assiminea bifasciata,* the amphipod *Orchestia ancheidos,* four species of marsh crabs genus *Sesarma* and juvenile fiddler crabs *Uca anulipes*.

The estuary during the 1950's survey was described as having an open mouth with highly turbid conditions but no hydrological information or description of flow was included.

Lower reaches of estuaries usually have sandy bottoms and are more saline whereas the higher reaches are characterised by finer sediment and are less saline (Day 1951). Teske & Wooldridge (2003) have argued that sediment particle size is more important than salinity in limiting the distribution of macrobenthos within several South African estuaries.

During this survey sediments collected during sub-tidal benthic sampling were found to be similar from the mouth to the upper reaches, and dominated by medium to fine sands. This indicated that the mouth, middle and upper reaches of the estuary are experiencing similar water movements.

These results are echoed by the organic content levels which also showed a fairly uniform distribution of percentage total organic carbon (TOC) in sediment samples collected at sites throughout the system. If the Teske & Wooldridge (2003) argument is accepted the similar sediments should have produced similar benthic faunal communities at all stations. In reality the 2012 and 2013 surveys indicated both a very low species diversity and abundance of invertebrates at all stations.

Totals of only nine taxa in August 2012 and two species in January 2013 were recorded. The apparently favourable sediments for benthic macroinvertebrates were overridden by the low salinities and strong outflows prevailing in the system during both sampling periods, but particularly in February.

Zooplankton data are limited to samples collected during August 1977, March 1979 and August 2012. The March 1979 samples were adversely affected by high flows while sampling in February 2013 was abandoned due to flood conditions. Eight taxa were identified to species and one to genus level in the 1977 and 1979 samples.

The 1977 sample consisted virtually entirely of two copepods *Pseudodiaptomus hessei* and *Bestiola (Bestiolina) similis* with a settled sample volume of *ca.* 90 ml. Settled sample volume in March 1979 dropped to 12.3 ml. The 2012 samples produced a greater diversity of 15 taxa identified to species or generic level and an assortment of 13 taxa identified to family or higher level plus various larval stages. The settled volumes in the 2012 samples were all less than 0.5 ml.

A list of the species collected during this study is given in Table 3-23.

3.9.2 Factors Affecting the Invertebrate Fauna

The main factors affecting the abundance of the different invertebrate groups found in the Mzimvubu estuary are summarised in Table 3-24.

Table 3-24: Effect of abiotic characteristics and processes

Factor	Affected categories
Mouth condition (provide temporal implications where applicable)	A restricted or closed mouth would normally lead to a decrease in species richness due to both an absence of marine associated species and reduction or loss of intertidal habitat. An open mouth would also allow increased salinities driven by tidal input. An open mouth is also important for the input of larvae from the marine environment and emigration of late juveniles or adults of dependent fish and invertebrates.
Retention times of water masses	An increase in retention times of water masses will allow increases in the abundance of resident zooplankton. Increased retention times would favour estuarine resident subtidal macrofauna tolerant of reduced salinity
Flow velocities (e.g. tidal velocities or river inflow velocities)	Increased flow velocities would scour and flush the system of fine sediment leaving a greater proportion of coarse sediment. High flow velocities would also flush out zooplankton, whether holo- or meroplankton.
Total volume and/or estimated volume of different salinity ranges	A change in total volume or estimated volume of different salinity ranges would result in a corresponding change in habitat accessible to the invertebrate macrofauna, particularly if the mesohaline area increases (salinity values above 17-20). Associated species would respond accordingly – i.e. marine dominated species would increase with a greater marine volume component and estuarine resident species would retreat to the upper reaches, where there is less habitat available and vice versa.
Floods	A severe flood would scour the system, flushing most macrobenthic invertebrates out to sea and inundating the system with a high sediment load. Therefore an initial decrease in abundance of all invertebrates would be expected followed by a sharp increase as the fauna recovers and exploits the newly available nutrients, detritus and particulate organic matter.
Salinities	Sustained low salinities would have a negative impact for those species with a lack of tolerance of such conditions.
Turbidity	This is a generally turbid system with clearer water periods when tidal effects become more pronounced. The fauna of this system is capable of handling these variations.
Dissolved oxygen	Oxygen levels below ~50% surface saturation will have a negative effect on populations of zooplankton Oxygen levels below ~50% surface saturation will have a negative effect on populations of all other invertebrate species, however, the polychaete *Capitella capitata* will tolerate extremely low values.
Subtidal, intertidal and supratidal habitat	The benthic invertebrate macrofauna occupy intertidal and subtidal habitats and changes in their abundance would correspond to any change in these provided other conditions are suitable
Sediment characteristics (including sedimentation)	Minimal influence on the water column habitat, although *Pseudodiaptomus* spp. does have a preference for muddy substrata. Species composition might also change if sediments change in particle size composition
Phytoplankton biomass	An increase in phytoplankton would result in an increase in zooplankton.
Benthic micro-algae biomass	Increased benthic microalgal biomass will favour burrowing forms.
Zooplankton biomass	Increased zooplankton biomass will favour zooplanktivores.
Aquatic macrophyte cover	There are no reported submerged aquatic macrophytes in the Mzimvubu- all are intertidal. The intertidal riparian fringe reeds, sedges and mangroves tend to trap fine sediments and change sediment composition accordingly with consequent effects on sediment dependent invertebrates.
Fish biomass	Increased predation on invertebrates if fish biomass increases

3.9.3 Reference Condition

All available historical and recent descriptions and data point to an estuary where conditions and processes have been and still are driven by events in the relatively large and hilly catchment. Descriptions going back 150 years point to highly variable conditions at the mouth which appears to have been generally open although with widely varying depths. Reference to “freshets” similarly go back 150 years with comments on rapid increases of several metres in river level.

Such an event would effects environmental changes in terms of, *i.e.* flow rates, salinities, temperatures, turbidities, bed erosion and sediment dispersal, all factors which would critically influence all components of the estuarine fauna. The historical picture and therefore the reference condition would have been one of restricted habitat diversity and physical and chemical variability with a corresponding limiting effect on invertebrate diversity and abundance.

The resident zooplankton has a relatively short recovery time, as shown by the contrasts in zooplankton abundance during low and high flow periods, but macrobenthic diversity characterized by larger, longer lived species would very probably not have the time to recover before the next disturbance.

3.10.1 Health of the Invertebrate Component

Health scores for the invertebrate component are provided in Table 3-25.

Table 3-25: Similarity scores Present condition relative to the Reference condition

Variable	Change from natural	Score	Confidence
1. Species richness	Historical descriptions going back 150 years indicate little if any change in the estuarine environment. While some habitat reduction may have occurred through localized infilling it is highly unlikely that any habitat within the estuary has been totally lost or significantly compromised and consequently it is equally unlikely that species richness has been reduced.	98	H
2. Abundance	It is possible that abundance may have been reduced due to some loss of intertidal habitat.	95	H
3. Community composition	Based on the comments already made in the boxes above there is no indication and no compelling reason to propose a significant change in the community composition.	95	H
Invertebrate score			**95**
Degree to which deviation from natural is due to non-flow related impacts			95%
Adjusted score			99

3.10 Fish

3.10.1 Fish Groups

Estuaries serve as nursery areas for a number of estuarine-dependent marine fish, providing a sheltered, productive environment which is essential to the survival of these species. Apart from these euryhaline marine species, estuarine fish communities are also represented by a combination of stenohaline marine species, those restricted to estuaries, and euryhaline freshwater species (Blaber 1985).

Estuarine fish species can also be divided into functional guilds based on trophic position and food preference. The three primary food sources in estuaries are detritus, phytoplankton and aquatic macrophytes (Bennet 1989), the former representing the dominant food source in subtropical systems.

Table 3-26 provides a classification of South African fish fauna, according to their dependence on estuaries (Whitfield 1994).

Table 3-26: Classification of South African fish fauna

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	a. Juveniles dependant of estuaries as nursery areas
IIb	b. Juveniles occur mainly in estuaries, but are also found at sea
IIc	c. 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 a. Indigenous b. Translocated from within southern Africa c. Alien	Euryhaline freshwater species that can penetrate estuaries depending on salinity tolerance. Includes some species which may breed in both freshwater and estuarine systems. Includes the following subcategories:
V	Obligate catadromous species which use estuaries as transit routes between the marine and freshwater environments

Harrison (2003) was the primary source of data used in this report (add detail). In addition, a reference community for permanently open subtropical estuaries was constructed from taxa that were recorded at a frequency of greater than or equal to seventy percent, from the national fish survey conducted by Harrison (2003).

A total of 1098 fish, representing 28 taxa and 14 families was collected from the Mzimvubu Estuary during Harrison's (2003) nationwide survey. The Mugilidae and Gobiidae families were represented by the most number of species, 7 and 6, respectively.

The Ambassidae, Carangidae and Sparidae families were each represented by 2 species. The Estuarine Round-herring Gilchristella aestuaria was the dominant species in the study accounting for 37.8% of the total catch, followed by the Spotted Grunter Pomadasys commersonnii (19.6 %), and Liza spp. (7.6 %). Collectively the Mugilidae family accounted for 24.7 % of the total catch.

The modelled fish community for subtropical open estuaries was very similar to the actual catches, with only seven species not recorded in the system during the snapshot survey. The species not recorded were: Scomberoides lysan, Hilsa kelee, Leiognathus equula, Liza tricuspidens, Liza macrolepis, Valamugil robustus and Silago sihama.

Table 3-27 lists the Fish collected and percentage contribution in the Mzimvubu during Harrison's nationwide study, and a modelled list determined for permanently open subtropical systems

Table 3-27: Fish collected and percentage contribution in the Mzimvubu

Family	Taxa	EDC	Harrison (2003) modelled	Harrison (2003) no.	Harrison (2003) % contribution
Ambassidae	Ambassis natalensis	I	x	10	0.9
	Ambassis gymnocephalus			31	2.8
Carangidae	Caranx heberi	II			
	Caranx sexfasciatus	II	x	10	0.9
	Caranx ignobilis			6	0.5
	Scomberoides lysan	II	x		
Cichlidae	Oreochromis mossambicus	IV	x	1	0.1
Clupeidae	Gilchristella aestuaria	I	x	415	37.8
	Hilsa kelee	II	x		
Elopidae	Elops machnata	II	x	7	0.6
Gobiidae	Glossogobius callidus	I	x	13	1.2
	Caffrogobius gilchristi			4	0.4
	Caffrogobius natalensis			1	0.1
	Oligolepis acutipennis	I	x	29	2.6
	Oligolepis keiensis			24	2.2
	Psammogobius knysnaensis			8	0.7
Haemulidae	Pomadasys commersonnii	II	x	215	19.6
Leiognathidae	Leiognathus equula	II	x		
Monodactylidae	Monodactylus falciformis	II	x	2	0.2
Mugilidae	Liza alata	II	x		
	Liza dumerilii	I	x	11	1.0
	Liza macrolepis	II	x		
	liza sp	II		83	7.6
	Liza tricuspidens	II	x		
	Mugil cephalus	II	x	37	3.4
	mugillidae	II		82	7.5
	Myxus capensis	IV	x	32	2.9
	Valamugil buchanani	II	x		
	Valamugil cunnesius	II	x	9	0.8
	Valamugil robustus	II	x		
	Valamugil sp	II		11	1.0
Platycephalidae	Platycephalus indicus	II		1	0.1
Sciaenidae	Argyrosomus japonicus	II	x	11	1.0
Sillanginidae	Silago sihama	II	x		
Soleidae	Solea bleekeri	II	x	23	2.1
Sparidae	Acanthopagrus berda	II	x	11	1.0
	Rhabdosargus holubi	II	x	10	0.9
Teraponidae	Terapon jarbua	II	x	1	0.1
	Total no.			**1098**	**100.0**
	Total taxa		**27**	**28**	

Typically river mouth estuaries are considered to be relatively species poor in comparison with permanently open estuaries due to, inter alia, the prevailing low salinities that preclude any marine associated taxa, and unstable sediments and relatively low residence times that result in impoverished food resources.

The 28 taxa recorded by Harrison falls in the upper range of species collected in other subtropical river mouth systems (13-34 species). The modelled community for subtropical open estuaries comprises 27 species, indicating that in spite of the highly dynamic physic chemical conditions, the system is still favourable for a relatively large number of taxa.

The catch, in terms of numbers, was dominated by the estuarine resident Gilchristella aestuaria. This result is somewhat surprising given the strong flows that characterise this estuary, and the species known susceptibility to changes in flow. Strydom et al. (2002), in a study of two warm temperate estuaries, showed that despite the more abundant food sources in the Great Fish Estuary, G. aestuaria densities were still lower than the Kariega Estuary.

Strydom et al., (2002) found larvae and juvenile densities of G. aestuaria to be inversely related to river flow, citing the flushing out of larvae and early juveniles in the Great Fish as a possible explanation. G. aestuaria do, however, possess a number of characteristics that assist in guarding against the impacts of high flow. In KZN, G. aestuaria spawns during winter in order to take advantage of the stable and productive conditions associated with this season (Whitfield 1980c). Melville-Smith et al. (1981) showed that in the Sundays Estuary the larvae avoid ebb-tide surface flows in order to maintain their position in the middle and upper reaches.

It is probable that this species takes advantage of any slack water present during high flows in order to prevent flushing out of the system. In addition, a report compiled by CSIR (1983) showed that the Mzimvubu displayed a remarkably high zooplankton: benthic invertebrate biomass suggesting that G. aetuaria would have a competitive advantage as a zooplanktivore,

The Large proportion of mugilids is not particularly surprising given the success of this group in South African estuaries (James et al. 2005). Traits that contribute to the prominence of this group in South African estuaries, include extended spawning seasons which guard against recruitment failure, strong euryhalinity, and a detritus based diet, which in the case of estuaries essentially represents a perennial food source (Cowley et al. 2001).

The system is also important for a number of angling targeted taxa, most notably Pomadasys commersonnii and Argyrosomus japonicas. Both species are estuarine dependant marine species that utilize the system extensively as nursery grounds. Adults also frequent the system due to the favourable foraging conditions in the system. A. japonicas in particular favours high turbidity conditions for foraging.

The Mzimvubu is well known as a nursery and pupping ground for the Zambezi shark Charcharhinus leucas. Little is known regarding the ecology of this species, however, the turbid waters and associated freshwater olfactory cues provided by this system provide favourable conditions for this species.

It remains unclear the relative importance of this system for the conservation of this species, however, initial indications suggest that the paucity of large freshwater dominated systems along the coastline, high incidences of shark attacks in the area, and initial acoustic records from the Natal Sharks Boars would suggest that this system is of considerable importance for the conservation of this near threatened species.

3.10.2 Reference Condition

The processes that characterize this system and drive the fish community have not been altered significantly. The major change to the fish community has been as a result of significant fishing pressure. Pomadasys commersonnii and Argyrosomus japonicas have been exploited heavily by anglers, with anglers suggesting there has been a major decline in both populations in recent years. This trend is not unique to the Mzimvubu, the National Spatial Biodiversity Assessment provided quantitative data of these declines across the country, indicating the relative to pristine conditions, populations of P. commersonnii and A. japonicas have declined to less than 40 % and 4 %, respectively.

The Zambezi shark Charcharhinus leucas, is another species that has been targeted for various reasons by anglers, leading to declines in population size. Angling targeted species are large and therefore have a major impact on the biomass of fish fauna relative to historic conditions. Table 3-28 indicates the Similarity scores for the fish fauna in the Present condition relative to the Reference condition.

Table 3-28: Similarity scores for the fish fauna

Variable	Change from natural	Score	Confidence
1. Species richness	The physical processes that drive this system are still largely intact. As a consequence there is unlikely to have been any change in species richness relative to reference conditions	100	M
2. Abundance	Abundance/biomass will have decreased as a result of direct fishing pressure. Angling targeted species such as Pomadasys commersonnii and Argyrosomus japonicas would have seen a decline in numbers, as would the near threatened Zambezi shark	75	M
3. Community composition	Fishing pressure would affect community composition with a reduction in those species targeted by anglers	75	M
		Fish score	75
		Degree to which deviation from natural is due to non-flow related impacts	90
		Adjusted score	98

3.11 Birds

3.11.1 Available Information

The only bird counts available for the Mzimvubu are from January 2002 and the present winter and summer counts done in September 2012 and February 2013.

3.11.2 Bird Groups

For the purposes of this study, the birds found on the estuary have been separated into eight groups (Table 3-29).

Gulls and terns (mainly gulls) dominated with waterfowl being the next most common group (Figure 3-9). Numbers of piscivorous birds actually feeding in the estuary (*i.e*. excluding gulls and terns) were low.

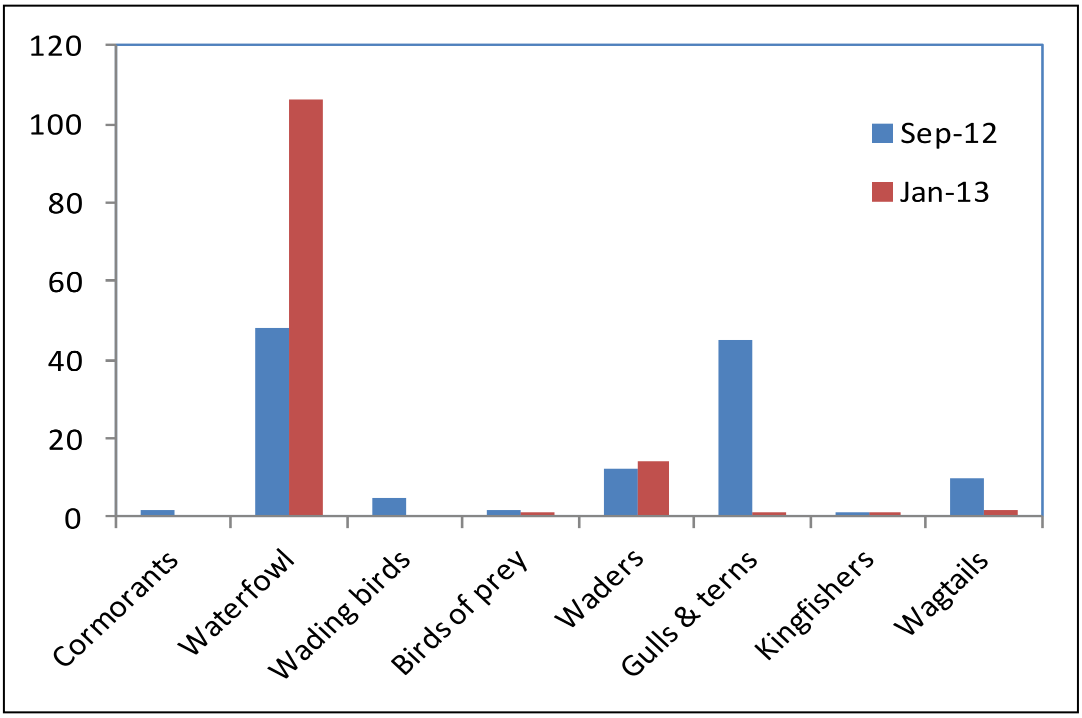


Figure 3-9: Different Groups counted during this Study in Summer and Winter

Table 3-29: Major bird groups found in the Mzimvubu Estuary, and their defining features

	Defining features, typical/dominant species
Diving/swimmings piscivores	The estuary supports a few species of pursuit swimming piscivores which catch their prey by following it under water and therefore prefer deeper water habitat. These include Reed Cormorant and White-breasted Cormorant.
Wading piscivores	This group comprises the egrets, herons and hamerkops. Their diet varies with fish usually dominating, but often includes other vertebrates, such as frogs, and invertebrates. Wading piscivores prefer shallow water with larger species utilizing deeper areas.
Herbivorous waterfowl	This group is dominated by species that tend to occur in lower salinity or freshwater habitats. Egyptian and spurwing geese were the most common and tend to feed in terrestrial areas away from the estuary and floodplain as well as in the estuary.
Omnivorous waterfowl	This group comprises ducks which eat a mixture of plant material and invertebrate food such as small crustaceans - Yellow-billed Duck was the only species in this group.
Benthivorous waders	This group includes all the waders *(e.g.* Greenshank, Grey plover). They are the smallest species on the estuary, and feed on benthic macroinvertebrates in exposed and shallow intertidal areas. Invertebrate-feeding waders forage mainly on exposed sandbanks, mudflats and in the inter-tidal zone. The numbers recorded were very small. A few resident species occur such as White-fronted Plover and Three-banded plover.
Piscivorous gulls & terns	This group comprises the rest of the Charadriiformes, and includes all the gull and tern species using the estuary. These species are primarily piscivorous, but also take invertebrates. Gulls and terns can be very abundant and use the estuary primarily for roosting
Piscivorous kingfishers	Three species of kingfishers were recorded but in low numbers. They breed and perch on the river banks and prefer areas of open water with overhanging vegetation.
Piscivorous birds of prey	The African Fish Eagle is the only species in this group. They are not confined to a diet of fish, also taking other vertebrates and invertebrates.

3.11.3 Baseline Description - the Reference Condition

It is unlikely that the Mzimvubu estuary has ever constituted a major water bird habitat, apart from possibly for gulls and terns which tend to feed at sea but rest on sandbanks. Waterfowl such as Egyptian and spurwing geese are to some extent only water associated in name as much of their feeding and breeding, especially in the case of Egyptian geese, occurs away from water which is used more as a refuge. Conditions in the river or estuary would not necessarily have influenced their numbers.

The steep sides and consequent small intertidal areas with their poor benthic invertebrate fauna would not have provided a significant feeding ground for migratory waders. High summer flows, even in relatively pristine catchment conditions would have arguably resulted in increased turbidities which would have deterred piscivores relying on vision to locate prey.

A total of 30 water-associated bird species have been recorded either on or closely associated with the estuary.

3.11.4 Health of the Avifaunal Component

The Mzimvubu estuary has been subject to relatively little physical modification. i.e. the bulk of the original habitats still exist. Any declines in species richness or abundance could arguably be attributed to general broader trends rather than specific local changes. The changes from the reference condition are thus likely to be relatively slight. Table 3-30 indicates the Similarity scores of birds in the Present condition relative to the Reference condition.

Table 3-30: Similarity scores of birds

Variable	Change from natural	Score	Confidence
1. Species richness	Unlikely and no records to indicate that species loss has occurred.	95	M
2. Abundance	Possibly some reduction through human disturbance and loss of marginal habitats.	70	M
3. Community composition	No real indication of species loss, change in relative abundance or appearance of species that could be attributed to human influence.	90	M
Bird score		70	
% impact due to non-flow related impacts -		95	
Adjusted score		99	

4. PRESENT ECOLOGICAL STATUS

Scores were allocated to the various health parameters, both abiotic and biotic which assessed for the Mzimvubu estuary and an overall Present Ecological Status for the system was calculated from the EHI score (Table 4-1).

Table 4-2 summarises the above findings. The EHI score for the Mzimvubu Estuary in its present state was estimated to be 83 (i.e. 83% similar to natural condition), which translates into a Present Ecological Status (PES) of B.

Table 4-1: PES scores and descriptions

EHI Score	Present Ecological Status	General description
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	C	Moderately modified
41 – 60	D	Largely modified
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

Table 4-2: Calculation of the Present Ecological Status of the Mzimvubu Estuary

Habitat Health Score	Weighting	Score	Weighted score
Hydrology	25	93	23
Hydrodynamics and mouth condition	25	100	25
Water quality	25	78	20
Physical habitat alteration	25	95	24
		Habitat health score	**92**
Biotic Health Score	**Weighting**	**Score**	**Weighted score**
Macrophytes	20	63	13
Microalgae	20	65	13
Invertebrates	20	95	19
Fish	20	75	15
Birds	20	70	14
		Biotic Health Score	**74**
		Estuarine Health Score	**83**
		Present Ecological Status	**B**

4.1 Overall EHI Score

Table 4-3: Present ecological status of the Mzimvubu Estuary

Variable	Health score/100	Health score net of non-flow related impacts	Confidence
Hydrology	93	93	H
Hydrodynamics and mouth condition	100	100	H
Water quality	79	79	L/M
Physical habitat alteration	95	100	M
Habitat health score	**92**	**93**	
Microalgae	65	93	M
Macrophytes	63	97	M
Invertebrates	95	100	H
Fish	75	98	M
Birds	70	98	M
Biotic Health Score	**74**	**97**	
Estuary Health Score	**83**	**95**	
Present Ecological Status	**B**	**A**	
Overall Confidence	**M**	**M**	

4.1.1 Relative Contribution of Flow and Non-flow related impacts on Health

Estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an adjusted health score of 95, which would increase the PES to an A category.

4.1.2 Overall Confidence

Confidence levels were high and medium for most of the components. The fact that these included hydrology and hydrodynamics meant that they affected the confidence of all subsequent components. Only two components had enough data to yield medium-confidence assessments. The overall confidence of the study was considered to be **medium**. The implications of this are that:

- One has to be extremely cautious and apply the precautionary principle in setting the Preliminary Reserve; and
- Efforts should be made to collect baseline and monitoring data that will help to fill some key gaps in understanding.

5. THE RECOMMENDED ECOLOGICAL CATEGORY

5.1 Ecological Importance of the Mzimvubu Estuary

The Estuary Importance Score (EIS) for the estuary takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (Table 5-1).

Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. These importance scores ideally refer to the system in its natural condition.

The scores have been determined for all South African estuaries, apart from functional importance, which is scored by the specialists in the workshop. In this case, functional importance was deemed to be very high (100), because of the significant role this estuary plays in the delivery of nutrients and sediments to the coastal environment and the nursery function to a variety of fish species including the Zambezi shark and white steenbras.

The EIS for the Mzimvubu Estuary, based on its present state, was therefore estimated to be 82, i.e., the estuary is rated as “Highly Important” (Table 5-3).

Table 5-1: The Ecological Importance of the Mzimvubu Estuary

Criterion	Weight	Score
Estuary Size	15	90
Zonal Rarity Type	10	30
Habitat Diversity	25	90
Biodiversity Importance	25	73
Functional Importance	25	100
Weighted Estuary Importance Score		**82**

Table 5-2: Functional importance score

Functional importance score	
a. Estuary: Input of detritus and nutrients generated in estuary	40
b. Nursery function for marine-living fish and crustaceans	100
c. Movement corridor for river invertebrates and fish breeding in sea	80
d. Roosting area for marine or coastal birds	60
e. Catchment detritus, nutrients and sediments to sea	100
Functional importance score - Max (A to D)	**100**

Table 5-3: Estuarine Importance Scores and Significance

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

The PES for the Mzimvubu is a B. The estuary is rated as “Highly important” (functional importance score 100), and it is designated as a desired protected area in the Biodiversity Plan for the National Biodiversity Assessment. Thus the Recommended Ecological Category for the estuary is an **A or Best Attainable State.**

Table 5-4: Guidelines for assigning the Recommended Ecological Category

Current/Desired Protection Status and Estuary Importance	Recommended Ecological Category	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 (refer to Turpie et al., 2002 and Turpie and Clark, 2007)		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B class
Important	PES + 1, min C	Important estuaries should be in an A, B or C class
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D class.

6. QUANTIFICATION OF OPERATIONAL AND ECOLOGICAL RESERVE SCENARIOS

6.1 Description of Operational and Ecological Reserve Scenarios

Four future water flow scenarios were evaluated to assess potential impacts on the estuary as part of this study as summarised in Figure 6-1 and Table 6-1.

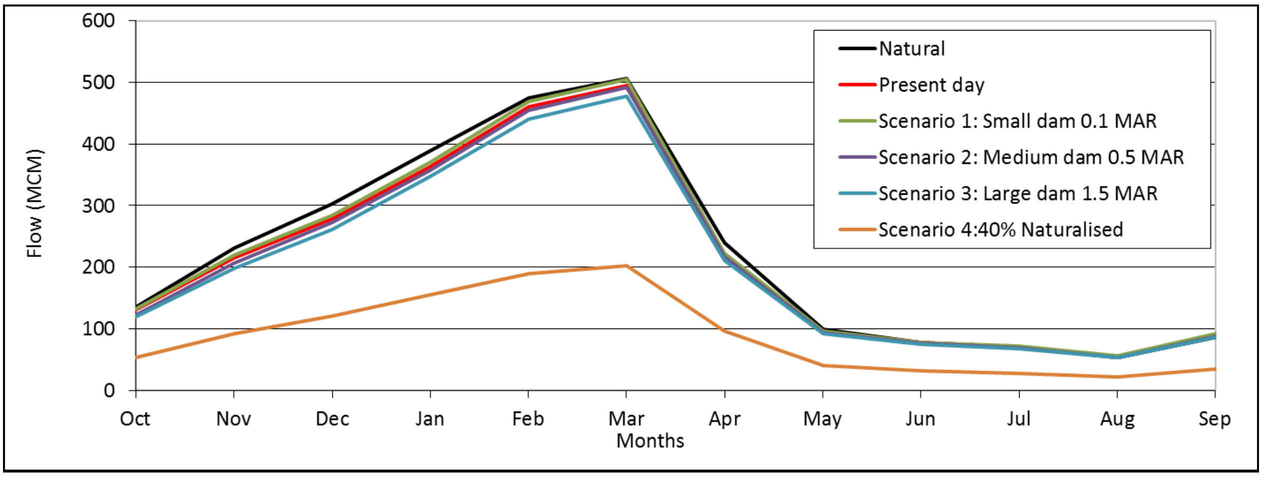


Figure 6-1: Average Monthly Volumes under the different Runoff Scenarios evaluated

Table 6-1: Summary of the scenarios evaluated in this study

Scenario name	Description	MAR (million m^3)	Percentage remaining
Natural	Natural Flow	2665.58	100
Present	Present (includes Irrigation From Run Of River, Afforestation and Alien Invasive Plants)	2552	96
Scenario 1	Small dam 0.1 MAR (Ntabelanga)	2594.98	97
Scenario 2	Medium dam 0.5 MAR (Ntabelanga)	2502.96	94
Scenario 3	Large dam 1.5 MAR (Ntabelanga)	2427.86	91
Scenario 4	40% Naturalised	1066.23	40

6.1.1 Flows and Abiotic States under Scenario 1

A summary of the monthly flows is presented in Table 6-2, Table 6-3 and Figure 6-2.

In general, this scenario represents very little impact on flows relative to present-day.

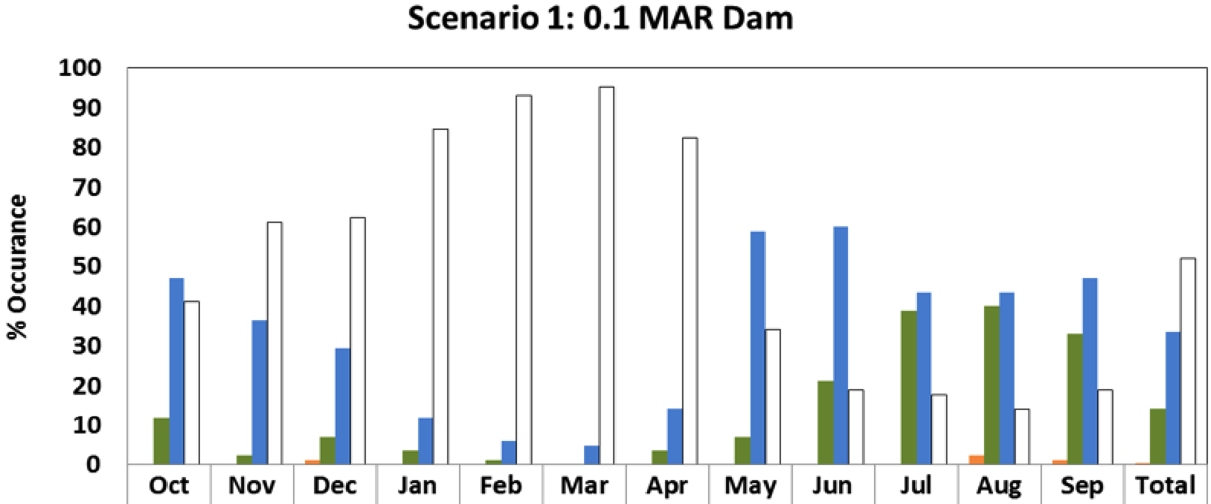
Table 6-2: Simulated monthly inflows to the Mzimvubu Estuary for Scenario 1 (in m³/s)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	16.6	15.0	20.4	23.2	130.6	229.5	134.4	43.6	16.9	10.0	7.1	11.9
1921	18.7	293.0	251.4	68.9	22.6	15.8	9.5	85.1	78.9	39.7	46.8	28.3
1922	66.3	197.7	83.3	230.0	536.9	277.2	62.5	12.0	11.5	251.4	101.7	14.2
1923	10.1	8.7	18.3	94.2	134.2	93.5	31.8	11.9	10.6	8.1	8.9	15.8
1924	15.2	23.3	385.3	142.3	47.7	596.0	348.0	72.6	15.8	10.1	7.3	11.4
1925	12.1	22.8	19.3	65.2	39.0	299.7	114.7	19.6	28.3	19.2	9.7	28.5
1926	38.7	33.1	54.7	35.0	37.7	695.5	247.3	14.6	8.9	9.7	11.7	10.1
1927	30.7	21.6	115.8	305.4	170.5	85.5	32.2	12.4	10.7	8.3	14.6	12.8
1928	16.0	23.8	60.7	42.5	47.5	265.1	97.4	17.6	52.0	54.4	27.7	104.0
1929	98.9	88.1	135.9	140.7	49.4	89.5	57.8	20.7	18.5	16.8	45.4	34.2
1930	23.2	13.8	29.1	324.8	322.0	293.6	111.1	22.1	10.6	378.5	141.8	13.0
1931	18.7	23.3	93.2	42.2	294.7	116.2	21.7	15.5	16.9	20.9	14.6	58.5
1932	47.7	229.7	184.2	46.1	17.6	53.9	31.7	11.2	7.8	8.2	7.1	6.1
1933	5.2	362.9	375.3	603.6	217.5	146.1	64.2	16.4	12.1	28.7	17.9	8.3
1934	31.2	76.8	174.6	71.3	28.8	68.1	123.8	94.7	84.0	35.8	31.2	20.2
1935	13.0	11.4	6.4	11.2	291.5	160.2	39.1	70.4	40.9	19.3	10.5	9.0
1936	26.9	528.8	182.1	65.5	503.7	208.7	36.1	10.3	8.5	7.6	6.4	7.7
1937	12.0	12.9	33.8	116.9	272.4	91.5	127.7	54.6	22.3	25.4	22.9	14.1
1938	18.6	38.5	263.8	239.2	712.9	216.3	22.2	19.1	16.4	21.6	18.8	136.7
1939	84.9	55.8	32.9	23.9	434.0	227.0	59.3	127.0	63.5	16.6	9.3	25.8
1940	22.5	24.3	75.0	107.7	129.1	61.3	43.1	20.9	10.8	10.5	9.6	7.8
1941	20.4	16.2	7.2	59.2	336.5	261.2	97.6	41.3	18.8	9.6	13.0	18.6
1942	45.3	291.8	383.8	184.3	49.4	164.8	206.3	78.5	36.0	26.0	179.6	85.9
1943	78.1	356.1	288.9	120.6	98.7	137.3	51.5	12.0	20.9	20.5	10.6	197.0
1944	89.4	17.4	5.6	44.7	220.3	235.6	74.0	13.6	10.3	7.8	6.0	5.2
1945	34.6	17.4	11.0	129.4	97.8	147.2	68.4	25.8	15.2	10.4	7.4	6.4
1946	9.8	34.3	43.0	94.4	150.7	202.7	87.6	18.7	50.0	33.4	12.8	14.3
1947	18.8	344.8	237.8	167.3	295.6	261.4	91.6	21.1	11.4	8.3	6.2	5.1
1948	15.3	13.8	11.5	42.3	58.5	50.7	35.8	19.1	10.1	8.8	7.4	7.6
1949	8.6	14.6	23.0	27.4	265.1	403.2	134.9	49.9	26.9	18.0	58.2	34.2
1950	26.4	18.4	219.6	101.8	123.6	64.3	24.0	12.1	9.0	7.3	13.1	24.9
1951	54.3	21.7	7.0	38.8	205.0	86.7	33.2	20.1	14.3	12.8	9.0	16.1
1952	16.2	25.1	77.3	51.4	57.0	40.3	39.0	20.4	9.6	6.8	7.9	27.2
1953	54.4	57.2	50.7	39.2	60.7	111.0	49.8	67.8	54.8	24.5	10.6	12.5
1954	46.1	39.6	24.4	541.9	544.7	133.0	39.9	22.1	21.1	14.7	7.5	10.3
1955	17.1	35.7	23.9	15.0	164.7	295.2	103.4	20.1	18.4	12.0	7.7	11.0
1956	21.6	101.4	427.8	324.2	150.9	261.0	110.6	23.1	14.2	12.3	20.1	88.0
1957	75.5	33.4	35.7	210.6	121.9	37.5	62.8	36.5	14.1	9.8	7.2	7.3
1958	7.4	131.3	223.1	76.5	76.3	51.2	64.7	430.5	160.7	33.0	31.5	19.4
1959	15.6	27.1	31.8	54.4	44.5	37.4	35.6	23.0	12.4	8.6	10.8	19.1
1960	18.0	52.1	158.6	74.4	53.6	128.5	139.7	54.5	16.9	9.9	9.1	8.2
1961	5.8	74.4	53.0	45.0	216.7	191.5	65.1	17.0	10.7	7.3	8.5	7.0
1962	12.1	115.0	71.9	405.2	214.4	538.5	201.4	24.6	12.1	38.0	22.7	7.7
1963	127.2	177.5	68.3	134.2	65.2	141.3	102.9	31.9	313.5	122.0	16.7	15.9
1964	101.4	42.2	18.5	39.5	101.7	37.5	14.9	15.5	204.2	107.6	57.9	30.3
1965	73.4	95.4	29.0	263.4	129.7	15.8	9.7	49.3	31.7	11.7	13.9	17.6
1966	12.6	11.7	30.2	188.8	156.7	472.9	261.0	62.3	28.8	30.3	17.6	7.6
1967	11.6	17.8	14.1	14.9	24.9	49.9	32.6	12.7	7.4	6.9	9.6	14.3
1968	13.0	15.6	12.1	9.0	55.8	235.7	93.4	34.1	19.5	11.0	8.8	7.0
1969	32.7	22.4	29.4	20.6	57.4	25.1	8.3	9.4	15.6	11.4	76.1	66.9
1970	119.6	54.2	19.4	95.1	84.4	44.3	33.1	52.7	31.4	29.4	45.3	24.1
1971	181.6	82.8	27.6	132.7	472.6	262.9	64.6	15.5	11.9	9.0	6.6	6.6
1972	9.8	96.1	39.6	17.8	284.4	175.6	64.7	20.8	9.8	9.3	11.3	14.7
1973	15.1	59.8	37.7	408.0	431.6	519.1	169.3	63.4	38.4	18.2	11.0	6.5
1974	7.4	76.9	58.6	36.4	46.7	56.6	32.8	13.0	7.7	6.4	6.2	66.1
1975	29.6	20.1	480.6	573.0	530.3	1020.	331.9	66.3	33.2	14.9	9.1	22.7
1976	321.1	117.3	13.5	65.1	123.3	80.4	37.3	14.4	11.0	10.2	9.1	20.5
1977	58.3	41.2	67.8	63.8	52.9	171.7	536.6	170.3	18.8	9.3	11.5	30.5
1978	66.7	57.5	173.9	64.5	89.8	49.8	28.6	20.2	12.5	30.8	27.2	27.1

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1979	18.5	11.2	13.4	86.2	128.6	53.5	17.7	9.7	7.3	7.1	4.8	102.3
1980	47.3	44.5	23.6	115.0	220.8	70.4	15.9	24.3	19.7	10.0	19.7	17.9
1981	10.1	15.1	24.5	53.8	85.3	280.5	114.0	19.9	19.0	21.6	11.4	11.6
1982	76.9	37.5	3.0	7.3	4.9	10.0	15.2	10.3	7.4	21.2	11.1	11.5
1983	19.2	99.2	194.9	105.5	76.6	133.7	102.3	34.1	18.5	25.9	15.3	7.3
1984	33.2	43.5	15.5	163.5	630.4	179.1	12.3	6.6	5.6	4.8	2.8	3.6
1985	280.4	140.3	136.5	219.7	108.9	53.3	26.3	10.0	8.4	7.4	17.2	23.0
1986	133.5	131.7	42.5	25.2	37.3	67.8	33.7	9.6	10.9	8.0	26.2	923.3
1987	325.7	55.0	29.4	49.5	575.7	371.3	100.8	37.6	23.5	18.0	13.5	12.6
1988	14.9	56.7	195.8	105.9	550.6	188.1	137.0	57.2	16.1	13.8	6.4	2.9
1989	33.8	460.7	176.5	71.6	28.4	305.7	136.6	22.2	12.7	9.6	15.1	7.4
1990	19.0	9.9	38.3	141.3	159.3	53.1	11.3	5.5	6.1	4.5	2.6	7.8
1991	251.0	118.6	172.9	72.2	84.7	47.6	26.5	11.5	6.1	4.2	6.3	6.6
1992	7.0	16.2	8.4	9.7	55.1	121.0	54.0	11.7	5.6	3.6	5.5	19.9
1993	147.1	82.0	158.5	207.1	254.9	332.1	105.2	9.8	8.2	14.6	14.9	5.8
1994	6.4	18.6	21.3	77.4	38.3	184.9	113.3	31.5	25.8	17.8	7.1	7.9
1995	22.4	32.7	380.7	626.9	546.0	164.3	40.2	14.6	11.2	27.5	16.7	8.2
1996	14.2	216.6	227.6	332.2	172.8	121.8	100.1	40.8	328.5	132.4	26.7	12.3
1997	19.1	37.1	18.2	112.8	671.5	425.2	100.3	22.1	12.3	9.8	12.6	9.1
1998	8.8	94.5	159.2	147.3	255.2	134.5	40.8	13.2	8.5	6.9	4.4	3.1
1999	27.8	26.0	323.2	615.2	453.3	646.9	292.7	76.2	29.6	12.7	7.0	17.8
2000	28.9	38.5	78.4	166.9	132.8	99.5	55.0	20.8	11.8	11.6	11.6	14.7
2001	44.0	379.6	257.1	158.2	94.1	151.6	59.9	34.5	25.4	46.2	110.0	74.7
2002	25.5	11.9	28.1	50.7	36.8	67.2	38.2	17.0	12.4	8.3	7.4	19.3
2003	11.9	11.5	7.0	28.2	74.8	166.8	67.1	13.2	10.1	36.2	28.0	99.4
2004	46.4	69.4	144.9	209.3	101.9	80.8	36.5	12.0	8.5	6.4	6.4	4.5

Table 6-3: Summary of the monthly flow (in m^3/s) distribution under Scenario 1

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	321.8	471.6	436.2	617.1	678.1	747.6	378.2	212.0	315.9	271.7	147.8	313.2
90%ile	112.3	224.4	261.1	324.6	519.7	390.5	157.4	69.4	51.2	37.3	45.4	71.6
80%ile	68.1	115.5	186.3	207.6	294.8	267.5	114.1	50.4	28.9	27.7	23.5	28.3
70%ile	46.0	81.0	155.8	142.1	219.7	224.9	100.7	34.1	20.7	20.8	16.7	20.5
60%ile	30.9	56.1	75.9	113.7	157.8	173.3	70.6	22.5	17.5	16.7	13.3	17.6
50%ile	22.5	39.6	50.7	86.2	128.6	141.3	62.5	20.7	14.3	12.0	11.3	14.2
40%ile	18.7	32.9	32.5	65.4	96.3	114.2	42.2	18.9	12.1	10.0	9.6	11.6
30%ile	15.7	22.9	25.2	50.8	67.2	80.5	36.1	14.8	10.8	9.4	8.6	8.2
20%ile	12.5	17.4	19.1	39.4	52.2	53.8	32.1	12.4	9.8	8.2	7.2	7.5
10%ile	9.8	13.8	11.7	23.5	37.9	45.6	19.3	10.7	8.0	7.0	6.4	6.4
1%ile	5.7	9.7	5.2	8.7	15.6	14.9	9.3	6.4	5.6	4.1	2.8	3.1



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	1	0	0	0	0	0	0	0	2	1	0
State 2	12	2	7	4	1	0	4	7	21	39	40	33	14
State 3	47	36	29	12	6	5	14	59	60	44	44	47	34
State 4	41	61	62	85	93	95	82	34	19	18	14	19	52

Figure 6-2: % - Monthly/annual occurrences of the various abiotic states (Scenario 1)

6.1.2 Flows and Abiotic States under Scenario 2

A summary of the monthly flows is presented in Table 6-4, Table 6-5 and Figure 6-3. In general, this scenario represents very little impact on flows relative to present-day.

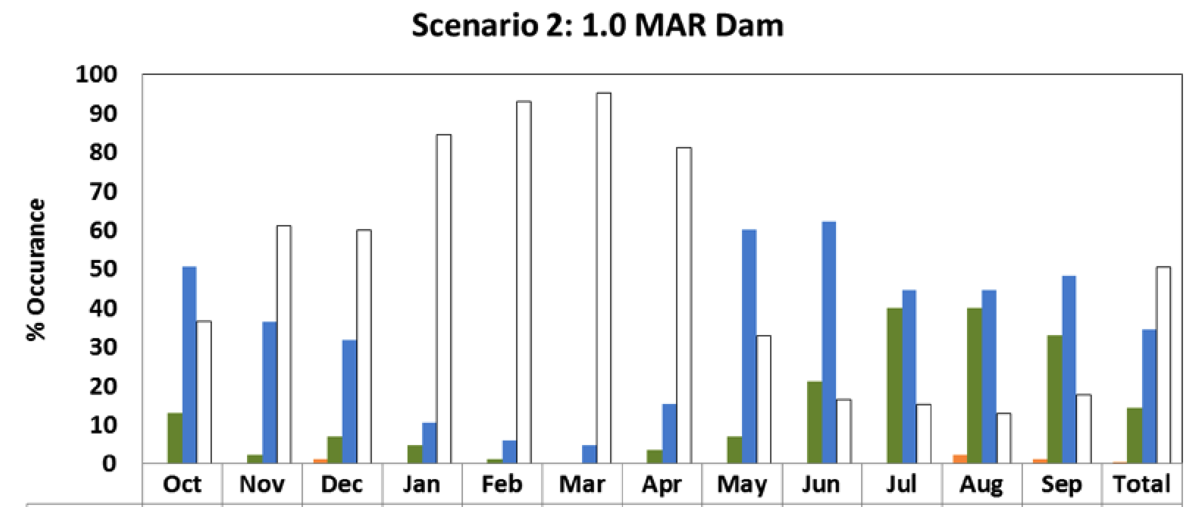
Table 6-4: Simulated monthly inflows to the Estuary for Scenario 2 (in m^3/s)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	14.6	14.4	18.9	19.8	127.6	222.5	131.5	42.3	16.8	10.0	7.1	11.9
1921	16.7	275.7	248.6	66.0	21.2	15.8	9.5	76.4	73.6	36.8	43.9	26.2
1922	64.6	193.0	79.8	227.4	533.4	274.3	60.8	12.0	11.3	242.0	98.5	14.2
1923	9.9	8.6	15.9	90.6	122.3	90.1	31.4	11.8	10.5	8.0	8.8	15.3
1924	14.8	21.7	362.1	139.2	46.7	591.1	345.4	69.6	15.6	10.0	7.3	11.3
1925	12.1	19.6	18.4	63.7	35.9	282.1	109.6	18.8	25.2	18.4	9.7	26.7
1926	36.0	31.5	49.7	33.2	36.6	680.4	244.1	14.6	8.9	9.7	11.4	10.1
1927	29.2	21.6	94.0	302.9	167.7	83.4	32.1	12.2	10.5	8.3	13.7	12.8
1928	15.7	21.4	47.2	38.3	34.9	262.7	94.2	16.8	47.5	51.3	26.5	100.0
1929	95.1	84.7	133.2	138.0	46.2	86.9	54.9	20.3	18.1	16.4	42.9	33.5
1930	22.3	13.8	27.3	305.8	319.2	290.9	108.1	22.0	10.5	370.1	138.6	13.0
1931	18.0	21.2	90.0	40.5	284.0	113.2	21.7	15.3	16.6	20.2	14.5	46.5
1932	40.2	227.1	181.5	43.3	17.1	48.8	28.6	11.1	7.8	8.2	7.1	6.1
1933	5.2	341.6	372.8	601.4	214.5	143.5	61.1	16.3	11.9	22.0	16.2	8.3
1934	30.5	73.7	163.5	68.2	27.9	63.7	120.7	91.8	81.1	34.9	29.6	20.2
1935	12.6	11.4	6.4	11.2	268.6	157.5	38.5	65.7	37.8	18.0	10.5	9.0
1936	20.8	522.0	179.0	62.8	501.3	205.9	34.7	10.3	8.4	7.6	6.4	7.7
1937	11.4	12.9	32.2	98.1	261.9	88.6	125.0	51.5	21.5	24.1	21.5	14.1
1938	17.7	35.0	251.7	236.6	710.5	213.3	22.2	18.6	15.9	19.8	18.2	122.4
1939	81.3	52.9	32.0	21.6	428.7	224.1	57.7	123.4	62.0	16.6	9.3	25.6
1940	21.6	23.1	73.7	104.3	125.7	58.5	41.4	20.8	10.7	10.3	9.6	7.8
1941	20.0	16.0	7.2	56.5	319.0	241.2	89.3	39.6	18.7	9.6	12.3	18.1
1942	33.9	282.5	381.3	181.6	47.4	161.3	203.5	75.6	33.9	25.3	174.1	82.8
1943	75.3	353.5	286.3	117.7	95.3	134.7	48.3	12.0	19.8	19.6	10.6	183.8
1944	86.3	17.4	5.6	44.4	207.7	232.8	71.7	13.5	10.2	7.8	6.0	5.2
1945	29.2	16.8	10.7	108.5	95.0	144.5	65.5	24.0	14.8	10.4	7.4	6.4
1946	9.7	31.7	42.2	86.4	134.1	199.4	84.8	17.5	46.3	31.5	12.8	13.9
1947	18.2	332.3	235.1	164.5	293.0	258.7	88.6	20.7	11.3	8.3	6.2	5.1
1948	10.8	12.9	10.9	41.7	52.4	48.2	35.0	18.8	10.1	8.8	7.4	7.6

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1949	8.5	14.1	22.0	22.9	224.8	395.8	132.0	47.1	25.0	17.6	52.3	32.8
1950	23.7	17.9	212.2	98.9	120.6	62.3	23.8	12.1	9.0	7.3	12.6	24.4
1951	41.3	19.8	7.0	36.9	188.6	83.7	32.3	19.9	14.1	12.5	9.0	15.7
1952	15.9	23.9	75.8	49.8	39.0	34.9	33.7	19.5	9.6	6.8	7.8	25.4
1953	49.5	51.6	46.2	34.3	48.9	108.3	46.7	65.1	51.9	23.8	10.6	12.4
1954	42.1	37.1	23.6	529.0	542.2	129.6	37.1	21.0	20.1	14.5	7.5	10.3
1955	16.4	32.4	23.0	15.0	155.2	278.4	100.3	19.9	17.4	11.9	7.7	11.0
1956	21.3	83.1	424.3	321.3	148.4	258.4	107.7	22.2	14.0	12.0	17.9	82.9
1957	70.8	32.3	34.9	199.1	119.0	35.9	59.3	35.0	14.0	9.8	7.2	7.3
1958	7.4	111.0	220.2	75.5	74.0	48.6	58.9	427.7	157.6	31.2	30.4	19.3
1959	15.5	24.3	29.2	52.7	38.0	35.3	33.2	22.2	12.4	8.5	10.4	17.2
1960	17.6	44.5	144.5	65.7	50.0	125.6	136.8	51.6	16.7	9.9	9.1	8.2
1961	5.8	65.3	45.6	41.6	210.2	188.7	62.2	16.5	10.6	7.3	8.5	7.0
1962	10.8	95.9	69.0	402.6	211.6	536.2	198.4	24.4	12.0	36.7	22.6	7.7
1963	111.5	174.8	64.9	131.4	62.8	138.4	100.0	31.2	308.4	118.9	16.7	15.3
1964	92.8	39.9	17.5	37.8	94.1	34.3	14.5	15.4	195.5	104.6	55.6	30.1
1965	70.7	89.4	26.9	259.7	126.7	13.5	9.7	44.3	30.0	11.7	13.3	17.1
1966	12.4	11.2	29.2	182.5	138.1	470.3	258.3	59.2	27.0	28.8	17.5	7.6
1967	11.3	15.3	14.1	14.9	24.4	49.2	32.0	12.7	7.4	6.9	9.6	14.3
1968	12.8	14.7	12.1	9.0	52.8	205.3	84.6	33.6	19.4	11.0	8.8	7.0
1969	28.9	21.3	26.9	20.3	52.4	24.9	8.3	9.4	14.8	11.2	59.9	61.3
1970	103.1	50.7	19.0	92.6	80.6	41.9	32.0	49.4	29.9	27.8	38.4	22.4
1971	160.9	78.3	25.8	129.2	469.8	260.2	63.0	15.4	11.8	9.0	6.6	6.6
1972	9.8	79.4	37.4	17.3	271.9	173.0	61.8	20.6	9.8	9.3	11.1	14.7
1973	14.1	57.4	36.7	387.0	428.8	516.5	166.4	61.2	37.1	18.1	11.0	6.5
1974	7.4	67.5	56.3	35.2	45.8	49.9	31.3	13.0	7.7	6.4	6.2	55.1
1975	28.2	17.3	461.8	570.4	527.7	1018.8	328.9	63.6	30.6	14.5	9.1	21.6
1976	310.6	113.9	13.4	62.8	116.5	76.9	35.9	14.4	11.0	9.9	8.7	15.6
1977	56.2	37.2	65.6	60.5	51.7	168.9	520.6	167.3	18.7	9.3	11.3	28.8
1978	59.8	55.6	165.0	61.3	86.8	46.8	28.2	20.1	12.5	26.6	25.9	27.1
1979	17.9	11.2	13.2	85.2	127.0	51.1	17.3	9.7	7.3	7.1	4.8	94.7
1980	45.9	42.9	22.3	107.2	182.4	67.4	15.9	21.8	18.5	10.0	19.1	17.9
1981	10.1	15.1	23.5	50.5	83.7	255.6	110.9	19.9	18.5	20.4	11.4	11.6
1982	76.4	31.6	2.6	7.3	5.3	10.3	15.0	10.2	7.4	21.1	11.1	11.5
1983	18.3	80.9	172.1	97.7	70.5	130.3	99.5	33.1	17.3	24.5	15.1	7.3
1984	26.9	37.1	14.9	154.3	626.7	175.8	12.3	6.6	5.6	4.8	2.8	3.6
1985	259.6	137.6	133.8	216.7	106.1	50.4	25.5	10.0	8.4	7.3	15.5	21.3
1986	117.5	128.9	39.6	23.2	34.2	64.3	32.2	9.6	10.5	7.9	24.7	908.6
1987	322.7	52.2	26.8	46.6	573.4	368.6	97.9	35.9	22.8	17.5	12.9	11.9
1988	14.0	46.5	187.8	102.9	547.1	185.2	134.4	54.2	15.9	12.4	6.4	2.9
1989	30.2	448.8	173.4	68.8	27.1	300.5	133.6	22.0	12.3	9.6	12.7	7.3
1990	15.8	9.4	37.4	134.5	154.4	52.3	11.3	5.5	6.1	4.5	2.6	7.8
1991	223.0	110.8	169.4	69.2	81.7	46.9	25.9	11.5	6.1	4.2	6.3	6.6
1992	7.0	16.2	8.4	9.7	52.8	115.9	51.9	11.7	5.6	3.6	5.5	18.6
1993	125.4	73.4	144.1	196.0	252.3	329.6	102.0	9.8	8.0	13.6	13.9	5.8
1994	6.4	18.6	19.8	68.1	35.8	168.5	110.5	29.5	25.4	17.7	7.1	7.9
1995	21.1	31.2	362.6	624.4	543.3	161.4	39.4	14.5	11.2	27.1	16.7	8.2
1996	13.9	194.4	224.7	328.7	169.7	119.0	97.2	40.0	324.0	129.4	25.0	12.3
1997	16.5	33.3	17.2	104.5	669.0	422.7	97.1	19.6	11.6	8.8	11.2	9.0
1998	8.6	79.5	156.7	143.9	252.5	131.2	40.4	13.2	8.4	6.9	4.4	3.1
1999	20.6	23.2	307.7	612.6	450.7	644.5	290.0	73.3	28.5	12.5	7.0	17.3
2000	28.1	35.6	76.7	151.8	128.4	96.2	53.0	20.8	11.8	11.6	11.6	14.7
2001	39.4	362.6	254.3	155.5	91.1	148.8	57.6	33.0	24.2	43.0	103.8	71.7
2002	25.4	11.8	26.8	47.4	34.0	62.2	36.6	16.1	11.9	8.3	7.3	17.4
2003	11.8	10.7	6.9	4.6	66.3	163.5	64.2	13.1	10.0	33.2	27.1	89.0
2004	43.2	65.9	142.8	206.1	98.9	77.9	34.3	11.6	8.5	6.4	6.3	4.5

Table 6-5: Summary of the monthly flow (in m³/s) distribution under Scenario 2

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	312.5	460.5	430.3	614.5	675.6	734.5	373.4	209.0	310.9	262.5	144.3	299.8
90%ile	99.9	214.0	253.3	315.1	517.1	384.9	154.6	65.4	47.1	35.9	41.1	67.5
80%ile	65.8	98.9	179.5	196.6	285.8	260.7	110.5	47.6	27.3	25.5	23.1	26.8
70%ile	40.1	73.6	143.9	138.9	211.3	211.8	97.7	33.1	19.7	19.8	16.1	20.0
60%ile	28.5	51.8	74.5	104.4	150.8	168.7	68.0	22.0	17.0	16.5	12.7	16.3
50%ile	21.1	37.1	45.6	85.2	122.3	138.4	58.9	20.1	14.1	11.9	11.1	14.1
40%ile	17.7	31.4	30.9	63.4	92.9	111.3	41.0	18.1	11.8	10.0	9.6	11.6
30%ile	14.9	21.4	24.0	47.9	63.5	77.1	34.4	14.7	10.6	9.3	8.5	8.2
20%ile	12.0	16.6	18.2	37.6	47.2	51.0	31.4	12.2	9.8	8.2	7.2	7.5
10%ile	9.8	13.2	11.3	20.0	35.2	43.9	19.1	10.6	7.9	7.0	6.3	6.4
1%ile	5.7	9.3	5.1	6.9	15.2	13.0	9.3	6.4	5.6	4.1	2.8	3.1



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	1	0	0	0	0	0	0	0	2	1	0
State 2	13	2	7	5	1	0	4	7	21	40	40	33	14
State 3	51	36	32	11	6	5	15	60	62	45	45	48	35
State 4	36	61	60	85	93	95	81	33	16	15	13	18	51

Figure 6-3: % - Monthly/annual occurrences of the various abiotic states (Scenario 2)

6.1.3 Flows and Abiotic States under Scenario 3

A summary of the monthly flows is presented in Table 6-6, Table 6-7 and Figure 6-4. In general, this scenario represents very little impact on flows relative to present-day.

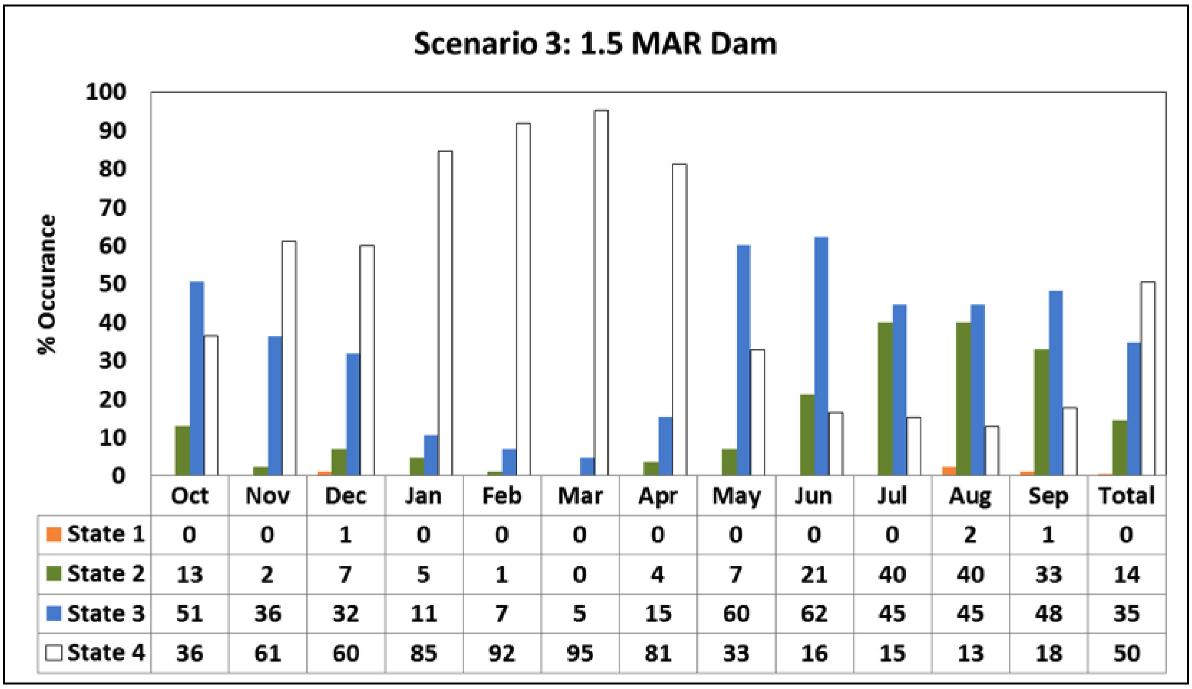
Table 6-6: Simulated monthly inflows to the Estuary for Scenario 3 (in m³/s)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	14.6	14.4	18.9	19.8	127.6	215.6	124.8	42.3	16.8	10.0	7.1	11.9
1921	16.7	270.1	234.6	66.0	21.2	15.8	9.5	76.4	73.6	35.7	39.2	26.2
1922	64.6	168.3	76.6	225.8	530.2	272.2	60.8	12.0	11.3	232.6	95.9	14.2
1923	9.9	8.6	15.9	90.6	121.0	86.7	31.4	11.8	10.5	8.0	8.8	15.3
1924	14.8	21.7	332.9	131.6	46.7	585.8	343.9	67.1	15.6	10.0	7.3	11.3
1925	12.1	19.6	18.4	63.7	35.9	282.1	109.6	18.8	25.2	18.4	9.7	26.7
1926	36.0	31.5	49.7	33.2	36.6	633.1	234.9	14.6	8.9	9.7	11.4	10.1
1927	29.2	21.6	87.4	288.0	165.4	83.4	32.1	12.2	10.5	8.3	13.7	12.8
1928	15.7	21.4	47.2	38.3	29.5	235.8	91.4	16.8	46.7	50.5	26.5	100.0
1929	83.1	81.5	131.1	136.1	43.9	84.8	52.6	20.3	18.1	16.4	42.9	33.5
1930	22.3	13.8	27.3	300.0	298.9	289.3	105.6	22.0	10.5	363.6	135.9	13.0
1931	18.0	21.2	90.0	40.5	268.3	110.8	21.7	15.3	16.6	20.2	14.5	46.5
1932	39.1	209.2	179.6	43.3	17.1	41.8	26.9	11.1	7.8	8.2	7.1	6.1
1933	5.2	322.9	371.0	600.3	212.1	141.8	58.4	16.3	11.9	22.0	16.2	8.3
1934	30.5	73.7	143.7	65.6	27.9	59.3	118.5	91.1	80.3	34.9	29.6	20.2
1935	12.6	11.4	6.4	11.2	243.8	155.3	38.5	61.3	37.8	18.0	10.5	9.0
1936	20.8	507.8	176.3	60.8	499.8	203.6	34.7	10.3	8.4	7.6	6.4	7.7
1937	11.4	12.9	32.2	98.1	242.2	85.1	115.0	48.9	21.5	24.1	21.5	14.1
1938	17.7	35.0	238.4	231.8	709.4	210.6	22.2	18.6	15.9	19.8	18.2	121.4
1939	76.7	52.1	32.0	21.6	416.5	219.6	57.7	122.8	62.0	16.6	9.3	25.6
1940	21.6	23.1	73.7	104.3	125.7	58.5	41.4	20.8	10.7	10.3	9.6	7.8
1941	20.0	16.0	7.2	56.5	319.0	241.2	89.3	39.6	18.7	9.6	12.3	18.1
1942	33.9	269.3	349.3	170.5	47.4	145.4	188.3	73.5	33.9	25.3	164.8	77.3
1943	72.7	351.3	284.5	115.3	94.3	131.0	48.1	12.0	19.8	19.6	10.6	178.5
1944	82.8	17.4	5.6	44.4	200.7	222.3	71.7	13.5	10.2	7.8	6.0	5.2
1945	29.2	16.8	10.7	103.2	84.7	138.1	64.6	24.0	14.8	10.4	7.4	6.4
1946	9.7	31.7	42.2	86.4	134.1	187.4	77.0	17.5	44.5	31.5	12.8	13.9
1947	18.2	310.7	217.1	162.7	291.4	256.5	88.6	20.7	11.3	8.3	6.2	5.1
1948	10.8	12.9	10.9	41.7	52.4	48.2	35.0	18.8	10.1	8.8	7.4	7.6
1949	8.5	14.1	22.0	22.9	224.8	377.0	128.1	43.1	25.0	17.6	52.2	32.8
1950	23.7	17.9	185.6	90.4	120.0	62.3	23.8	12.1	9.0	7.3	12.6	24.4
1951	41.3	19.8	7.0	36.9	175.9	80.1	32.3	19.9	14.1	12.5	9.0	15.7
1952	15.9	23.9	75.8	49.8	39.0	34.9	33.7	19.5	9.6	6.8	7.8	25.4
1953	49.5	51.6	46.2	34.3	48.6	93.3	45.2	60.8	50.1	23.8	10.6	12.4
1954	42.1	37.1	23.6	495.4	497.8	124.0	35.8	21.0	20.1	14.5	7.5	10.3
1955	16.4	32.4	23.0	15.0	155.2	267.9	95.9	19.9	17.4	11.9	7.7	11.0
1956	21.3	83.1	392.8	312.2	148.4	239.6	105.4	22.2	14.0	12.0	17.9	82.9
1957	70.8	32.3	34.9	177.4	116.8	35.9	58.2	35.0	14.0	9.8	7.2	7.3
1958	7.4	108.6	213.7	75.5	74.0	48.6	55.0	409.6	155.3	31.2	30.4	19.3
1959	15.5	24.3	29.2	52.7	38.0	35.3	33.2	22.2	12.4	8.5	10.4	17.2
1960	17.6	44.5	144.5	65.7	49.6	119.6	130.7	51.2	16.7	9.9	9.1	8.2
1961	5.8	65.3	45.6	41.6	195.0	175.3	59.6	16.5	10.6	7.3	8.5	7.0
1962	10.8	95.9	59.0	361.8	197.6	535.0	195.9	24.4	12.0	36.7	22.6	7.7
1963	111.3	157.9	63.2	128.5	62.8	133.3	97.7	31.2	303.8	116.3	16.7	15.3
1964	86.6	39.9	17.5	37.8	81.7	33.5	14.5	15.4	185.9	102.1	55.6	30.1
1965	70.7	80.0	26.9	254.9	124.7	13.5	9.7	44.3	30.0	11.7	13.3	17.1
1966	12.4	11.2	29.2	182.5	130.0	447.1	256.3	58.0	27.0	28.8	17.5	7.6
1967	11.3	15.3	14.1	14.9	24.4	49.2	32.0	12.7	7.4	6.9	9.6	14.3
1968	12.8	14.7	12.1	9.0	52.8	205.3	84.6	33.6	19.4	11.0	8.8	7.0
1969	28.9	21.3	26.9	20.3	52.4	24.9	8.3	9.4	14.8	11.2	59.9	61.3
1970	103.1	50.7	19.0	92.6	80.6	41.9	32.0	49.4	29.9	27.8	38.4	22.4

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1971	160.9	76.8	25.8	124.1	415.3	244.8	63.0	15.4	11.8	9.0	6.6	6.6
1972	9.8	79.4	37.4	17.3	249.1	153.2	58.5	20.6	9.8	9.3	11.1	14.7
1973	14.1	57.4	36.7	363.0	396.0	492.7	164.1	61.2	37.1	18.1	11.0	6.5
1974	7.4	67.5	56.3	35.2	45.8	49.9	31.3	13.0	7.7	6.4	6.2	55.1
1975	28.2	17.3	434.1	546.6	525.9	1017.8	326.4	61.5	30.6	14.5	9.1	21.6
1976	298.9	110.8	13.4	62.8	114.7	76.3	35.9	14.4	11.0	9.9	8.7	15.6
1977	56.2	37.2	65.6	60.5	51.7	168.9	480.3	164.9	18.7	9.3	11.3	28.8
1978	59.8	55.6	162.1	61.3	83.8	46.2	28.2	20.1	12.5	26.6	25.9	27.1
1979	17.9	11.2	13.2	85.2	127.0	51.1	17.3	9.7	7.3	7.1	4.8	94.7
1980	45.9	42.9	22.3	107.2	181.4	62.5	15.9	21.8	18.5	10.0	19.1	17.9
1981	10.1	15.1	23.5	50.5	83.7	250.6	104.3	19.9	18.5	20.4	11.4	11.6
1982	76.4	31.6	2.6	7.3	5.3	10.3	15.0	10.2	7.4	21.1	11.1	11.5
1983	18.3	80.9	172.1	97.7	70.5	115.2	93.2	33.1	17.3	24.5	15.1	7.3
1984	26.9	37.1	14.9	146.3	561.4	167.7	12.3	6.6	5.6	4.8	2.8	3.6
1985	254.5	118.9	109.1	209.3	98.3	46.7	25.5	10.0	8.4	7.3	15.5	21.3
1986	110.5	103.1	37.8	23.2	34.2	61.4	32.2	9.6	10.5	7.9	24.7	869.8
1987	320.6	50.0	26.8	45.1	568.9	366.8	95.5	35.9	22.8	17.5	12.9	11.9
1988	14.0	46.5	169.3	100.6	544.0	182.8	132.6	51.7	15.9	12.4	6.4	2.9
1989	30.2	434.4	170.9	66.7	27.1	294.6	131.2	22.0	12.3	9.6	12.7	7.3
1990	15.8	9.4	37.4	134.5	154.4	52.3	11.3	5.5	6.1	4.5	2.6	7.8
1991	223.0	106.3	139.2	64.1	81.5	46.9	25.9	11.5	6.1	4.2	6.3	6.6
1992	7.0	16.2	8.4	9.7	52.8	115.9	51.9	11.7	5.6	3.6	5.5	18.6
1993	125.4	73.4	144.1	186.2	222.4	295.9	96.6	9.8	8.0	13.6	13.9	5.8
1994	6.4	18.6	19.8	68.1	35.8	159.0	97.6	29.5	25.4	17.7	7.1	7.9
1995	21.1	31.2	335.7	623.2	541.5	159.1	39.4	14.5	11.2	27.1	16.7	8.2
1996	13.9	179.5	217.3	325.5	168.6	115.8	94.8	40.0	319.6	127.3	25.0	12.3
1997	16.5	33.3	17.2	90.6	667.6	421.2	94.2	19.6	11.6	8.8	11.2	9.0
1998	8.6	69.5	147.8	140.6	250.6	128.2	40.4	13.2	8.4	6.9	4.4	3.1
1999	20.6	23.2	305.3	591.4	449.2	643.0	288.0	71.0	28.5	12.5	7.0	17.3
2000	28.1	35.6	76.7	151.8	118.3	92.6	53.0	20.8	11.8	11.6	11.6	14.7
2001	39.4	330.6	252.3	153.4	88.7	146.7	57.6	33.0	24.2	43.0	101.6	71.7
2002	25.4	11.8	26.8	47.4	34.0	62.2	36.6	16.1	11.9	8.3	7.3	17.4
2003	11.8	10.7	6.9	4.6	63.3	138.1	57.3	13.1	10.0	33.2	27.1	80.3
2004	41.8	63.5	142.8	174.1	96.6	75.8	34.3	11.6	8.5	6.4	6.3	4.5

Table 6-7: Summary of the monthly flow (in m³/s) distribution under Scenario 3

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	302.3	446.2	399.4	604.0	674.3	703.0	365.7	204.0	306.3	253.5	140.5	289.1
90%ile	96.5	197.3	246.7	307.3	499.0	372.9	151.5	61.4	45.8	35.4	38.9	67.5
80%ile	65.8	97.4	172.9	178.4	272.9	251.8	106.4	45.2	27.3	25.5	23.1	26.8
70%ile	39.3	72.6	142.1	135.7	200.1	209.6	94.7	33.1	19.7	19.8	16.1	20.0
60%ile	28.5	51.1	74.5	101.6	150.8	159.1	67.4	22.0	17.0	16.5	12.7	16.3
50%ile	21.1	37.1	45.6	85.2	120.0	133.3	57.6	20.1	14.1	11.9	11.1	14.1
40%ile	17.7	31.4	30.9	63.4	84.4	103.8	41.0	18.1	11.8	10.0	9.6	11.6
30%ile	14.9	21.4	24.0	47.9	62.9	75.9	34.4	14.7	10.6	9.3	8.5	8.2
20%ile	12.0	16.6	18.2	37.6	47.2	50.9	31.4	12.2	9.8	8.2	7.2	7.5
10%ile	9.8	13.2	11.3	20.0	34.8	41.8	19.1	10.6	7.9	7.0	6.3	6.4
1%ile	5.7	9.3	5.1	6.9	15.2	13.0	9.3	6.4	5.6	4.1	2.8	3.1



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	1	0	0	0	0	0	0	0	2	1	0
State 2	13	2	7	5	1	0	4	7	21	40	40	33	14
State 3	51	36	32	11	7	5	15	60	62	45	45	48	35
State 4	36	61	60	85	92	95	81	33	16	15	13	18	50

Figure 6-4: % - Monthly/annual occurrences of the various abiotic states (Scenario 3)

6.1.4 Flows and Abiotic States under Scenario 4

A summary of the monthly flows is presented in Table 6-8, Table 6-9 and Figure 6-5. In general, this scenario represents a 40% decrease in flow relative to reference.

Table 6-8: Simulated monthly inflows to the Estuary for Scenario 4 (in m³/s)

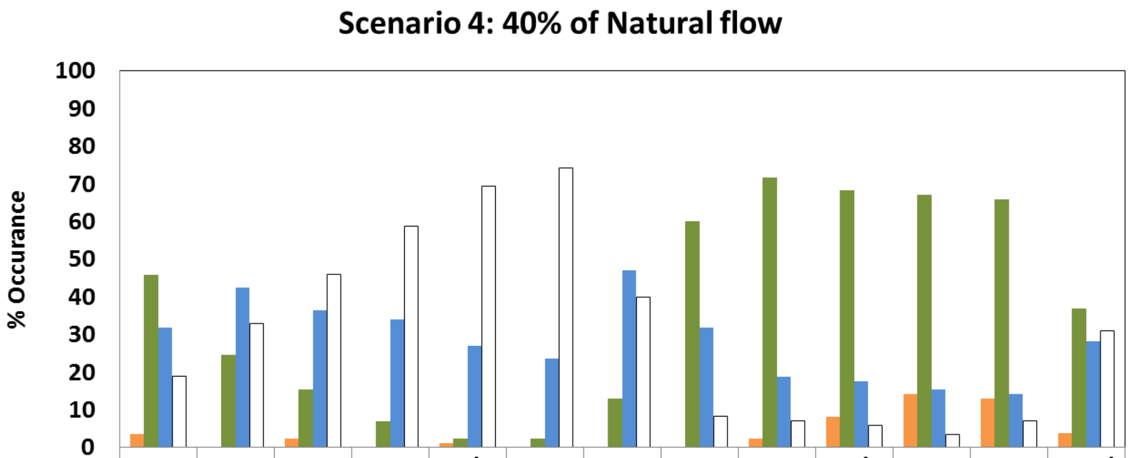
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	10.2	8.5	14.1	16.6	31.0	68.7	42.4	14.7	6.7	4.4	3.1	4.3
1921	9.5	99.2	97.4	29.8	9.8	6.0	3.5	38.2	33.4	15.3	15.4	9.7
1922	16.3	85.5	35.2	92.4	195.5	106.5	25.3	5.3	4.6	95.8	41.4	6.1
1923	4.1	4.1	12.9	30.3	56.6	33.3	10.4	5.1	4.6	3.5	3.7	5.6
1924	6.9	15.1	142.1	57.8	20.4	223.9	136.2	28.1	7.0	4.5	3.3	4.4
1925	4.7	17.7	12.3	19.4	20.5	100.6	44.4	7.9	10.7	7.7	4.1	9.5
1926	14.7	14.4	27.3	20.8	16.2	252.9	103.4	8.1	4.1	3.9	4.7	4.3
1927	10.6	6.9	54.6	126.0	74.8	32.1	12.3	5.4	4.6	3.6	5.5	4.7
1928	5.8	11.6	28.1	15.3	27.8	108.3	45.9	7.2	18.9	20.7	10.7	23.4
1929	48.5	40.6	54.0	65.2	24.0	36.1	24.2	8.6	7.5	6.8	14.5	12.6
1930	10.4	5.4	12.2	134.2	135.8	115.1	45.5	9.9	4.7	131.9	50.0	5.3
1931	8.4	10.5	24.4	16.9	113.5	51.8	9.4	6.5	6.7	8.0	6.0	22.2
1932	21.2	101.7	87.7	25.6	8.3	30.9	16.6	4.8	3.4	3.2	2.9	2.6
1933	2.3	128.5	153.3	263.6	116.9	70.8	29.4	6.7	5.1	12.9	7.6	3.4
1934	9.9	23.0	83.0	39.9	12.7	27.5	48.3	37.9	35.5	14.8	12.3	7.8
1935	5.3	4.6	2.2	8.4	129.5	75.2	16.9	28.9	18.8	7.9	4.6	3.9
1936	17.7	205.6	79.5	34.8	205.3	96.4	19.5	5.0	3.8	3.3	2.8	3.4
1937	5.8	4.9	22.3	63.7	99.0	35.6	54.0	23.7	8.4	9.3	8.4	5.2
1938	8.2	15.9	80.1	99.4	280.1	92.3	10.5	7.8	6.8	8.4	7.5	59.9
1939	40.0	25.8	18.5	19.1	149.1	84.0	24.3	39.1	25.4	7.4	4.2	6.2
1940	10.9	15.3	32.2	44.0	48.4	26.7	16.7	7.5	4.6	4.2	3.9	3.1
1941	6.3	6.7	3.5	29.2	131.0	110.1	51.5	24.6	8.7	4.3	5.1	6.3
1942	25.1	108.5	148.8	86.3	23.9	65.9	78.9	30.5	14.3	10.4	59.8	37.6
1943	33.5	107.7	126.2	62.1	43.6	59.0	22.5	5.3	7.7	7.9	4.4	76.1
1944	37.9	8.0	2.3	19.6	85.2	100.0	38.0	6.9	4.6	3.5	2.7	2.3
1945	17.7	8.2	6.2	50.0	42.9	62.4	29.9	10.6	5.9	4.3	3.2	2.7

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1946	4.4	20.4	23.3	44.5	56.2	77.2	42.5	10.3	20.9	13.3	5.4	5.6
1947	7.1	128.9	103.4	80.5	125.2	97.3	37.6	8.8	4.8	3.7	2.8	2.4
1948	11.2	7.7	7.2	18.6	42.0	32.7	18.6	7.8	4.4	3.8	3.4	3.5
1949	3.9	7.5	13.8	22.7	100.2	157.3	61.2	19.5	10.5	7.1	21.0	14.5
1950	11.7	8.0	94.7	56.2	51.0	27.4	9.7	5.2	3.9	3.1	5.1	9.5
1951	30.9	13.1	3.7	21.1	89.1	45.9	16.1	8.4	5.9	5.1	3.7	5.3
1952	6.3	11.9	30.6	27.0	33.3	21.8	21.5	9.7	4.2	3.0	3.4	11.0
1953	21.1	26.4	32.2	27.5	32.3	51.5	23.0	23.2	20.6	9.7	4.7	5.5
1954	26.3	21.0	13.8	206.6	226.1	67.1	20.6	9.1	8.2	6.0	3.4	4.1
1955	9.0	20.3	13.5	9.9	54.4	120.0	46.5	9.1	7.6	5.1	3.4	4.3
1956	6.8	55.7	162.6	132.5	62.6	113.2	51.6	10.6	6.1	5.2	7.6	26.1
1957	34.4	18.8	18.6	85.9	58.2	19.0	26.1	14.1	5.8	4.2	3.2	3.1
1958	3.1	53.2	79.5	37.0	28.5	21.2	25.8	153.0	65.6	13.2	11.5	8.2
1959	6.6	15.2	20.1	18.2	22.6	15.5	17.0	9.9	5.1	3.8	4.3	8.2
1960	7.2	24.9	69.7	42.1	27.9	48.1	58.5	24.8	7.3	4.3	3.8	3.5
1961	2.7	25.6	35.6	29.3	84.0	77.2	29.8	7.6	4.7	3.3	3.5	3.0
1962	7.4	46.6	40.1	161.9	101.3	208.7	80.6	10.5	5.1	14.1	8.6	3.3
1963	42.2	78.5	35.8	60.1	32.7	59.6	46.8	14.2	94.9	40.6	7.5	6.8
1964	44.4	20.5	16.8	20.2	42.1	14.1	5.6	5.2	79.9	43.0	23.9	12.5
1965	29.4	49.8	16.4	69.6	66.5	15.2	4.2	23.7	13.8	5.0	5.2	6.9
1966	5.4	5.5	12.1	48.0	95.2	213.2	113.7	26.6	12.4	12.9	7.4	3.5
1967	5.1	12.7	8.6	8.1	16.2	17.6	15.5	6.2	3.3	2.8	3.9	5.6
1968	6.2	9.7	6.8	4.6	22.9	98.1	43.8	13.6	7.9	4.7	3.7	3.2
1969	16.1	12.2	21.6	18.4	31.9	14.1	3.7	4.2	6.7	4.7	27.3	19.7
1970	55.2	26.4	12.8	41.6	46.3	21.9	13.3	20.1	12.2	10.6	20.4	10.8
1971	69.8	33.4	13.9	49.9	179.3	98.3	25.7	6.9	5.2	4.0	2.9	2.7
1972	4.3	52.1	23.2	11.8	108.2	77.2	27.0	8.6	4.3	3.9	4.7	5.9
1973	8.2	26.7	21.6	156.9	163.0	204.1	73.5	27.3	15.8	7.7	4.7	2.9
1974	3.0	30.0	36.0	29.9	20.3	23.7	15.0	5.5	3.4	2.9	2.5	29.4
1975	14.1	13.8	181.7	236.5	230.4	398.1	143.7	27.1	13.0	6.2	4.2	8.9
1976	123.2	49.6	6.5	25.4	44.0	34.5	18.3	6.6	4.5	4.5	4.3	11.5
1977	20.8	21.2	25.6	36.9	28.4	60.2	259.2	84.9	8.7	4.4	4.7	8.4
1978	25.7	23.1	60.6	30.2	24.5	17.8	11.8	6.8	4.3	12.0	10.3	6.7
1979	7.3	5.3	7.7	21.6	38.8	23.5	9.1	4.6	3.4	3.0	2.3	32.9
1980	16.1	24.6	15.2	38.1	91.2	35.1	7.6	9.8	7.7	4.3	6.9	6.9
1981	4.7	9.3	20.9	24.5	24.1	119.8	54.8	9.7	7.5	8.2	4.8	5.6
1982	15.0	18.3	5.6	3.5	2.7	5.7	7.1	4.4	3.0	7.8	4.5	4.8
1983	8.1	40.2	76.8	59.2	44.1	64.2	43.5	13.4	7.7	10.5	6.4	3.6
1984	17.9	25.8	9.9	71.7	249.7	80.1	7.0	3.4	2.9	2.5	1.8	1.8
1985	85.8	73.4	71.6	92.1	71.4	36.5	14.4	4.9	4.0	3.5	6.4	9.6
1986	58.7	69.6	23.9	18.3	18.8	29.4	16.3	4.7	4.7	3.7	8.7	328.4
1987	143.4	31.9	15.3	20.8	206.1	152.0	45.0	15.9	10.2	7.9	6.4	5.8
1988	7.7	29.3	86.8	50.0	204.1	76.4	57.5	24.5	7.3	6.5	3.6	1.9
1989	16.2	180.3	84.7	40.8	17.9	81.3	41.7	9.3	5.9	4.2	6.4	4.0
1990	8.6	4.9	14.8	38.1	40.2	17.1	5.1	3.1	3.1	2.4	1.7	5.4
1991	80.1	44.5	66.3	26.5	29.9	21.1	10.3	5.0	3.1	2.3	2.7	3.3
1992	3.2	6.8	3.6	5.5	15.4	25.5	14.4	5.3	2.8	2.0	2.4	5.8
1993	55.5	32.4	66.1	76.3	107.2	125.7	40.1	5.0	4.0	5.8	6.3	3.0
1994	3.3	6.0	13.3	29.7	22.2	83.9	55.6	14.4	11.3	7.9	3.6	3.3
1995	7.7	11.9	143.4	235.6	227.9	78.6	18.9	6.6	4.7	10.5	6.9	3.8
1996	6.8	92.7	81.6	119.7	71.5	40.6	42.7	19.2	134.7	58.8	12.8	6.2
1997	9.1	16.4	8.2	52.5	241.3	185.3	50.1	11.3	6.3	5.0	5.6	4.5
1998	4.6	42.0	73.4	55.1	86.0	58.6	20.8	6.1	4.1	3.4	2.4	1.9
1999	17.3	15.9	103.5	217.8	166.8	218.9	107.7	31.6	12.1	5.7	3.5	6.9
2000	12.3	20.2	34.0	64.4	56.0	39.0	22.5	8.8	5.1	4.7	4.6	6.0

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2001	21.0	145.4	111.9	62.4	27.3	53.9	29.6	10.3	9.1	15.7	28.5	21.4
2002	9.0	5.4	15.9	23.9	14.9	22.8	13.1	6.9	5.4	3.8	3.4	8.0
2003	4.8	5.0	7.3	44.0	33.0	67.8	28.4	5.7	4.3	11.5	10.0	43.8
2004	20.0	23.0	54.2	107.6	54.6	33.7	15.8	5.9	4.1	3.0	3.2	2.6

Table 6-9: Summary of the monthly flow (in m^3/s) distribution under Scenario 4

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	126.4	184.3	165.7	240.9	254.6	276.1	162.2	95.8	101.3	101.6	51.6	116.4
90%ile	46.9	96.6	103.4	129.9	200.7	155.1	68.6	27.8	19.9	14.5	15.1	23.0
80%ile	26.9	50.3	80.4	81.6	126.0	106.9	50.4	23.3	12.2	10.5	8.6	10.9
70%ile	17.9	32.3	65.0	61.7	94.4	83.9	43.7	14.0	8.3	7.9	6.8	8.2
60%ile	14.8	25.7	35.4	49.9	68.5	75.7	33.0	10.1	7.4	6.9	5.4	6.3
50%ile	10.2	20.5	24.4	39.9	51.0	60.2	25.7	8.8	6.1	5.1	4.7	5.6
40%ile	8.2	15.9	19.5	29.8	41.3	43.8	20.7	7.7	5.1	4.4	4.2	4.8
30%ile	7.0	12.3	14.2	25.4	30.1	33.4	16.6	6.6	4.6	4.0	3.6	3.9
20%ile	5.7	8.2	12.2	20.1	24.0	25.1	13.3	5.4	4.3	3.6	3.3	3.3
10%ile	4.3	5.7	7.0	16.7	18.3	18.3	9.2	5.0	3.6	3.1	2.8	2.8
1%ile	2.6	4.5	2.3	4.4	7.4	5.9	3.6	3.4	2.9	2.3	1.8	1.9



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	4	0	2	0	1	0	0	0	2	8	14	13	4
State 2	46	25	15	7	2	2	13	60	72	68	67	66	37
State 3	32	42	36	34	27	24	47	32	19	18	15	14	28
State 4	19	33	46	59	69	74	40	8	7	6	4	7	31

Figure 6-5: % - Monthly/annual occurrences of the various abiotic states (Scenario 4)

6.2 Abiotic components

This section summarises the estimated changes in each of the abiotic components under the different scenarios, and provides expected health scores for each.

6.2.1 Hydrology

The simulated changes in hydrology are summarised in Table 6-10 and scored in Table 6-11.

Table 6-10: Summary of changes under the different scenarios

Parameter	Scenarios 1 - 4
Low flows	Under Scenario 1 to 3 low flows are very similar to Reference conditions. Under Scenario 4 low flows are severely reduced by about 60% from the Reference conditions
Changes in the occurrences and magnitudes of floods	Under Scenario 1 to 3 the flood regime is very similar to the Reference conditions. Under Scenario 4 the magnitude of floods is severely reduced - 60% reduction from Reference conditions volumes.

Table 6-11: Similarity scores for hydrology relative to the Reference condition

Variable	Present	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Conf
a. Low flows	91	91	90	90	40	H
b. Flood regime	95	95	93	90	40	L
Hydrology score	93	93	91	90	40	

6.2.2 Hydrodynamics and Mouth Condition

This section describes changes in the occurrence of the different abiotic states under the different run-off scenarios as a proxy for the change in hydrodynamics. Mouth closure is not expected under any of the scenarios. Changes and scores are summarised in Table 6-12 and Table 6-13.

Table 6-12: Summary of Changes in the Percentage Frequency

State	Scenarios					
	Natural	Present	1	2	3	4
1	0	0	0	0	0	4
2	11	14	14	14	14	37
3	33	34	34	35	35	28
4	56	52	52	51	50	31

Table 6-13: Similarity Scores for Hydrodynamics

Variable	Present	1	2	3	4	Conf
a. Mouth condition & abiotic states	100	100	100	100	100	M
Hydrodynamics and mouth conditions score	100	100	100	100	100	M

Note: Only the first parameter is scored due to lack of data.

6.2.3 *Water Quality*

Scoring of Future scenarios in respect of Salinity/DIN/DIP, SS/Turbidity/ Transparency, DO and Toxic substances followed a similar approach as described earlier for the Present State. Based on the above the estimated changes in water quality (salinity, DIN, DIP, suspended solids and dissolved oxygen) in different zones under the different scenarios are presented in Table 6-14.

Details on the change in the axial salinity gradient, DIN/DIP, suspended solids, dissolved oxygen, and toxic substances are provided in Table 6-15 and Table 6-16.

Table 6-14: Estimated Changes in Water Quality in Different Zones

Zones in Estuary	Volume weighting for Zone	Estimated SALINITY concentration (PSU) based on distribution of abiotic states					
		Reference	Present	Scn 1	Scn 2	Scn 3	Scn 4
Lower Zone	0.34	12	13	13	13	18	23
Middle Zone	0.33	2	2	2	2	6	13
Upper Zone	0.33	0	0	0	0	0	5
Zones in Estuary	**Volume weighting for Zone**	**Estimated DIN concentration (µg/l) based on distribution of abiotic states**					
		Reference	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Lower Zone	0.34	93	154	154	154	154	141
Middle Zone	0.33	91	174	174	174	174	163
Upper Zone	0.33	91	180	180	180	180	179
Zones in Estuary	**Volume weighting for Zone**	**Estimated DIP concentration (µg/l) based on distribution of abiotic states**					
		Reference	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Lower Zone	0.34	13	23	23	23	23	19
Middle Zone	0.33	13	29	29	29	29	26
Upper Zone	0.33	13	30	30	30	30	30
Zones in Estuary	**Volume weighting for Zone**	**Estimated TURBIDITY (NTU) based on distribution of abiotic states**					
		Reference	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Lower Zone	0.34	158	166	166	164	163	119
Middle Zone	0.33	182	191	191	189	189	143
Upper Zone	0.33	184	194	194	192	192	151
Zones in Estuary	**Volume weighting for Zone**	**Estimated DISSOLVED OXYGEN concentration (mg/l) based on distribution of abiotic states**					
		Reference	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Lower Zone	0.34	8	8	8	8	8	8
Middle Zone	0.33	8	8	8	8	8	8
Upper Zone	0.33	8	8	8	8	8	8

Table 6-15: Expected Changes in Axial Salinity Gradient

Parameter	Summary of changes
1. Changes in longitudinal salinity gradient and vertical stratification	Under all scenarios, ⇧ due to decrease in flow
2a. DIN/DIP in estuary	Due to increased nutrient input from diffuse sources, in the catchment settlements and cattle concentrations in the estuary increased under Present state (and future scenarios) compared with reference. The slight improvement evident during Scenario 4 is related to a reduction in river inflow
2b. Suspended solids/Turbidity/ Transparency in estuary	Slight ⇧ associated with increased erosion in catchment during Present State, as well as Scenarios 1-3. However, as a result of marked reduction in (turbid) river inflow during Scenario 4, the system becomes "clearer' thus the greater decrease in similarity to Reference.
2c. DO in estuary	As with Present state, no marked changes in DO levels is expected during any of the future scenarios
2d. Toxic substances in estuary	Slight ⇧ accumulation under all scenarios

Table 6-16: Summary of changes and calculation of the water quality health score

	Variable	**Present**	**1**	**2**	**3**	**4**	**Conf**
1	Salinity						
	Similarity in salinity	**95**	**95**	**94**	**73**	**~~314~~**	**M**
2	General water quality in the estuary						
a	N and P concentrations	68	68	68	68	71	M
b	Water clarity (suspended solids/turbidity/transparency)	98	98	98	98	88	M
c	Dissolved oxygen (mg/l) concentrations	100	100	100	100	100	M
d	Toxic substances	90	90	90	90	90	L
	Water quality score	**79**	**79**	**78**	**70**	**44**	

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

6.2.4 Physical Habitat Alteration

Scoring motivation: All assessments and scoring for the habitat variables for the scenarios were done similarly to those for the present day situation. Changes and scores are summarised in Table 6-17 and Table 6-18.

Table 6-17: Summary of changes in physical habitats under the different scenarios

Parameter	Scenario 1
a. Supratidal area and sediments	Flood regime very similar to present. All other drivers of geo-physical estuarine morphology/habitat and sediment characteristics unchanged from present. Thus scores the same as present.
b. Intertidal areas and sediments	Scores the same as present, for the above mentioned reasons.
c. Subtidal area and sediments	Scores the same as present, for the above mentioned reasons.
d. Estuary bathymetry/water volume	Scores the same as present, for the above mentioned reasons.
Parameter	**Scenarios 2 & 3**
a. Supratidal area and sediments	Scenarios 2 and 3 are very similar (differences are too small to score differently (less than 5%)) i.t.o. effects on sediment & morphology. Additional small reduction in floods relative to present, with similar relative effects throughout estuarine zones & areas. All other drivers of geo-physical estuarine morphology/habitat and sediment characteristics unchanged from present. Thus additional small reduction in scores from present.
b. Intertidal areas and sediments	Small reduction in scores from present, for the above mentioned reasons.
c. Subtidal area and sediments	Small reduction in scores from present, for the above mentioned reasons.
d. Estuary bathymetry/water volume	Small reduction in scores from present, for the above mentioned reasons. Also, cumulative effect on estuary bathymetry/water volume considered now to be discernible.
Parameter	**Scenario 4**
a. Supratidal area and sediments	Major reduction in flood regime, which is a critical driver of estuarine morphology & sediment characteristics throughout the estuary. Less flushing of sediments and probably relatively more/longer intrusion of marine sediments. “Dormant/ less dynamic” cohesive sediment deposits also allow for more consolidation (& vegetation), with increased resistance to erosion/flushing. These effects will propagate through the whole estuary. Overall major impacts on habitats, thus related scores.
b. Intertidal areas and sediments	Scores much reduced from present, for the above mentioned reasons.
c. Subtidal area and sediments	Scores much reduced from present, for the above mentioned reasons.
d. Estuary bathymetry/water volume	Scores much reduced from present, for the above mentioned reasons.

Table 6-18: Similarity scores for physical habitats under different scenarios

Variable	Present	1	2	3	4	Conf
1a. Resemblance in intertidal sediment structure and distribution: % similarity in intertidal area exposed	95	95	90	90	50	L-M
1b. Resemblance in intertidal sediment structure and distribution: % similarity in sand fraction relative to total sand and mud	95	95	90	90	50	L-M
2. Resemblance of sub-tidal area to ref. (depth, bed, channel)	95	95	90	90	50	L-M
Physical habitat score	95	95	90	90	50	

6.3 Biotic Component

6.3.1 Microalgae

The change in flow from present to Scenario 3 is too small to result in a change in microalgal biomass in the estuary. During Scenario 4 there is a large reduction in river flow (97% at present to 40%) causing a high proportion of flows to be in State 2 (14% at present to 37%) and State 1 (0.3% at present to 3.7%).

These conditions can last from weeks to months, supporting a shift in phytoplankton community structure to one dominated by flagellates and dinoflagellates (60% change from natural) and an increase in benthic microalgal biomass as a result of more stable conditions (83% at present to 80%).

However, no change in muddiness or occurrence of hypoxic/anoxic events are predicted limiting large changes in community composition or species richness. Changes and scores are summarised in Table 6-19 and Table 6-20.

Table 6-19: Summary of how the Microalgae Changes

Scenario	Summary of changes
1	No change in hydrodynamics, nutrients or turbidity compared to present. No marked changes in microalgal abundance, richness or community composition.
2	No change in hydrodynamics, nutrients or turbidity compared to present. Just a 1% increase in salinity compared to present. No marked changes in microalgal abundance, richness or community composition.
3	Similar to scenarios 1 and 2 with just slightly deeper saline intrusion into lower reaches (95% salinity at present compared to 73% in scenario 3). This is likely to result in a slight change in species richness and community composition from present (11%) as estuary becomes more stratified. No expected changes in sediment characteristics so benthic microalgal community composition and species richness remain unchanged.
4	Large reduction in river flow resulting in increase in salinity intrusion (95% salinity at present changing to 31% in scenario 4). Lower flow likely to result in lower average nutrient concentrations (68% at present changing to 71 in scenario 4) and an increase in turbidity (98% at present changing to 88%). This is likely to result in a large change in species richness and community composition from present (32%) as estuary becomes more stratified. Extended period of elevated benthic microalgal biomass likely to stabilise sediment and cause a slight increase in organic matter resulting in a slight change in species richness (taxa tolerant of eutrophic conditions) and community composition (15%).

Table 6-20: Similarity Scores of Microalgae under the Different Scenarios

Phytoplankton	Present	1	2	3	4	Confidence
1. Species richness	70	70	70	59	38	M
2 Abundance	72	72	72	72	71	M
3. Community composition	65	65	65	54	33	M
Benthic microalgae	**Present**	**1**	**2**	**3**	**4**	**Confidence**
1. Species richness	85	85	85	85	70	M
2 Abundance	83	83	83	83	80	M
3. Community composition	85	85	85	85	70	M
Microalgae score	**65**	**65**	**65**	**54**	**33**	

6.3.2 Macrophytes

Scenarios 1, 2 and 3 represent very little change in flow and related abiotic conditions in response to the present state. See Table 6-21.

Scenario 4 is a futuristic scenario used to test the sensitivity of the estuary to flow reduction. This scenario represents a 60% decrease in flow relative to reference conditions. Salinity for Scenarios 1 and 2 was the same as present conditions.

For Scenario 3 salinity increased from 13 to 18 in the lower reaches and from 2 to 6 in the middle reaches. These salinity changes are still within the tolerance range of the dominant reeds and so no major habitat changes are expected in response to this. For Scenario 4 the salinity in the lower reaches increases from 12 (reference conditions) to 23 and from 2 to 13 in the middle reaches.

Conditions in the middle reaches would still favour reeds and sedges whereas the higher salinity conditions in the lower reaches may result in salt marsh displacing the reed and sedge habitat. Increase in catchment disturbance and mud input would encourage macrophyte growth along the banks. The large increase in DIN and DIP would provide favourable conditions for the growth of all macrophytes.

Table 6-21: Summary of how the Macrophytes change

Scenario	Summary of changes
1&2	Scenarios 1 and 2 represent very little change in flow and related abiotic conditions and macrophytes would therefore be similar to the present state.
3	For Scenario 3 salinity increases from 13 to 18 in the lower reaches and from 2 to 6 in the middle reaches. These salinity changes are still within the tolerance range of the dominant macrophytes (reeds, sedges & lagoon hibiscus) and so no major habitat changes in terms of area are expected in response to this. Some change (5% lower than present) in species and community composition in response to salinity change expected. This equates to a 1 ha loss of reeds & sedges and the community composition score is the same as for the present state.
4	The salinity in the lower reaches increases from 12 (reference conditions) to 23 ppt and from 2 to 13 ppt in the middle reaches. Conditions in the middle reaches would still favour reeds and sedges whereas the higher salinity conditions in the lower reaches would result in salt marsh displacing the reed and sedge habitat. Salt marsh would cover approximately 5 ha. There would be a loss of swamp forest which grows best under brackish conditions. The open and saline conditions would encourage the growth and spread of mangroves. It is estimated that they would increase in cover from 0.03 ha (present state) to 1 ha under this scenario. The increase in low flow conditions and large reduction in floods would increase sedimentation and reed & sedge encroachment into the main channel in the middle and upper reaches. There would be a loss of open water habitat. Changes in species richness (40% decrease) in response to salinity changes are expected.

Table 6-22: Area Covered by Macrophyte Habitats

Macrophyte habitat	Reference area cover (ha)	Scenario 4 area (ha)	Minimum
Floodplain	66	30	30
Reeds & sedges	10	10	10
Swamp forest	5	2	2
Mangroves	0	1	0
Alien plants	0	5	0
Salt marsh	0	2	0
% similarity	**Sum min / (sum ref + present) /2**		**42/(131)/2 = 64%**

Table 6-23: Similarity Scores of Macrophytes under the Different Scenarios

Variable	Present	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Conf
1. Species richness	85	85	85	80	60	M
2 Abundance	63	63	63	63	56	M
3. Community composition	66	66	66	66	64	M
Macrophyte score	**63**	**63**	**63**	**63**	**56**	**M**

6.3.3 Invertebrates

This section describes the changes in invertebrates for the different run-off scenarios. Changes and scores are summarised in Table 6-24 and Table 6-25.

Table 6-24: Summary of anticipated macro-invertebrate faunal change

Scenario	Summary of changes
1 -3	No change in hydrodynamics (low flows and floods) under Scenarios 1-3. As floods and strong flows are major determinants of conditions in the estuary, little change in the physico-chemical environment would be expected. Mouth closure is not expected under any of the scenarios. No faunistically significant changes are expected in DIN, DIP, turbidity or dissolved oxygen. Possibly slightly greater upstream penetration of saline water could, all things being equal, occur under Scenario 3 with resultant upstream extension of low salinity sensitive species.
4	Under this Scenario there would be a major reduction in the flood regime resulting in less strong flow impact, less sediment mobility, possible sediment consolidation, more salinity penetration as the mouth remains open, greater water clarity and the development of a more diverse, sheltered marine habitat type fauna.

Table 6-25: Similarity scores of invertebrates under the different scenarios

Variable	Present	1	2	3	4	Confidence
1. Species richness	95	95	95	92	60	H
2 Abundance	95	95	95	92	60	H
3. Community composition	95	95	95	92	60	H
Invertebrate score	**95**	**95**	**95**	**95**	**60**	

6.3.4 Zooplankton

This section describes the anticipated changes in the zooplankton under the different run-off scenarios. Changes and scores are summarised in Table 6-26 to Table 6-28.

Table 6-26: Summary of anticipated zooplankton faunal change

Scenario	Summary of changes
1 - 3	No change in hydrodynamics (low flows and floods) under Scenarios 1-3. As floods and strong flows are major determinants of conditions in the estuary, little change in the physico-chemical environment would be expected. Mouth closure is not expected under any of the scenarios. No faunistically significant changes are expected in DIN, DIP, turbidity or dissolved oxygen. Possibly slightly greater upstream penetration of saline water could, all things being equal, occur under Scenario 3 with resultant upstream extension of low salinity sensitive species.
4	Under this Scenario there would be a major reduction in the flood regime resulting in much shorter periods of strong outflow and greater tidally driven salinity penetration as long as the mouth remains open. The typical estuarine mero- and holoplankton would be forced upstream while areas nearer the mouth and under greater tidal influence would show a change towards a more neritic type community, especially after flood tide periods.

Table 6-27: Similarity scores of the zooplankton fauna under the different scenarios

Variable	Present	1	2	3	4	Confidence
1. Species richness	95	95	95	92	60	H
2. Abundance	95	95	95	92	60	H
3. Community composition	95	95	95	92	60	H
Zooplankton score						

Table 6-28: Combined similarity scores for invertebrates

Variable	Present	1	2	3	4	Confidence
1. Species richness	95	95	95	92	60	M
2. Abundance	95	95	95	95	60	M
3. Community composition	95	95	95	95	60	M
Invertebrate score	95	95	95	92	60	

6.3.5 Fish

This section describes the anticipated changes in the fish under the different run-off scenarios. Changes and scores are summarised in Table 6-29 and Table 6-30.

Table 6-29: Summary of anticipated change of fish fauna under the different scenarios

Scenario	Summary of changes
1 -3	The physical processes that drive the fish fauna in the system will not be greatly affected under any of these scenarios. The slight increase in saline penetration under scenario three may lead to an extension of the marine fauna up the system, however, this is considered to be negligible.
4	Scenario 4 would result in a major change in the physical processes of the system, reducing flows and resulting in a more stable marine inlet type system. Species diversity is likely to increase with an influx of marine associated taxa. Community composition will follow suit. Habitat suitability for the Zambezi Shark will be significantly impaired, as will coastal productivity.

Table 6-30: Similarity scores of the fish fauna under the different scenarios

Variable	Present	1	2	3	4	Conf
1. Species richness	100	100	100	100	80	M-H
2 Abundance	75	75	75	73	45	M-H
3. Community composition	75	75	75	73	45	M-H
Fish score	75	75	75	73	45	

6.3.6 Birds

This section describes the possible changes in the aquatic avifauna under the different run-off scenarios. Changes and scores are summarised in Table 6-31 and Table 6-32.

Table 6-31: Summary of anticipated changes in the aquatic avifauna

Scenario(s)	Summary of changes
1 -3	The birds utilising the Mzimvubu estuary will be drawn to particular areas depending largely on their feeding prospects which come down basically to the presence of fish in the water column or invertebrates which will be largely a part of the benthos. Bird diversity and abundance will therefore depend on the presence of suitable accessible habitats where they can feed. As indicated in the section on the macro-invertebrate fauna, if there is no change in the hydrodynamics and the associated physico-chemical parameters under scenarios 1-3 there will be little or no faunistic, *i.e.* food resource changes as far as the aquatic birds are concerned.
4	This scenario represents potentially very different conditions where the mouth will apparently remain open, the riverine influence will be significantly reduced and the marine influence will become proportionately greater. If so, this would significantly change the physico-chemical environment in the estuary in terms of *i.a.* sediment stability, salinity, temperature and water clarity. Under these conditions one would expect changes in the zooplankton, fish and benthic invertebrate communities which would represent major feeding opportunities as far as the aquatic birds are concerned.

Table 6-32: Similarity scores for aquatic birds under the different scenarios

Variable	Present	1	2	3	4	Conf
1. Species richness	95	95	95	95	80	H
2 Abundance	70	70	70	70	60	H
3. Community composition	90	90	90	90	70	H
Bird score	**70**	**70**	**70**	**70**	**60**	

6.3.7 Ecological Categories associated with Alternative Water Flow Scenarios

The individual Estuarine Health Index (EHI) scores, as well as the corresponding ecological category under different scenarios are provided in Table 6-33.

The estuary is currently in a B-category. It will remain in this category under Scenario 1, 2 and 3, but is expected to decline to a very low D category for the hypothetical scenario 4 where a large proportion of the MAR is removed.

Scenario 3 allows the addition of the proposed Ntabelanga Dam to a maximum of 1.5 of the MAR, and suggests that the estuary will remain in a B-category (PES = B). This however, presupposes that anthropogenic changes do not degrade the condition of the estuary further, and that the listed Anthropogenic Management requires are put in place and maintained.

Table 6-33: EHI score and corresponding Ecological Category

	Weight	Present	1	2	3	4	Conf
Hydrology	25	93	93	91	90	40	H
Hydrodynamics and mouth condition	25	100	100	100	100	100	H
Water quality	25	79	79	78	70	44	H
Physical habitat alteration	25	95	95	90	90	50	M
Habitat Health Score		**92**	**92**	**90**	**88**	**59**	
Microphytes	20	65	65	65	54	33	M
Macrophytes	20	63	63	63	63	56	M
Invertebrates	20	95	95	95	92	60	H
Fish	20	75	75	75	73	45	M
Birds	20	70	70	70	70	60	M
Biotic Health Score		**74**	**74**	**74**	**70**	**51**	
Estuary Health Score		**83**	**83**	**82**	**79**	**55**	
Present Ecological Status		**B**	**B**	**B**	**B**	**D**	

7. RECOMMENDATIONS

7.1 Recommended Ecological Flow Requirement for the Mzimvubu Estuary

For a high confidence Reserve study, the Recommended Ecological Water Requirement (REC=EWR) 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 will still maintain the estuary in the Recommended Ecological Category (REC).

Where any component of the health score is less than 40, modifications to flow and measures to address anthropogenic impacts must be found and implemented to aid in the improvement of the overall estuarine health.

For lower confidence studies, such as this one, a more conservative flow scenario (or a slight modification thereof to address low-scoring components) should be chosen, using the following guidelines.

Table 7-1: Guidelines for the recommended Ecological Water Requirement Scenario

Overall Confidence	Choice of Recommended Ecological Requirement' Scenario
Very Low (rough estimate) less than 40% certain	The scenario with the lowest change in river inflow that will maintain the estuary in the Recommended Ecological Category or obtain a health score that is one category higher (large safety buffer).
Low 40 - 60% certain	The scenario with the highest change in river inflow that will maintain the estuary in the Recommended Ecological Category or obtain a health score that is one category higher (large safety buffer)
Medium 60-80% certain	The scenario with the highest change in river inflow that will maintain the estuary in the Recommended Ecological Category or obtain a health score that is half a category higher (small safety buffer)
High >80% certain	The scenario with the highest change in river inflow that will maintain the estuary in the Recommended Ecological Category (no safety buffer)

Based on this assessment, it is considered that the Best Attainable State for the estuary is a **B-category**. It should be noted that although some anthropogenic impacts would be difficult to remove, such as the global impacts on migratory birds, and the status of marine fish stocks, it is possible to reverse the impacts associated with the changes at the mouth of the system and restore a beach on the south bank (see recommendations below).

The flow requirement scenario which will keep the estuary in the recommended ecological category is Scenarios 1 and 2. Scenario 3 (larger Ntabelanga Dam) would lower the ecological status of the estuary but would remain within the lower range of a B category.

It is understood that Scenario 3 is likely to be implemented.

A summary of the recommended flow scenario monthly flow (in m^3/s) distribution under Scenario 3 are presented in Table 7-2.

Table 7-2: Summary of the recommended flow Scenario 3

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	312.5	460.5	430.3	614.5	675.6	734.5	373.4	209.0	310.9	262.5	144.3	299.8
90%ile	99.9	214.0	253.3	315.1	517.1	384.9	154.6	65.4	47.1	35.9	41.1	67.5
80%ile	65.8	98.9	179.5	196.6	285.8	260.7	110.5	47.6	27.3	25.5	23.1	26.8
70%ile	40.1	73.6	143.9	138.9	211.3	211.8	97.7	33.1	19.7	19.8	16.1	20.0
60%ile	28.5	51.8	74.5	104.4	150.8	168.7	68.0	22.0	17.0	16.5	12.7	16.3
50%ile	21.1	37.1	45.6	85.2	122.3	138.4	58.9	20.1	14.1	11.9	11.1	14.1
40%ile	17.7	31.4	30.9	63.4	92.9	111.3	41.0	18.1	11.8	10.0	9.6	11.6
30%ile	14.9	21.4	24.0	47.9	63.5	77.1	34.4	14.7	10.6	9.3	8.5	8.2
20%ile	12.0	16.6	18.2	37.6	47.2	51.0	31.4	12.2	9.8	8.2	7.2	7.5
10%ile	9.8	13.2	11.3	20.0	35.2	43.9	19.1	10.6	7.9	7.0	6.3	6.4
1%ile	5.7	9.3	5.1	6.9	15.2	13.0	9.3	6.4	5.6	4.1	2.8	3.1

7.2 Thresholds of Potential Concern

Since the estuary has to meet national ecological management policy and objectives, the Thresholds of Potential Concern[5] (TPCs) should be seen as targets to be met within 5 years. Thereafter the estuary should be maintained such that these thresholds are not breached. The TPCs for the Mzimvubu Estuary area listed in Table 7-3.

Table 7-3: Ecological Specifications and TPCs for Abiotic Component

	Ecological Specification	Threshold of Potential Concern
Water quality	Salinity distribution not to cause exceedance of TPCs for fish, invertebrates, macrophytes and microalgae	• Salinity Salinity should remain unchanged
	System variables (pH, dissolved oxygen & transparency) not to exceed TPCs for biota	• River inflow: 7.5 less than pH > 8.5 DO less than 6 mg/ℓ Suspended solids/turbidity (naturally turbid) • Estuary: Turbidity (naturally turbid) 7.5 less than pH > 8.5 DO less than 6 mg/ℓ
	Inorganic nutrient concentrations not to cause in exceedance of TPCs for macrophytes and microalgae	• River inflow (low flows): DIN >…. µg/ℓ; DIP >…. µg/ℓ • River inflow (high flows): DIN>….. µg/ℓ; DIP >…… µg/ℓ • Estuary (low flows): DIN >….. µg/ℓ; DIP >…… µg/ℓ • Estuary (high flows): DIN >.... µg/ℓ; DIP >…… µg/ℓ
	Presence of toxic substances not to cause exceedance of TPCs for biota	• River inflow: Trace metals (to be determined) Pesticides/herbicides (to be determined) • Trace metals: Concentrations in estuary waters exceed target values as per SA Water Quality Guidelines for coastal marine waters (DWAF, 1995)
Hydrodynamics		
Sediment dynamics		

[5] *Thresholds of potential concern (TPC's) are a set of operational goals that together define the spatial and temporal variation in ecological conditions for which the estuary ecosystem is managed.*

Macrophytes	Maintain the diversity of macrophyte habitats in the estuary. Reeds & sedges covering approximately 16 ha. Prevent further disturbance and development of the floodplain habitat.	Sedimentation in main channel and colonisation by vegetation. 50 % loss of reed & sedge habitats in non-flood year due to salinity changes. No increase in invasive species in riparian zone.

7.3 Mouth Management

The mouth of the Mzimvubu Estuary has been constrained to a large extent by the access road that was established behind the area formerly known as First Beach. This road has effectively entrained of the mouth of the estuary towards the right bank under typical flow conditions.

The possible removal of this access road (in favour of existing alternative access routes to the properties along this road), would re-establish variability in the estuary mouth configuration.

7.4 Sediment Dynamics

There are indications that the road established behind the former First Beach area may have played a major role in altering local sediment patterns, and creating enabling conditions for the erosion and loss of First Beach. The findings of the workshop suggested that there is a realistic possibility that this might be reversed through the removal of the road and associated revetment. The removal of the road would therefore have the potential to re-establish this once-popular recreational beach.

The functional importance of the Mzimvubu Estuary in delivering sediments to the marine and coastal environments is extremely high. Without the continued delivery of this material through the estuary, there is a high likelihood of effects on local and regional beaches in terms of increased vulnerability to coastal erosion.

In order to protect local and regional sediment supply to the marine and coastal environment, it is recommended that sand mining within the estuary functional zone and a suitable buffer zone should be avoided.

7.5 Land Use Management

One of the major factors lowering the PES is the condition of the vegetation/habitats within the estuarine functional zone (i.e. those areas that lie below the 5 m contour). There is an area of approximately 26 ha of disturbed floodplain that was identified by the study as having the potential for rehabilitation. The previous impacts to these areas are reversible, and rehabilitation here would significantly enhance the functional integrity and importance of the estuary as a whole.

Given the potential for future loss of the estuarine functional zone through future development and the consequences this would have on the ecological status of the estuary, it is recommended that local land-use plans place restrictions on further loss of habitat in the estuarine functional zone/floodplain.

Given the extensive and frequent flooding of this estuary it is recommended that these measures extend to the 10m contour (or 10m above mean sea level).

It should be noted that the adjacent coastal forest and scarp forest associated with the estuary is an important adjunct riparian habitat to the estuary that contributes to the biodiversity and conservation importance of the Mzimvubu Estuary. These areas should be considered for development restrictions in order to protect these values. This could be co-ordinated with SANBI's National Freshwater Ecosystem Priority Areas programme (NFEPA).

7.6 Exploitation of Marine Living Resources

One of the major factors contributing to the lowering of the PES of the Mzimvubu is the high fishing pressure on this estuary. Enhancing the nursery function of the estuary through the management of fishing pressure would significantly enhance the functional importance of the estuary for species of conservation interest. The study has suggested the possible partial closure of the estuary to fishing in order to protect important fish stocks and sensitive habitats.

Additional measures focused on the mouth condition would contribute towards ensuring access for fish species of particular concern.

7.7 Invasive Alien Plants

The extent of disturbance to floodplain vegetation was identified as a significant factor lowering the PES of the estuary, and an invasive alien plant management programme would make a significant contribution towards addressing this and enhancing the functional importance of the floodplain as a feature of the estuary.

7.8 Water Quality Management

The canalised creek that flows from the town of Port St John's is a point source pollution risk to the estuary, and the study results suggest that this is compromising the estuary water quality to some extent. Measures to address the quality of water in the canal/creek are recommended (particularly regarding the quality of any treated wastewater effluent disposed into the creek).

There are apparently elevated lead levels in portions of the estuary, and this issue requires further investigation to determine whether this is a result of a pollution source/event, or due to naturally higher background levels of the metal. Water quality monitoring should be implemented as part of the EMP.

7.9 Monitoring Requirements

An EMP would be prepared in terms of the implementation of the Ntabelanga Dam. This would include any necessary mitigations and actions required in connection with the dam's environmental impact on the estuary.

In addition to this there should be an ongoing EMP for the estuary itself which would be undertaken exclusive of the implementation of the Ntabelanga Dam.

In both regards, there should be a long-term monitoring programme undertaken for the estuary, the minimum recommended requirements of which are given in Table 7-4.

Table 7-4: Recommended minimum requirements for long term monitoring

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. Stations)
Hydrodynamics	Record water levels	Continuous	As close to estuary mouth as possible to capture tidal rise and fall – currently on road bridge and sufficient for needs
	Measure freshwater inflow into the estuary	Continuous	Head of estuary
	Aerial photographs of estuary (spring low tide)	Bi-annual	Low spring tide during winter and summer
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	Entire estuary
Water quality	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow	At least monthly on going	Recommend that sampling point be added to DWA WQ monitoring network closer to head of estuary, 15 km from mouth
	Longitudinal salinity & temperature profiles (in situ)	To be measured when biotic surveys require information for interpretation	Entire estuary 6-10 stations
	Measurements along grid of station in (at least surface and bottom samples) for pH, dissolved oxygen, suspended solids/turbidity/Secchi depth and inorganic nutrients		
Macrophytes	Ground-truthed maps to update the maps produced for 2013 and verify the areas covered by the different macrophyte habitats; Record number of macrophyte habitats; identification of total number of macrophyte species; number of rare or endangered species, or those with limited populations documented during a field visit; Assess extent of invasive species in the estuarine area within the 5 m contour line.	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,	Summer and winter survey every 3 years	Entire estuary (5 stations)

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. Stations)
	and counts of hole densities;		
Fish	Record species and abundance of fish, based on seine net and gill net sampling.	Summer and winter survey every 3 years	Entire estuary (5 stations)
Birds	Undertake counts of all water associated birds, identified to species level.	A series of monthly counts, followed by winter and summer survey every year	Three estuary sections

8. REFERENCES

1. CSIR. 2005. An assessment of the status of the Mzimvubu Estuary and recommendations for its management. CSIR Report ENV-S-C 2005-090.
2. Day, J.H. 1981. Estuarine Ecology: with particular reference to southern Africa. A. A. Balkema, Cape Town, pg. 286-287.
3. Department of Water Affairs and Forestry (DWAF) 1995. South African Water Quality Guidelines for Coastal Marine Waters. Volume 1: Natural Environment. Pretoria.
4. Department of Water Affairs and Forestry, South Africa. 2005. Mzimvubu to Keiskamma Water Management Area: Internal Strategic Perspective of the Mzimvubu to Mbashe ISP Area. Prepared by Ninham Shand, Tlou and Matji, FST Consulting and Umvoto Consortium. DWAF Report No.: P WMA 12/000/00/0305
5. Department of Water Affairs and Forestry (DWAF) 2008. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries. Version 2. Pretoria.
6. Department of Water Affairs and Forestry (DWAF) 2012 Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries. Version 3. Pretoria.
7. Eagle, GA and Bartlett, PD. 1984. Preliminary chemical studies in four Cape estuaries. CSIR Report T/SEA 8307. CSIR Environmentek, Stellenbosch.
8. Eyre, B and Balls, P. 1999. A comparative study of nutrient behaviour along the salinity gradient of tropical and temperate estuaries. Estuaries 22 (2A): 313-326.
9. Eyre, B. 2000. Regional evaluation of nutrient transformation and phytoplankton growth in nine river-dominated sub-tropical east Australian estuaries. Marine Ecology Progress Series 205: 61-83.
10. Ferguson, A, Eyre, B and Ga, J. 2004. Nutrient cycling in the sub-tropical Brunswick Estuary, Australia. Estuaries 27 (1): 1-17.
11. Harrison T.D. 1990. Investigation into the biology and ecology of the fishes of Natal's small estuarine systems. Interim Step Report No. 2. Report No WAT 11/90. CSIR, Durban.
12. Harrison T.D., Cooper J.A.G. & Ramm A.E.L. 2000 State of South African estuaries. Geomorphology, Ichthyofauna, Water Quality and Aesthetics. State of the Environment Series Report No: 2. Department of Environmental Affairs and Tourism, South Africa. 127 pp.
13. Kululwa, M., Gaulana, L., Elliot, W. & Mlondolozi, M. 2008. Mzimvubu River Spring Survey. Department of Water & Forestry (DWAF), pp. 1-25.
14. Perry J.E. 1989 The impact of the September 1987 floods on the estuaries of Natal/Kwazulu; a hydro-photographic perspective. CSIR Research Report 640.
15. Taljaard S, Slinger JH, Van Niekerk L and Huizinga P. 1997. Topographic and physic-chemicakl surveys of three easter Cape estuaries during august 1996. (1) Mngazi River Estuary (2) Mzimvubu River Estuary (3) Mntafufu River Estuary. CSIR Report ENV/S-T 97003.
16. Turpie, J. and Clark, B. 2007. Development of a conservation plan for temperate South African estuaries on the basis of biodiversity importance, ecosystem health and economic costs and benefits. C.A.P.E. Regional Estuarine Management Programme, Final Report.

17. Turpie, J.K., Clark, B., Knox, D., Martin, P., Pemberton, C. & Savy, C. 2004. *Improving the biodiversity rating of South African estuaries*. Vol 1. Contributions to information requirements for the implementation of resource directed Measures for estuaries. WRC Report no. 1247/1/04. 121pp.

18. Turpie, J.K. & Whittington, P. (in prep). Birds of the Wild Coast 2002-2012. Ostrich.

19. Van Niekerk, L. & Turpie, J.K. (eds) 2012. South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report Number CSIR/NRE/ECOS/ER/2011/0045/B. Council for Scientific and Industrial Research,

20. Whitfield A.K. 2000 Available scientific information on individual South African estuarine systems. WRC report No. 577/3/00. (Updates available online via Consortium for Estuarine Research and Management website).

APPENDIX A

DATA AVAILABLE FOR THIS STUDY

Component	Baseline information requirements for high confidence	Data available for this study
General	Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the Reference condition (if available).	Aerial photos for 1938, 1961, 1973, 1990. 2005
	Available orthophotographs	Yes
Hydrology	Catchment size delineation	Simulated monthly flows, 1920 to 2004
	Measured river inflow data (gauging stations) at the head of the estuary over a 5-15 year period	Not available, catchment poorly gauged and station above estuary installed in 2009, but not calibrated.
	Measured rainfall data in the catchment (or in a representative adjacent catchment)	
	Hydrological parameters (evaporation rates, radiation rates)	
	Flow losses (e.g. abstraction, impoundment) and gains (e.g. discharges, transfer schemes)	
	Flood hydrographs for reference condition	Not available
Bathymetry	Bathymetric/topographical surveys including berm height, cross sections at 10 – 50 m in the mouth region, cross section profiles at 500 m to 1000 m intervals upstream of the mouth, and floodplain topography.	Bathymetric data available (CSIR, 1996)
Hydrodynamics	Continuous water level recordings near mouth of the estuary	Yes,
	Water level recordings at 2-6 stations along the length of the estuary over a spring and a neap tidal cycle (i.e. at least a 14 day period)	No data
	Long term data on daily mouth state (open/closed/overtopping) for temporarily open/ closed estuaries, particularly in systems that have a semi-closed mouth state.	N/A
	Data on wave conditions.	Not used
Sediments	Sediment grabs samples collected using a Van Veen or a Zabalocki-type Eckman grab (to characterize recent sediment movement) for particle size analyses, along entire estuary at 500 to 1 000 m intervals.	Samples collected in Jan 2013 (this study)
	Sediment core samples collected using a corer (for historical sediment characterization) at intervals similar to cross-section profiles (see bathymetry) or where considered appropriate by sediment specialist; collected at 3 - 6 year intervals, as well as after flood events.	No data
	Sediment load at head of estuary (including detritus component – particulate carbon/loss on ignition).	No data
Water quality	Longitudinal salinity and temperature profiles (in situ) collected over a spring and neap tide during high and low tide at: • end of low flow season • peak of high flow season	August 1996 (Taljaard et al (1997) August 2012 (this study) January 2013 (this study)

	Water quality measurements (i.e. system variables, and nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at: • end of low flow season • peak of high flow season	August 1996 (Dissolved oxygen & inorganic nutrients) (Taljaard et al (1997) August 2012 (pH, turbidity, SS, dissolved oxygen & nutrients) (this study) January 2013 (pH, turbidity, SS, dissolved oxygen & nutrients) (this study)
	Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary	Trace metals (2013) (Songca et al. 2013)
	Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary	Mar 2009 to Oct 2012 (31 data points) (DWA WQ monitoring programme [T3H020Q01])
	Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater	Available data (e.g. DWAF 195)
Macrophytes	Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the reference condition (earliest year available). A GIS map of the estuary must be produced indicating the present and reference condition distribution of the different plant community types.	1938, 1952, 1969 and 1977 aerial photographs consulted. GIS map was produced for the study from 2009 images for Chief Directorate: Surveys & Mapping. Ground truthing in August 2012 and January 2013.
	Number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit. The extent of anthropogenic impacts (e.g. trampling, mining) must be noted.	Colloty 2000 Adams et al. (2004) reported on the mangroves. Hoppe-Speer (2013) reported on the mangroves.
	Permanent transects (fixed monitoring stations that can be used to measure change in vegetation in response to changes in salinity and inundation patterns) must be set up along an elevation gradient: Measurements of percentage plant cover of each plant species in duplicate quadrats (1 m^2).Measurements of sediment salinity, water content, depth to water table and water table salinity.	This is only relevant for salt marsh habitats which are not found in the Mzimvubu Estuary.