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RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTU/MHLATUZE WATER MANAGEMENT AREA
WP 10544

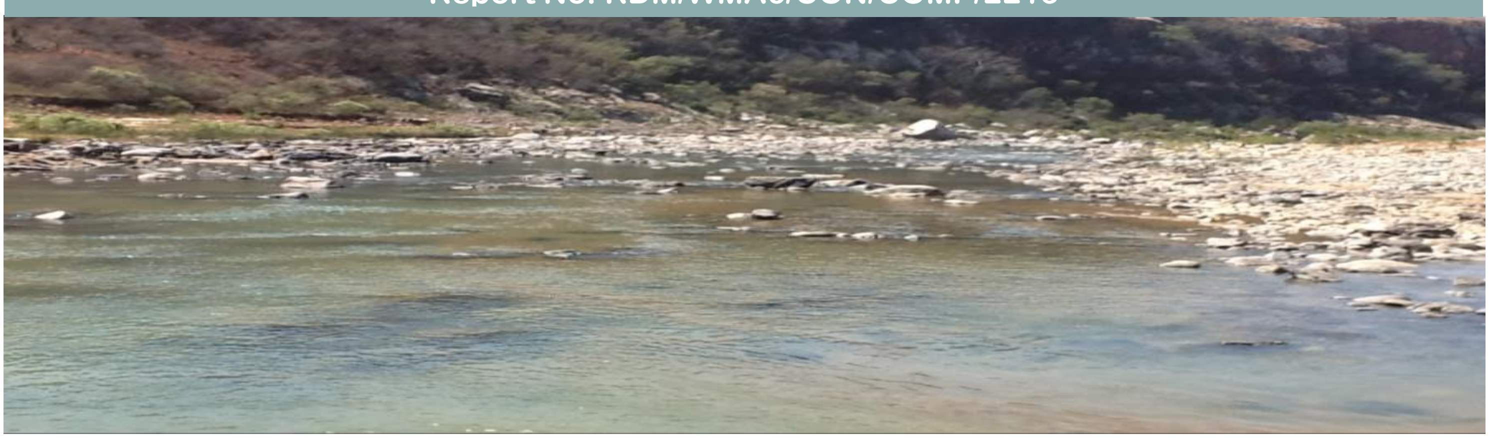
LAKE ST LUCIA

VOLUME 1: INTERMEDIATE ECOCLASSIFICATION AND EWR ASSESSMENT REPORT

FINAL

JULY 2016

Report No. RDM/WMA6/CON/COMP/2213



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DEPARTMENT OF WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS
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RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTHU-MHLATUZE WATER MANAGEMENT AREA:

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Consultants: Tlou Consulting (Pty) Ltd and Anchor Environmental Consultants (Pty) Ltd

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G. Basson	Hydrodynamics
J. Adams	Microalgae & Macrophytes
R. Perissinotto	Invertebrates
D. Cyrus	Fish
J. Turpie	Birds

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ABBREVIATIONS AND ACRONYMS

AEC	Alternative Ecological Category
DRIFT	Downstream Response to Imposed Flow Transformation
DSS	Decision Support System
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EIS	Ecological Importance and Sensitivity
EMC	Ecological Management Class
EWR	Environmental Water Requirements
LWR	Lake Water Requirement Approach
OCS	Off Channel Storage
PES	Present Ecological Status
REC	Recommended Ecological Condition
WMA	Water Management Area

GLOSSARY OF TERMS

- **Ecological Categories.** A distinction is made between Management Classes, which form part of the National Classification System, and Ecological Categories, which forms part of the Ecological Water Requirement assessment.
- **Ecological Category** (EC) replaces former terms used, namely: Ecological Reserve Category (ERC), Desired Future State (DFS) and Ecological Management Class (EMC).
- **Ecological Water Requirements** (EWR) should be used instead of the term Instream Flow Requirements (IFR) for various reasons, including international acceptance of the former term.
- **Preliminary Reserve** refers to Reserve signed off by the Minister or her representative in the absence of the Classification Process having been undertaken in the basin.
- **Recommended Ecological Condition** (REC) The target maintenance Ecological Condition for a water resource based solely on ecological criteria.
- **Reserve** refers to the EWR for maintaining a particular ecological condition where operational limitations and stakeholder consultation are taken into account. The Reserve includes both ecological and Basic Human Needs (BHN) requirements.

1 INTRODUCTION

1.1 Background to the study

The Chief Directorate: Resource Directed Measures (RDM); Department of Water and Sanitation (DWS), issued an open tender invitation for the "*Appointment of a Professional Service Provider to undertake Reserve Determinations for selected Surface water, Groundwater, Estuaries and Wetlands in the Usuthu to Mhlatuze Basins*". The focus on this area was a result of the high conservation status and importance of various water resources in the basin and the significant development pressures affecting the availability of water in the area.

Reserve determinations are required to assist the DWS in making informed decisions with respect to the magnitude of the impacts of the proposed developments on the water resources in the Water Management Area (WMA), and to provide the input data for Water Resource Classification of the area, and eventual gazetting of the Reserve (DWAF1999a).

In July 2013, DWS appointed Tlou Consulting to undertake the project.

1.1.1 Study objectives

The objectives of the study were to:

- determine the Ecological Reserve (DWAF 1999a) at various levels of detail, for the Nyoni, Matigulu, Mlalazi, Mhlatuze, uMfolozi, Nyalazi, Hluhluwe, Mzinene, Mkuze, Assegaai and Pongola rivers;
- determine the Ecological Reserve, at an Intermediate level, for the Pongola Floodplain;
- determine the Ecological Reserve, at an Intermediate level, for the Lake St Lucia Estuary System;
- determine the Ecological Reserve, at an Rapid level, for the Mlalazi Estuary;
- determine the Ecological Reserve, at a Rapid level, for the Amatikulu Estuary;
- determine the Ecological Reserve, at an Intermediate level, for Lake Sibaya;
- determine the Ecological Reserve, at a Rapid level for Kosi Lake and Estuary;
- classify the causal links between water supply and condition of key wetlands;
- incorporate existing EWR assessments on the Mhlatuze (river and estuary) and Nhlabane (lake and estuary) into study outputs;
- determine the groundwater contribution to the Ecological Reserve, with particular reference to the wetlands;
- determine the Basic Human Needs Reserve for the Usuthu-Mhlatuze WMA;
- outline the socio-economic water use in the Usuthu-Mhlatuze WMA;
- build the capacity of team members and stakeholders with respect to EWR determinations and the ecological Reserve.

1.1.2 Study team

The names and affiliations of the members of the study team for the Lake St Lucia EWR assessment are provided in Table 1.1.

Table 1.1 Members of the study team for Lake St Lucia EWR determination

Name	Affiliation	Role
Barry Clark	Anchor Environmental	St Lucia estuary team leader
Jane Turpie	Anchor Environmental	Birds, co-leader
Andre Görgens	Aurecon	Hydrology
Anton Sparks	Aurecon	Hydrology
Gerald Howard	Aurecon	Hydrology
Gerrit Basson	ASP Technology	Hydrodynamics
Janine Adams	Nelson Mandela Metropolitan University	Microalgae & Macrophytes
Renzo Perissinotto	Nelson Mandela Metropolitan University	Invertebrates
Digby Cyrus	CRUZ Environmental	Fish
Cate Brown	Southern Waters	Internal review
Adhishri Singh	Tlou Consulting	Project Manager

1.2 This report

This report is Volume 1 of two volumes of the Lake St Lucia Estuary Intermediate EWR Report:
Volume 1: Eco-classification and EWR Assessment Report
Volume 2: Hydrodynamic modelling of salinity and suspended sediment

This report is the Eco-classification and EWR Assessment Report for the Lake St Lucia Estuary and provides:

- an overview of the study area (Section 2);
- an overview of the approach adopted for the EWR assessment (Section 3);
- a description and assessment of the health of the Lake St Lucia estuary under present-day conditions (Section 4);
- the recommended ecological category for the Lake St Lucia estuary (Section 5);
- an assessment of the health of the system under the operational flows scenarios (Section 6)
- recommendations on the ecological flows requirements for the estuary, resource quality objectives and monitoring requirements (Section 7); and
- literature cited in the report (Section 8).

The report is structured as follows:

Chapter 1 provides an overview of the project, lists the project objectives and the members of the study team.

Chapter 2 defines the geographical boundaries of the study area;

Chapter 3 outlines the legislative framework for water resources management in South Africa and the approach adopted for this study;

Chapter 4 provides a baseline description and health assessment of the estuary. This chapter starts by introducing the context of the estuary, then describes each of the abiotic and biotic aspects of the estuary, from hydrology to birds. For each of these components, our understanding of the present condition is described, the reference condition is estimated, and then the present state is scored in terms of its similarity to the estimated reference state. The overall state of health is then determined using the Estuary Health Index.

Chapter 5 combines the EHI score with the Importance score for the system to determine the Recommended Ecological Category. It also summarises the overall confidence of the study and the degree to which non-flow factors have contributed to the degradation of the system.

Chapter 6 describes five alternative future scenarios, and determines the Ecological Category for each of these.

Chapter 7 provides the recommendations regarding the flow requirements for the system, the ecological specifications that must be met, and recommendations for a monitoring programme. It also discusses the way forward for management of the estuary mouth.

Chapter 8 lists all references cited in this report.

2 THE STUDY AREA

For the purposes of this study, the geographical boundaries of the Lake St Lucia estuarine system are defined as follows:

Downstream boundary:	Estuary mouth 28°23'37.27"S, 32°25'26.95"E
Upstream boundaries:	
Mkhuze	27°47'19.72"S, 32°30'32.19"E
Mzinene	27°52'47.43"S, 32°20'31.21"E
Hluhluwe	28° 6'10.45"S, 32°19'58.81"E
Nyalazi	28°15'27.95"S, 32°16'46.82"E
uMfolozi	28°26'58.47"S, 32°18'39.59"E
uMsunduzi	28°31'7.57"S, 32°18'21.21"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank (Figure 2.1)

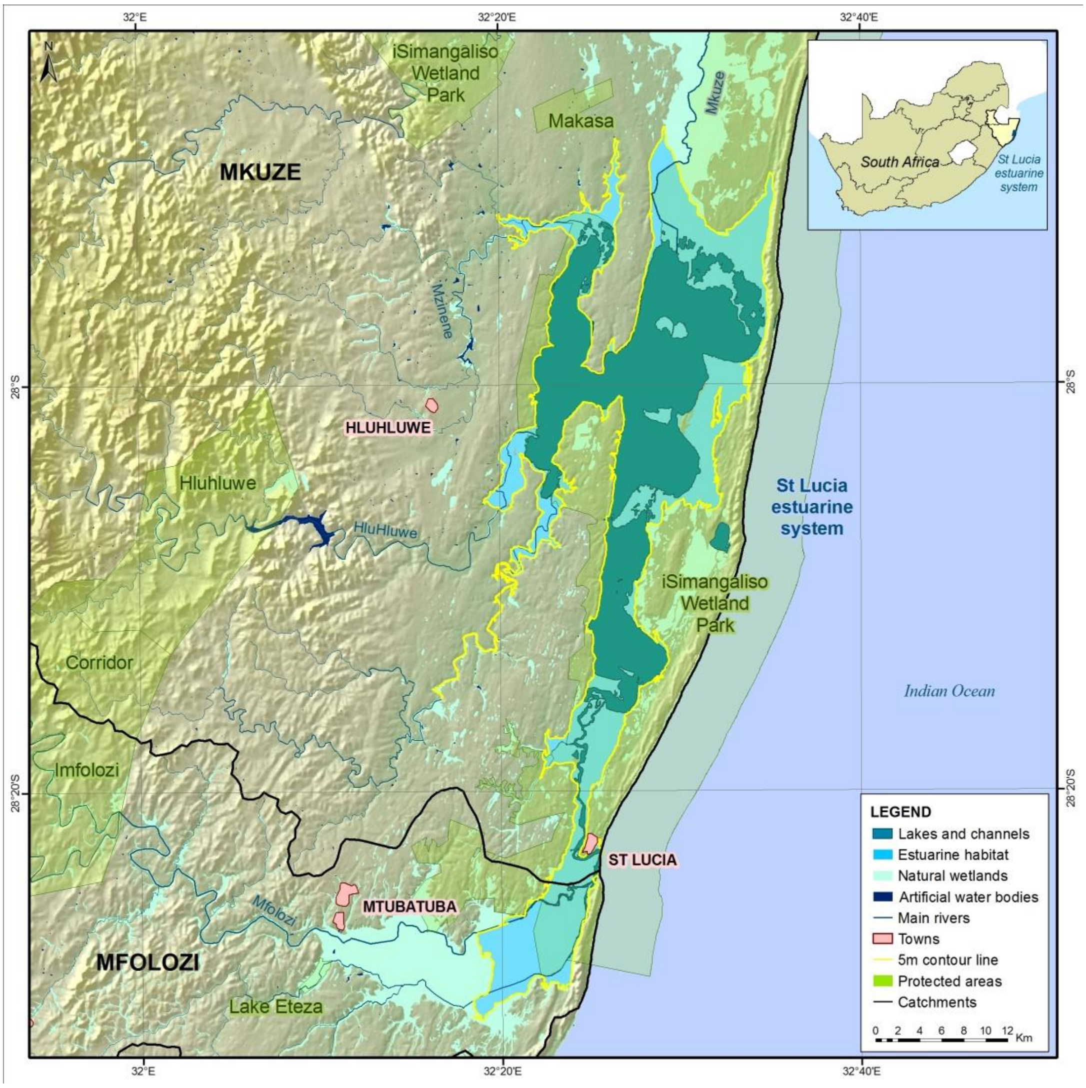


Figure 2.1. Map of the Lake St Lucia estuarine system. (Source: Clark *et al*. 2014a).

3 APPROACH

3.1 Water Resources Management in South Africa

South Africa's National Water Act (NWA) (No. 36 of 1998) requires the implementation of four types of regulatory activities in order to make optimal use of the country's water resources while minimising ecological damage:

1. **Resource-directed measures**, i.e. defining a desired level of protection for a water resource, and on that basis, setting environmental flows and specific goals for the quality of the resource (the Resource Quality Objectives);
2. **Source-directed controls**, i.e. controlling impacts on the water resource through the use of regulatory measures such as registration, permits, directives and prosecution, and economic incentives such as levies and fees, to ensure that the Resource Quality Objectives are met;
3. **Managing demand** on water resources to keep utilisation within the limits required for protection; and
4. **Monitoring** the status of the country's water resources on a continual basis, to ensure that the Resource Quality Objectives are being met, and to enable us to modify programmes for resource management and impact control as and when necessary.

The objective of Resource Directed Measures (RDM) is to ensure the protection of water resources, in the sense of protecting ecosystem functioning and maintaining a desired state of health (integrity or condition) of aquatic and groundwater-dependent ecosystems. This objective is met through various processes, including the setting of 'environmental flows', known as the **Ecological Reserve** (the quantity and quality of water reserved to support ecosystem function).

Water resources (river reaches, wetlands, estuaries, etc.) must first be classified according to a **National Water Resource Classification System** (NWRCS or "Classification System") (Dollar *et al.* 2010), to determine the future level of protection and define specific objectives for the resource (Resource Quality Objectives), which is then used to determine the quantity and quality of water to be allocated to the Reserve

Recognising that it will take some time to classify all water resources in the country, provision has been made in the NWA for the determination of a **Preliminary Reserve** and hence an interim framework issuing of water use licences. Methods to determine the Preliminary Reserve were established soon after the promulgation of the NWA and have been in use since then (DWAF 2008).

These methods follow a generic methodology which can be carried out at different levels of effort to produce a determination of the ecologists' Recommended Ecological Category and the associated Ecological Reserve. The methods have been slightly modified in the development and evolution of methods for rivers, estuaries, wetlands and groundwater, but the same process is essentially followed in each. This study follows the latest method for estuaries (Version 3 – DWA 2012). The steps of the method are outlined below.

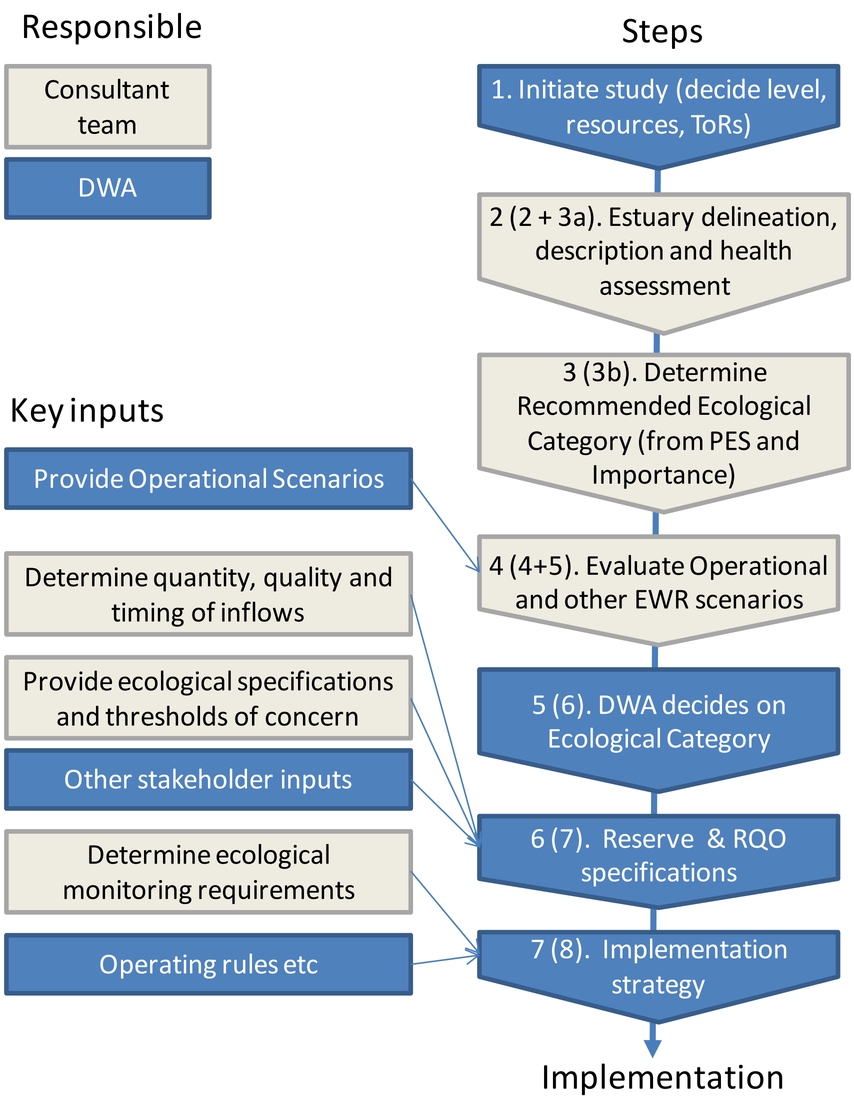


Figure 3.1. Procedures for determination of the preliminary Reserve for estuaries, giving Version 3 step numbers and former step numbers in parentheses (Source: DWA 2012).

Step 1: Initiate the study
This entails defining the study area, the study team, and the level of study.

Step 2: Define the resource units.
Delineate the geographical boundaries of the resource by breaking down the catchment into water resource units which are each significantly different from the other to warrant their own specification of the reserve, and clearly delineate the geographic boundaries of each unit.

Step 3: Determine Recommended Ecological Category (i.e. preliminary classification)

This step entails estimating the reference and present condition and ecological importance in order to determine the Recommended Ecological Category. The Reference Condition refers to the natural, unimpacted characteristics of a water resource, and must represent a stable baseline. This usually requires expert judgement in conjunction with local knowledge and historical data but in this case was assessed using the DRIFT modelling approach (see §0). Reference conditions are generally described in terms of:

- water quantity (amount, timing, pattern and levels of flow, including seasonal and inter-annual variability, flood and drought cycles)
- water quality (the concentrations of key water quality constituents, including their seasonal and inter-annual variability, and going as far as diurnal patterns of variability for constituents such as temperature, dissolved oxygen, salinity and pH)
- geomorphological and vegetation aspects of habitat. In the case of estuaries, this also includes mouth condition.
- character, composition and distribution of aquatic biota.

The Present Ecological Status of resource quality (water quantity, water quality, habitat and biota), is assessed in terms of the degree of similarity to reference conditions. This helps to identify what may be desirable or achievable as a future management class. The assessment is summarised in terms of the classification system of A to F described in Table 3.1.

The Recommended Ecological Category is set as one of the first four ecological categories (A to D) utilized in identifying the present status assessment (Table 3.1). This category is the target for protection and management of the resource. This could be the same as the Present Ecological Status, or could be higher if an improvement in resource condition is desired. It has always been intended that when the full ecological Reserve implementation phase begins (using the Classification Process), the process of assigning the Ecological Class will be a consultative one, aimed at involving stakeholders in deciding the level of resource protection which is required. Criteria for assigning a class to a resource include:

- the sensitivity of the resource to impacts of water use (whether due to ecological sensitivity, or the sensitivity of water users);
- the importance of the resource, in ecological, social, cultural or economic terms;
- the value of the resource, in ecological, social, cultural or economic terms; and
- what can be achieved towards improvement of resource quality, given that not all past impacts may be reversible.

Step 4: Quantify Ecological Water Requirements

The reserve is quantified for the recommended category and alternative categories. This is the most technically demanding of the steps; the rules are rigorous procedures for deriving site-specific numerical objectives which are appropriate for the reference conditions of a particular resource.

Step 5: Ecological consequences of operational scenarios
Operational scenarios are evaluated in terms of the predicted future condition of the resource under each scenario. This is often done using expert judgement in conjunction with local knowledge and historical data but in this case was assessed using the DRIFT modelling approach (see §0).

Step 6: Decide on management category (DWA process)
DWA considers the recommended category in the light of other factors, and makes a decision (A to D).

Step 7: Reserve specification
This entails setting the Resource Quality Objectives (quantitative specifications), and the water quantity and quality parameters of the Reserve. In a Reserve determination study, these are presented as recommendations.

Step 8: Implementation strategy
This entails the strategy for implementation of flows (operating rules in the case of a dam) and other mitigation measures as well as designing a monitoring programme. In a Reserve determination study, these are presented as recommendations.

3.2 Modelling of hydrodynamic functioning

Simulation of abiotic conditions in the Lake St Lucia system under the reference condition, present state and future flow scenarios was undertaken using a one dimensional (1D) numerical model running on software from the Danish Hydraulics Institute (DHI), Denmark and the Digital Elevation Model prepared as part of the GEF-funded “Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system” commissioned by the iSimangaliso Wetland Park Authority (Basson *et al.* 2014).

Table 3.1 The six Ecological Classes for indicating the present ecological status of the resource, as well as selecting the future ecological status (italics). Categories A to D are within the desired range, whereas E and F are not (Kleynhans 1996, MacKay 1999).

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

Management of the mouth of the Lake St Lucia estuary has undergone a number of changes over the past few decades and is about to change again in the near future. Prior to the 1950s the uMfolozi River and Lake St Lucia estuary shared a common mouth. In the early 1950s, however, management authorities made a decision to divert the uMfolozi River away from Lake St Lucia owing to the perceived risk of allowing sediment laden water from the uMfolozi to enter the St Lucia Lakes. Thus, the uMfolozi and Lake St Lucia estuary mouth were kept separate mostly by artificially breaching of the uMfolozi some distance south of the Lake St Lucia estuary mouth. After separation of the two mouths it rapidly became clear that the St Lucia mouth has a natural tendency to close and that active intervention was required to keep the mouth open. Various interventions were implemented to achieve this, including dredging, artificial breaching, and the construction of groynes at the St Lucia inlet (Taylor 2006, Whitfield & Taylor 2009, Taylor 2013a, Stretch *et al*. 2013). Dredging was the most successful of these and continued up until 2002 after the onset of dry conditions which ultimately led to extreme hypersaline condition and desiccation of 90% of the lake in 2006.

The mouth was breached briefly by Cyclone Gamede in 2007 (a result of large storm waves coupled with high water levels in the sea) but otherwise remained closed until a decision was made by iSimangaliso to excavate a beach channel between the uMfolozi mouth and St Lucia in 2012. The beach canal was opened on 6 July 2012, at a time when the uMfolozi and St Lucia mouths were both closed. Water was able to flow from the uMfolozi into St Lucia for a period of time after this until the uMfolozi mouth breached naturally some two months later on 11 September 2012. Water exchange between St Lucia, the uMfolozi, was interrupted again for a period when the beach channel became silted up in late 2014. The uMfolozi mouth subsequently closed in January 2015 but the beach channel was re-opened in February 2015 again permitting water to flow across from the uMfolozi into the Lake St Lucia estuary. Subsequent to this, the iSimangaliso Wetland Park Authority announced in a press release (iSimangaliso 2016) that it had appointed a contractor to remove some 100 000 m^3 of dredge spoil (sand, silt and vegetation) that had been placed in the natural course of the uMfolozi River impeding its flow into Lake St Lucia in accordance with recommendations tabled by Clark *et al*. (2014b). The configuration of the mouth is thus about to change again in the near future. These changes have a very important bearing on the hydrodynamic and ecological functioning of the St Lucia system and also on the freshwater flow requirements for the system. While it is anticipated that the future configuration of the system following the removal of the dredge spoil is likely to prevail for the foreseeable future, hydrodynamic simulation modelling conducted for this study considered both the present day situation (Mouth A: Beach channel) and the future configuration (Mouth B: Dredge spoil removed).

3.3 Modelling of ecological functioning and responses

This study used a modified version of the DRIFT (Downstream Response to Instream Flow) Decision Support (DSS) framework setup as part of the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" that was commissioned by the iSimangaliso Wetland Park Authority (Clark et al. 2014a). This is a framework for a simplified ecosystem model, which focusses on those aspects of an aquatic ecosystem that are expected to be vulnerable to change in flow (e.g. as a result of climate change or water-resource developments), sediment supply (e.g. as a result of land-use changes) and/or management issues (e.g. harvesting of resources or colonization of the marshes) (King & Brown 2010).

The model was set up for three component areas of the system: the Lakes (upstream of Makakatana), the Narrows (down to the Lake St Lucia estuary estuary mouth) and the uMfolozi part of the system (including separated uMfolozi estuary mouth when applicable).

The DRIFT-Estuary model was configured to run on an annual time step for a 40 year period. The primary inputs were time-series data derived from the hydrological and hydrodynamic models (DWS 2015, Basson *et al.* 2014). These included freshwater inflows, water level, area, volume, mouth state, tidal prism, salinity, turbidity and velocity. These input parameters were used to estimate changes in a total of 2 abiotic and 39 biotic indicators.

The DRIFT approach is based on Response Curves constructed from any relevant knowledge including expert opinion and local wisdom and as such is suitable for use in regions where there are few biophysical data available for the flow-related aspects of aquatic ecosystems. Response Curves depict the relationship between a biophysical or socio-economic indicator and a driving variable (e.g. flow). Response Curves can link an indicator to any other indicator deemed to be driving change. The aim is not to ensure that every conceivable link is captured but rather to restrict the linkages to those that are most meaningful and can be used to predict the bulk of the likely responses to a change in the hydrological or hydrodynamic regime of an estuary or river. The Lake St Lucia estuary model contained some 411 response curves to describe 41 indicators in each of three areas.

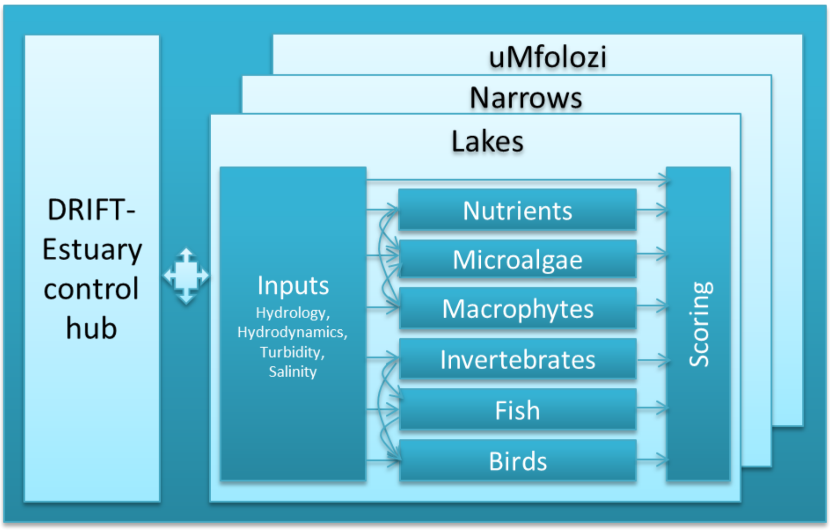


Figure 3.2. Schematic representation of the structure of the DRIFT-Estuary model (Source: Clark *et al.* 2014a).

Nutrient concentrations and all of the biotic parameters (microalgae, macrophytes, invertebrates, fish and birds) were estimated using response curves based on one or more of these drivers and/or other modelled parameters. The response curves were estimated based on available information and data from this and other estuary systems. Since the response curves had to take the full extent of potential variation of driver variables under all scenarios into account, the development of the curves was an iterative process requiring several rounds of modelling. The initial rounds were carried out in a series of workshops held with the specialist team as well as with other interested ecologists who had untaken studies on various aspects of the Lake St Lucia estuary system.

The most important nutrients driving primary production in estuaries (and indeed the Lake St Lucia system) are considered to be dissolved inorganic nitrogen (DIN) and phosphorus (DIP). Based on a review of available information and primary analysis of recent data on these two nutrients, key drivers influencing the levels of DIN and DIP in the Lake St Lucia estuarine system were identified as being cultivated land area, hippo population size, uMfolozi inflows to the St Lucia Lakes, tidal inflows, and salinity.

Seven major groups of biota occur in the estuary system: microalgae, macrophytes, invertebrates, fish, birds, crocodiles and hippopotamuses. Each of the first five biotic groups were divided into a number of subgroups that were considered to respond in a similar way to identified key drivers based on their habitat preferences as presented in the literature or in respect of expert knowledge where such information was lacking. It was not possible to determine drivers for the crocodile population, which has been relatively stable through major changes on the system, and this group was omitted from the model. Existing information on hippopotamuses suggested that their numbers were recovering from past hunting, and were not strongly influenced by habitat changes within the estuary (their floodplain feeding areas were assumed to be unaffected). Thus their population changes were modelled separately and provided as an input to the model, as one of the drivers of the nutrient status of the system. Hippo populations were allowed to grow naturally at the same population growth rate observed over the last 40 years (Taylor 2013b) reaching a maximum population size of 2400 individuals based on assumptions relating to the carrying capacity of the Lake St Lucia system.

During the modelling process, the drivers for the 39 modelled subgroups in each of the three areas (Lakes, Narrows and uMfolozi) were narrowed down to the major drivers for which suitable data were available in the model. Abiotic drivers were prioritised over biotic drivers as far as possible in order to minimise the possibility of compounding errors in the model, since most of the biotic drivers were themselves modelled from abiotic drivers. The groups, subgroups and drivers used in the model are summarised in Table 3.3

The model was initially calibrated by modelling actual changes over a period of 40 years. Calibration was on the basis of existing information where possible, or on the basis of expert judgement. Further modifications were made during the simulation of Reference, present day conditions and future scenarios. This was an interactive process because of the interdependence of the different groups and subgroups. During the modelling process, the different drivers could be switched on and off to compare their influence on the modelled outputs. In addition to the response curves, modifiers were also set on:

- Level of dependence on abundance in the previous year;
- Rate of recovery – input time taken to recover to median levels if median conditions restored;
- The minimum and maximum potential change relative to the baseline;
- Population growth effects; and
- Lag effects.

The overall health of the system was evaluated using a modified form of the Estuary Health Index (Figure 3.3). This involved (a) estimating what the estuary was like in its Reference condition (the Reference condition) in terms of physical and biological characteristics and processes, (b) scoring the present or future conditions relative to this estimated Reference state, which provides a score out of 100, and (c) converting the score to its health category (Table 3.2). Scores were computed using modelled outputs from each time period in order to capture differences in interannual variability, rather than using average conditions over the modelled 40-year period.

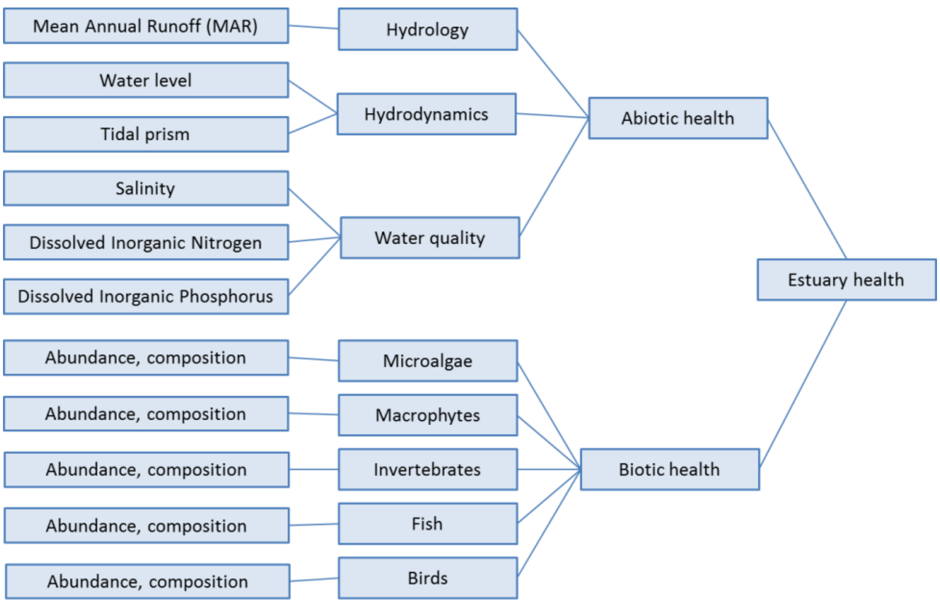


Figure 3.3. Structure of the modified Estuary Health Index used in this study (modified from Turpie *et al.* 2012, Turpie 1999). All weightings are equal.

Table 3.2. The six categories used for indicating the health of aquatic ecosystems (Kleynhans 1996), and the Estuary Health Index score ranges assigned to each category (Turpie *et al*. 2012). Categories A to D are within the acceptable range, whereas E and F are not.

EHI	Category	Description
91-100	A	Unmodified, or approximates natural condition
76 – 90	B	Largely natural with few modifications
61 – 75	C	Moderately modified
41 – 60	D	Largely modified
21 – 40	E	Seriously modified
0 – 20	F	Critically modified

Because of the changes in the hydrodynamic and ecological functioning and health of the system over time, historical data cannot be used to assess the present health of an estuary directly. Neither is it possible to assess present health based on recent conditions, because this does not capture the longer term fluctuations of the system. Therefore the approach adopted to estimating the present health of the system was to estimate what the system would look like over a long period (in this case 40 years) of historical rainfall, under present-day pressures and management (i.e. "Present Day Conditions"), and to compare this with what it would look like when those pressures were removed (i.e. "Reference Conditions"; see Figure 3.4). A similar approach was adopted for the assessment of the health of the system under future flow scenarios, for which time series data on ecological responses under the different options/scenarios were generated and health relative to Reference conditions assessed.

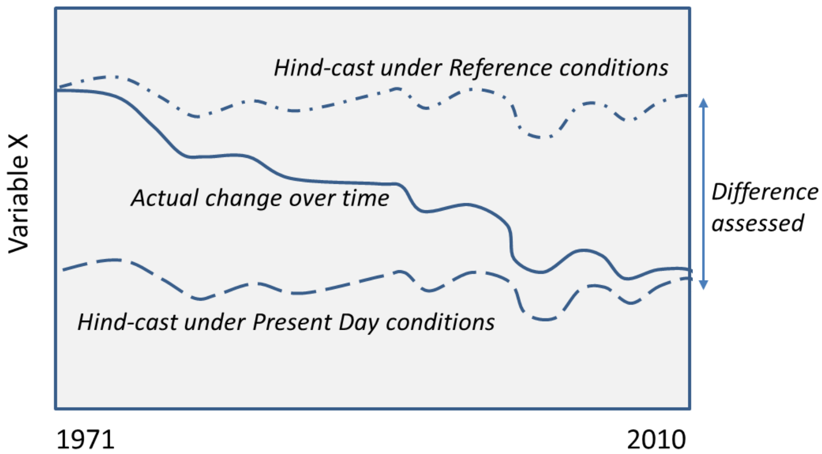


Figure 3.4. Schematic illustration of the way in which change in health is assessed using hind-casting of present day versus reference conditions over a defined rainfall period. (Source: Clark et al. 2014a)

Table 3.3. Biotic subgroups included in the model, and the driver variables used. All variables are summarised as average per year, unless stated otherwise. (FW = freshwater; ave = average)

Group	Subgroup	FW inflows	Salinity	Max salinity	Nutrients	Turbidity	Water level	Water volume	Water area	Area < 15 cm	Area < 1.4 m	Area 0.5-1.2 m	Inter-tidal area	Change in ave water level	Tidal prism	Max water velocity	Pelagic invert abundance	Benthic invert abundance	Fish abundance
Microalgae	Benthic microalgae				x	x											x	x	
	Phytoplankton				x	x										x	x		
	Epiphytes				x	x												x	
Macrophytes	Macroalgae		x		x							x				x			
	Submerged macrophytes		x		x	x						x				x			
	Reeds and sedges		x		x						x								
	Mangroves		x				x						x						
	Grass and shrubs		x				x												
	Salt marsh		x							x									
	Swamp forest		x				x												
	Floating macrophytes		x									x				x			
Invertebrates	Benthic estuarine		x			x			x						x				
	Benthic marine		x			x			x						x				
	Benthic freshwater		x			x			x										
	Benthic halophilic		x			x			x										
	Pelagic estuarine		x			x		x							x				
	Pelagic marine		x			x		x							x				
	Pelagic freshwater		x			x		x											
	Pelagic halophilic		x			x		x											
Fish	Resident planktivores		x			x		x									x		
	Resident benthivores		x			x		x										x	
	Marine planktivores		x			x		x							x		x		

Group	Subgroup	FW inflows	Salinity	Max salinity	Nutrients	Turbidity	Water level	Water volume	Water area	Area < 15 cm	Area < 1.4 m	Area 0.5-1.2 m	Inter-tidal area	Change in ave water level	Tidal prism	Max water velocity	Pelagic invert abundance	Benthic invert abundance	Fish abundance
	Marine benthivores		x			x		x							x			x	
	Marine omnivores		x			x		x							x				
	Marine piscivores		x			x		x							x				
	Freshwater benthivores		x			x		x							x			x	
	Freshwater detritivores		x			x		x							x				
	Freshwater piscivores		x			x		x							x				
	Catadromous detritivores	x	x												x				
	Catadromous piscivores	x	x												x				
Birds	Waterfowl		x				x												
	Cormorants & darters						x												x
	Pelicans			x			x							x					x
	Wading birds						x												x
	Flamingos		x				x												
	Waders						x			x				x				x	
	Gulls & Caspian terns						x												
	Common & Little Terns						x												x
	Other terns						x												x
	Kingfishers & birds of prey																		x

3.4 Confidence levels

The level of available historical data in combination with the level of effort expended during the assessment determines the level of confidence of the study. Four levels of study have been recognised in the past in terms of the effort expended during the assessment – desktop, rapid, intermediate and comprehensive. According to the "Methods for the Determination of the Ecological Reserve for Estuaries' (DWA 2012), a reserve determination study at anything other than a desktop level requires at least two to four data collection trips by the specialists, to sample low and high flow or closed and open mouth conditions, and requires 1-2 years to complete, depending on the month of initiation and the amount of data already available. With reduced effort and/or a lot of available information, the study could take as little as 3-6 months, but the outcome is likely to have much lower confidence. The recommended minimum requirement for a study is one data collection trip during the low flow period. In this study, which relied heavily on the work undertaken for the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" that was commissioned by the iSimangaliso Wetland Park Authority, effort lay somewhere between a rapid and intermediate study, in that some field data collection was carried out, but overall was classed as an 'Intermediate' study (Clark et al 2014). Nevertheless, the paucity of historical data on the system (particularly the hydrological data) meant that the confidence of the study was low. It was also highlighted in this study that this situation could only be remedied with some comprehensive and long term data collection on the system, particularly of freshwater inflows. Limited effort has been invested in additional monitoring of the Lake St Lucia system since the GEF study was completed, none of it on monitoring or calibrating gauges used to monitor freshwater inflow, thus the situation remains as it was at the start of the GEF study. Criteria for the confidence limits attached to statements in this study are shown in Table 3.4.

Table 3.4. Confidence levels for an Estuarine EWR study

Confidence level	Situation	Expressed as percentage
Very Low	No data available for the estuary or similar estuaries	(i.e. < 40% certain)
Low	Limited data available	40 - 60% certainty
Medium	Reasonable data available	60 – 80% certainty
High	Good data available	> 80% certainty

3.5 Assumptions and limitations for this study

The following assumptions and limitations should be taken into account:

- This study was undertaken purely as a desk-top assessment and no new data were collected as part of the study. The study did, however, built on an extensive body of research conducted as part of the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" that was commissioned by the iSimangaliso Wetland Park Authority as well as much valuable information that has been gathered through several medium- to long-term projects undertaken on this system by members of this team and other researchers during the past two decades. Findings and recommendations from the latter study are contained in a series of 6 volumes that cover hydrological functioning (Görgens *et al*. 2014), hydrodynamics and sediment transport (Illenberger & Clark 2014, Basson *et al.* 2014), ecological functioning (Clark *et al*. 2014a), socio-economics (Turpie *et al*. 2014) and a synthesis volume (Clark *et al*. 2014b).
- The hydrology of the Mkuse and uMfolozi catchments was modelled using the physically-based daily agro-hydrological catchment model, *ACRU,* developed by the School for Bio-Resources Engineering and Environmental Hydrology (SBEEH), of the University of KwaZulu-Natal (UKZN). The model was originally configured for use in the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" commissioned by the iSimangaliso Wetland Park Authority (Görgens *et al*. 2014) but was further refined for use in this study. Details of the refinements applied to the ACRU model for this study are described in DWS (2015). Refinements to the ACRU model have resulted in some minor changes to flow volumes reaching the estuary relative to those recorded during the GEF study which has implications for the comparability of the simulation data from the two studies. Confidence in the hydrology simulation data remains low though due to the low number of gauging stations in these catchments and the poor quality of measured flow data from gauging stations that do exist.
- Hydrological modelling of the Hluhluwe, Nyalazi and Mzinene catchments was undertaken using the WR2012 Pitman Model configuration obtained from the WR2012 study (WRC 2014). This differs from the approach used for the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" commissioned by the iSimangaliso Wetland Park Authority (Görgens *et al*. 2014) and has some bearing on the comparability between results from the two studies. Confidence in the hydrology simulation data for these catchments is also low due to the low number of gauging stations and the poor quality of measured flow data from gauging stations that do exist.
- Simulation of abiotic conditions in the Lake St Lucia system under the reference condition, present state and future flow scenarios was undertaken using a one dimensional (1D) numerical model running on software from the DHI Group, Denmark and the Digital Elevation Model prepared as part of the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" commissioned by the iSimangaliso

Wetland Park Authority (Basson *et al.* 2014). The accuracy of these simulations was heavily dependent on the accuracy of the simulated runoff data and showed a modest level of congruence with available observational data. Confidence in this component was thus Medium to Low.

- Ecological responses to projected abiotic changes in the estuary were simulated using the DRIFT-Estuary model setup as part of the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" commissioned by the iSimangaliso Wetland Park Authority (Clark *et al.* 2014). The accuracy of these simulations was heavily dependent on the accuracy of the simulated runoff data and abiotic characteristics of the system (mouth status, water quality characteristics, water level, etc.) and showed a modest level of congruence with available observational data. Confidence in this component was thus Medium to Low.
- All of the operational flow scenarios evaluated in this study included reductions in flow from Present Day. No Environmental Water Requirement (EWR) scenarios (hypothetical scenarios not considered by DWS but constructed to explore greater extremes or options such as increased runoff) were evaluated as part of this study. This is considered to be an important shortcoming as this does not allow for the identification of a Recommended Ecological Scenario (REC) as required in terms of the "Methods for the Determination of the Ecological Reserve for Estuaries" (DWS 2012).

4 BASELINE DESCRIPTION AND HEALTH ASSESSMENT

This section provides a summary description of pressures on and the current status and health of Lake St Lucia Estuary system. A detailed description of the current status and health of the system was presented in the outputs from the recent GEF-funded “Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system” that was commissioned by the iSimangaliso Wetland Park Authority. Descriptions of health of the different components of the Lake St Lucia system are taken largely from this study, specifically that on hydrological functioning (taken from Görgens *et al*. 2014), hydrodynamics and sediment transport (from Illenberger & Clark 2014 and Basson *et al.* 2014), and ecological aspects (from Clark *et al*. 2014a).

4.1 Overall context and pressures

The St Lucia estuarine lake system (Figure 2.1), located within the Maputaland-Pondoland-Albany global biodiversity hotspot, is South Africa’s largest and most important estuarine system from a biodiversity conservation perspective (van Niekerk & Turpie 2012). With a water surface of around 350 km^2 (Taylor 2006) and a shoreline of over 400 km, it accounts for 56% of South Africa’s total estuarine area and over 80% of the estuarine area of the southern African sub-tropical region (van Niekerk *et al.* 2013). This makes it the most important nursery ground for juvenile marine fish and prawns along the east coast.

The estuarine lake system is located wholly within the iSimangaliso Wetland Park. The first part of the currently protected area was set aside in 1895. The Greater St Lucia Wetland Park that was created in the 1980s and 1990s was made up of 16 different parcels of State-owned land, commercial forests and former military sites. It was renamed the iSimangaliso Wetland Park and declared South Africa’s first UNESCO World Heritage Site in December 1999. The Park covers an area of 3220 km^2 and 220 km of coastline which includes three major lake systems and eight interlinking ecosystems, containing a wealth of ecological and biological resources. While only one of ten UNESCO criteria need be fulfilled for an area to qualify as a World Heritage Site, the iSimangaliso Wetland Park fulfils three of these criteria:

- Criterion ix: To be an outstanding example representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.
- Criterion vii: To contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance.
- Criterion x: To contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

While the estuarine lake system and its immediate surrounds are protected, it is nevertheless vulnerable to a variety of external pressures. The estuary system is fed by a large catchment area that is drained by six rivers, and is vulnerable to the impacts that catchment activities and climate changes have on river inflows, as well as to direct pressures from the surrounding densely populated areas. Thus, in spite of its importance and protected status, the health of the estuary system has become compromised over the past century by the hydrological alteration of the lower uMfolozi floodplain area for sugar cane production as well as by reduction in freshwater inflows, increased sediment loads from the catchment areas, pollution and the over-utilisation of its resources (see Perissinotto *et al.* 2013).

Developments in and around the Lake St Lucia estuarine system over the past 100 years have resulted in dramatic changes to the hydrodynamic functioning of the system (Figure 4.1). These developments included:

- sugar cane farming in the lower uMfolozi floodplain which started in 1911;
- construction of drainage canals on the lower uMfolozi floodplain, canalisation and diversion of the lower uMfolozi River, a process that started in the late 1920s;
- artificial breaching of the mouth of the estuary, first undertaken in 1932, when the uMfolozi River was still part of the larger system and continuing until the present day;
- a policy decision, in force between 1952 and 2012, to separate the uMfolozi River from the Lake St Lucia system;
- the artificial maintenance of an open mouth between 1952 and 2002 by dredging and other measures (e.g. construction of groynes in the late 1960s);
- construction of drainage canals through the Mkuze Swamps, between 1972 and 1985; and
- efforts to reconnect the uMfolozi to Lake St Lucia thorough a range of link canals and back channels.

Of these, the artificial separation of the uMfolozi River from the Lake St Lucia system in 1952, which was driven by a concern that the introduction of large volumes of sediments from uMfolozi River into Lake St Lucia after its ability to deposit these in its floodplain had been curtailed by the canalisation of the river between high levees, has arguably had the greatest impact on the Lake St Lucia system. This has resulted in a large reduction in freshwater inputs to the Lake St Lucia system, lower water levels, periodic drying up of large portions of the lake system, prolonged closed mouth conditions and the development of hypersaline conditions, all of which have had a significant impact on diversity and abundance of the system's biota. In the 2000s, water levels receded and salinities increased to unprecedented levels, resulting in major die-offs of biota (Perissinotto 2013).

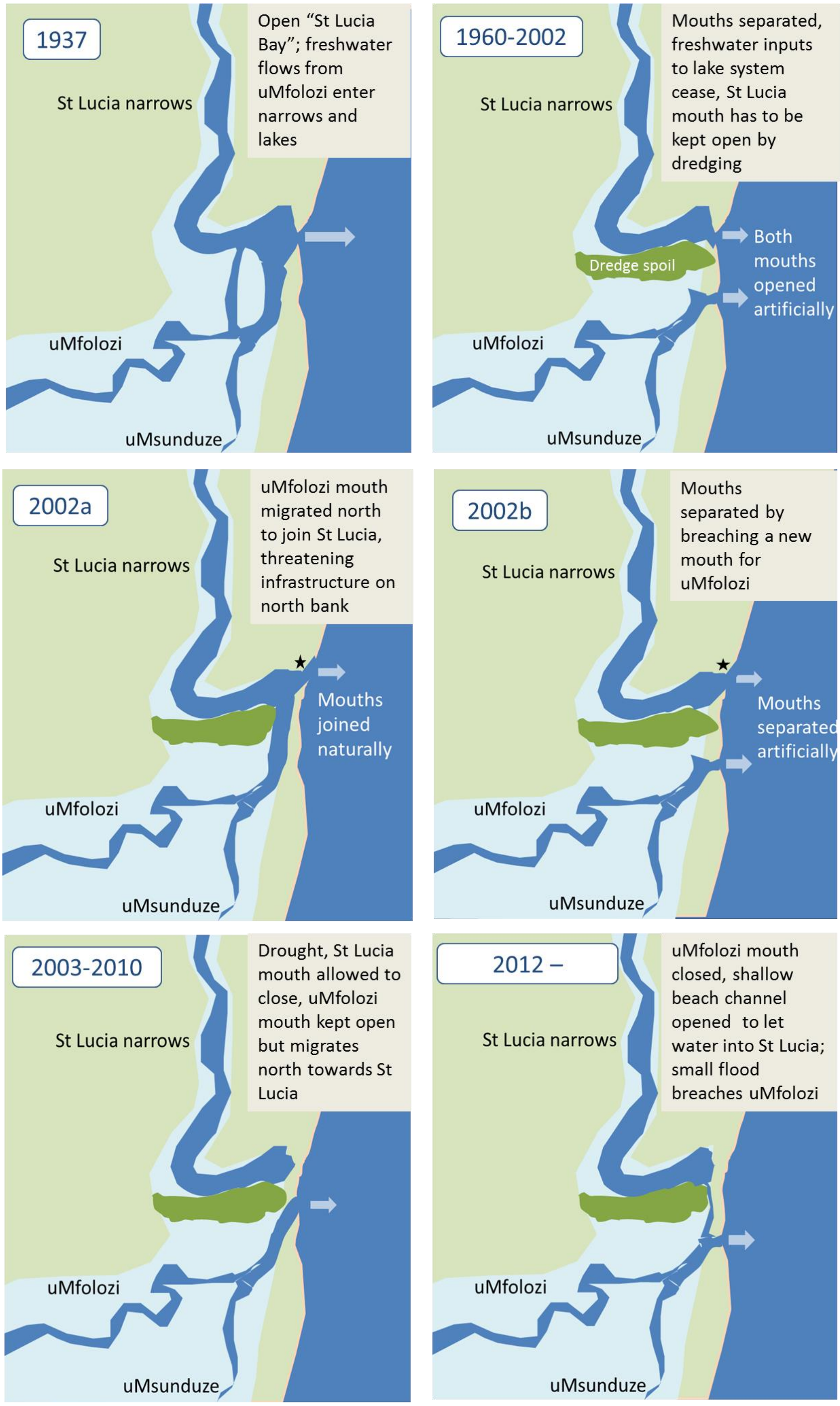


Figure 4.1. Changes in the structure and functioning of the mouth of the Lake St Lucia estuary system (Source: Clark et al. 2014b).

In 2008, the iSimangaliso Wetland Park Authority (iSimangaliso), the statutory body responsible for the park and protection of its world heritage values, made an application to the Global Environment Facility (GEF) for funding to assist with the restoration of the Lake St Lucia estuarine system. This application was successful and iSimangaliso was awarded a US$9 million grant that included provision for a study on the analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system. The approach adopted for this study and key finding are documented in a six volume report that covers hydrological functioning (Görgens *et al*. 2014), hydrodynamics and sediment transport (Illenberger & Clark 2014, Basson *et al.* 2014), ecological functioning (Clark *et al*. 2014a), socio-economics (Turpie *et al*. 2014) and a synthesis volume (Clark *et al*. 2014b) and are summarised briefly below.

The rehabilitation options considered in the Lake St Lucia GEF study included a range of interventions to alter the **hydrodynamics** of the estuary system with a view to achieving more natural abiotic functioning of the system, but with potentially different levels of impacts on the uMfolozi floodplain area. Three main hydrodynamic interventions were considered (Figure 4.2):

(1) "**Separate mouths + water transfers**" - maintaining separate uMfolozi and St Lucia mouths as in the past, but facilitating water transfers from the uMfolozi River into the lakes via constructed channels or pipelines,
(2) "**Do nothing**" - no further interventions in the mouth area (including cessation of breaching of the uMfolozi) with the expectation that the mouths will join naturally in time, and
(3) "**Actively facilitate a common mouth**" - interventions to facilitate the re-joining of the uMfolozi with the Lake St Lucia system and allowing the common mouth to operate as naturally as possible including closure during low flow periods.

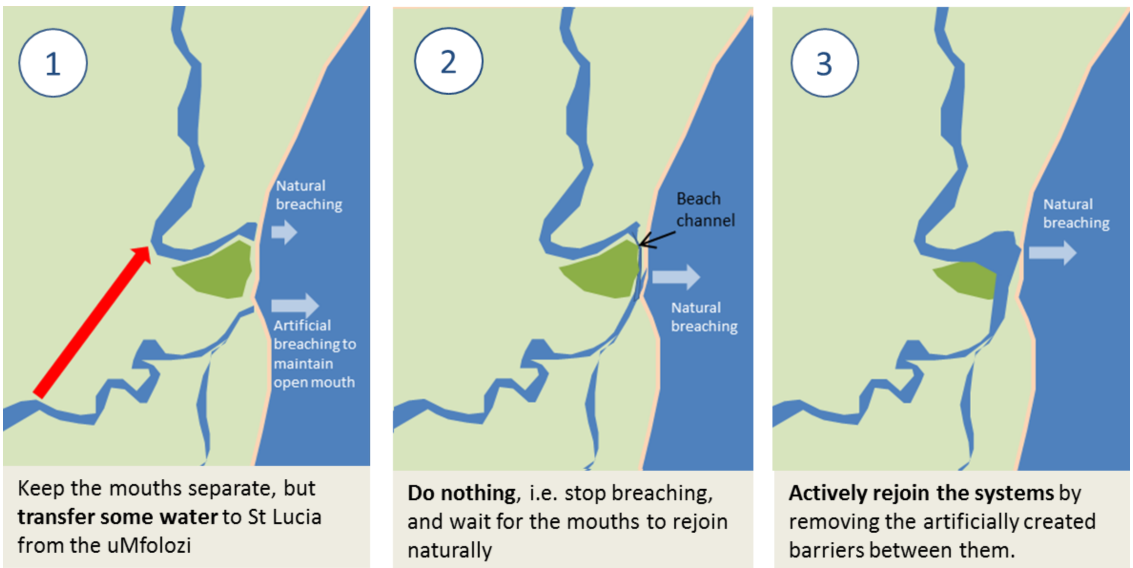


Figure 4.2. Schematic diagram of the three options considered in this study to restore the hydrodynamic functioning of the system (Source: Clark et al. 2014b).

These hydrodynamic interventions were also considered in conjunction with two further potential conservation interventions within the estuarine functional zone, namely (a) **rehabilitating portions of the uMfolozi floodplain**, and (b) **increased protection** of estuarine resources. Thus, the **rehabilitation options** were the various combinations of the hydrodynamic interventions with or without the supplementary conservation actions. In order to reduce the number of possible scenarios, the additional conservation measures were only considered in conjunction with the 3rd hydrodynamic interventions, as a fourth rehabilitation option.

In summary, four **rehabilitation options** are considered by the study as a whole:

(1) "Separate mouths + water transfers";
(2) "Do nothing";
(3) "Facilitate a common mouth"; and
(4) "Facilitate a common mouth + conservation"

It was also recognised that the potential outcome of these options depends on certain external factors that are beyond the control of iSimangaliso Authority. A decision was thus made to also consider (a) the degree to which future pressures on the catchment are managed and their impact on water and sediment inflows to the estuary system, and (b) the potential influences of climate change and associated sea-level rise. Each of the options were evaluated under four different hydrological scenarios (Figure 1.4).

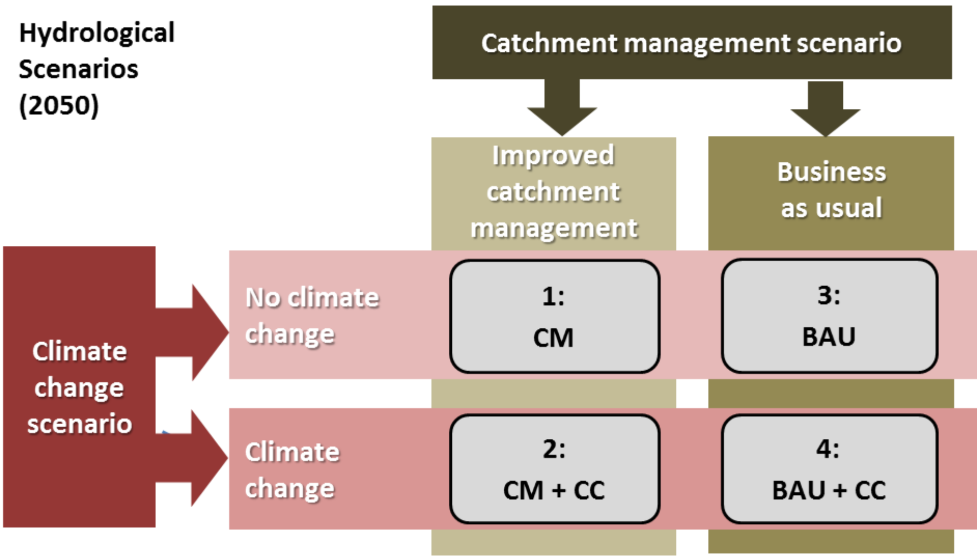


Figure 4.3 Hydrological scenarios used in the analysis (H1 – H4)

Scenarios were thus composed of alternative rehabilitation options (combinations of various hydrodynamic and non-hydrodynamic interventions carried out within the estuarine functional zone) under present day conditions and under a range of future catchment management and climate scenarios. An increase in mean sea level of 0.5 m was also included in the climate change scenarios.

Based on the findings of this study, Clark *et al*. (2014b) recommended that iSimangaliso pursue the approach of actively facilitating the re-joining of the uMfolozi with the Lake St Lucia system in conjunction with intensified conservation measures to address the growing problem of illegal fishing in the system. It was recommended that this be achieved by removing accumulated dredge spoil that had been deposited between the Lake St Lucia and uMfolozi mouths and that no artificial breaching of the mouth(s) of the system be permitted in future. In addition, it was recommended that other man-made barriers to flow within the lower floodplain be removed, parts of the river flooplains around the system be restored, that alien vegetation around the Lake St Lucia system be removed, river inflows be protected, and catchment land care practices be implemented in critical areas. In addition to the hydrological restoration of the system, it was recommended that further research is carried out to design and implement a stronger conservation strategy to eliminate illegal gill- and seine-net fishing within the estuary.

Clark *et al.* (2014b) explained that this intervention was expected to result in an improvement in the hydrodynamic functioning, health and conservation importance of the system. Continuing with the current management regime ("Do nothing") was projected to result in some improvement in this regard, but active interventions to join the mouth and improve conservation efforts would make a significant difference, and would also alleviate the potential costs to farmers in the floodplain. The cost of implementation of this "Common mouth" scenario was estimated to be relatively small compared with the expected benefits, and the intervention was expected to yield a positive rate of return even under very conservative assumptions. In comparison, the "Separate mouths + transfers" scenario was projected to be considerably more expensive, with lower net benefits, especially when non-use values were taken into consideration.

The iSimangaliso Wetland Park Authority have since indicated that these recommendation would be adopted in part at least, and that they appointed a contractor to remove some 100 000 m^3 of dredge spoil (sand, silt and vegetation) that had been placed in the natural course of the uMfolozi River impeding its flow into Lake St Lucia and that additional funds (a further R20 million over and above the R10 million that has been set aside for the first 100 000 m^3) has also been set aside to continue the work of restoring South Africa's largest estuarine system (iSimangaliso 2016). For the purposes of this study, both the Present Day and project future condition of the system was assessed.

It is important to note, however, that the first phase of dredge spoil removal programme that has been initiated by iSimangaliso (Figure 4.4) does not correspond exactly with that evaluated as part of the GEF study. Simulation data and results from the "Dredge spoil removal" scenario for this study thus do not correspond exactly with those from the GEF study (Figure 4.5).

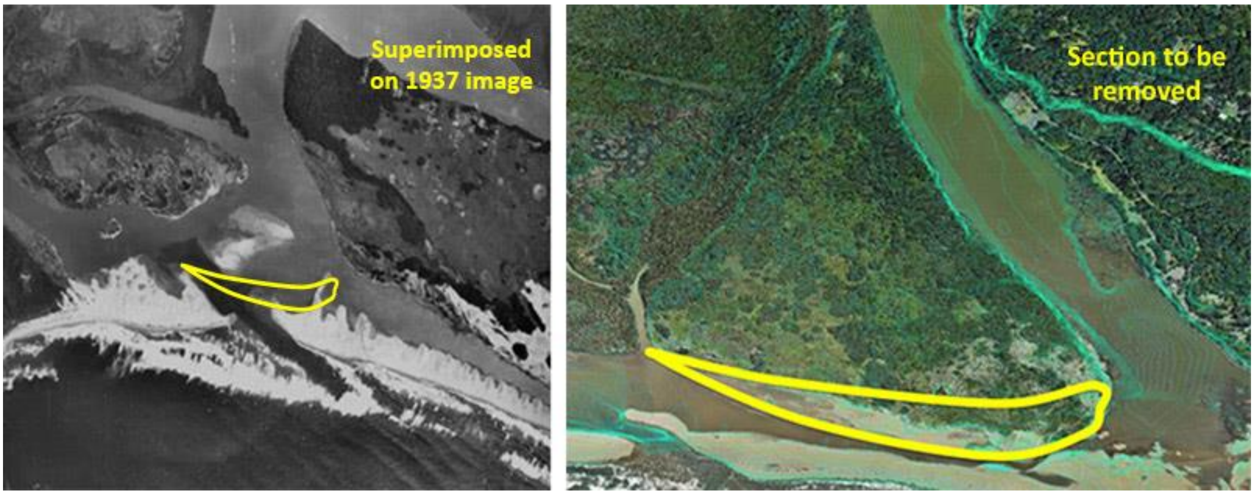


Figure 4.4. **The mouth of the Lake St Lucia system in 1937 (left) and as it is at present (2013, right). The 2013 photograph shows the dredge spoil material that was placed in the river course from the 1950s for a period to try and separate the uMfolozi River from Lake St Lucia. The yellow boundary shows the first portion of dredge spoil that will be removed as part of Phase 1 of the restoration action.**

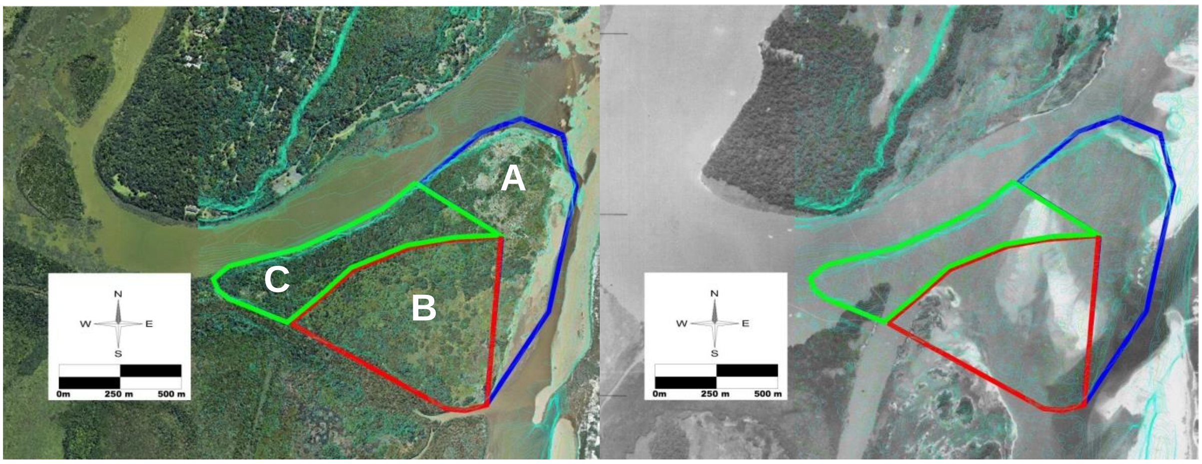


Figure 4.5. **Approach recommended for the phased removal of dredge spoil that had been historically dumped between the uMfolozi mouth and the St Lucia Narrows. The "Combined mouth" scenario evaluated in the GEF study (Clark et al. 2014) corresponded with the removal of dredge spoil in area A (diagram on left) while in the "Reference" state it was assumed that sediment had been removed from all three compartments as per the 1937 configuration on the right.**

4.2 Abiotic components

4.2.1 Hydrology

4.2.1.1 Natural and present-day flows[1]

Lake St Lucia has for the past sixty years been supplied with freshwater inputs by five rivers, in order from north to south being the Mkuze, Mzinene, Hluhluwe, Nyalazi and Mpate River. Inputs from the uMfolozi River in the south were cut off as a result of human interventions in the 1950s but have recently (2012) been restored (at least in part). The iSimangaliso Wetland Park Authority have, however, commenced with a process of fully restoring water flow from the uMfolozi system to Lake St Lucia in accordance with recommendations tabled by Clark *et al*. (2014b). (See Section 4.1 above for more details on this). For the purposes of this study, we evaluated the system under the present-day conditions (Mouth A: Beach channel) and the future configuration (Mouth B: after Phase 1 excavation – i.e. with dredge spoil removed as indicated in Figure 4.4).

The catchments of the five rivers feeding directly into Lake St Lucia together cover an area of approximately 8269 km^2 (Table 4.1; Figure 2.1) and are divided into 19 quaternary catchments (WRC 2009). The catchment of the uMfolozi River covers approximately 10,085 km^2 and is divided into 26 quaternary catchments (Figure 2.1, Görgens *et al*. 2014). These five rivers that flow directly into Lake St Lucia are all seasonal, flowing during the wet summer months, and are sometimes reduced to isolated pools and seepage areas in winter. Limited freshwater input to Lake St Lucia is also provided by a series of small streams and groundwater flows from the dune systems along the eastern shores of the lakes (Været et al. 2009, Stretch & Maro 2013, Görgens *et al*. 2014).

The natural and present-day mean annual runoff (MAR) for each of the five rivers is also presented in Table 4.1. The natural MAR of the uMfolozi catchment is clearly the largest of these (69% of the MAR of all the catchments combined) but it is important to note that not all of the runoff from this catchment actually enters the St Lucia Narrows or Lakes. Even when linked with Lake St Lucia (i.e. as it was prior to 1950 and as it is expected to be in the future), and the estuary mouth is open, a good portion of the runoff from the uMfolozi flows directly out to sea. It is only when the mouth is closed and/or during major flood events that a significant portion of this flow actually finds its way into the St Lucia Narrows and/or Lakes.

There has been a noticeable reduction in MAR from natural to present-day for all five rivers. Streamflow in the uMfolozi and Mkuze catchments at present has been reduced by just under 10% from Natural (Table 4.1, DWS 2015), while reductions in stream flow in the

[1] **Present-day flows** are flows that would have occurred over the modelled time period if present-day catchment conditions (population, land use, water demands) and climatic conditions (global circulation, sea level) were kept constant over the whole period. Similarly, **natural flows**, are modelled flows in the absence of any population or anthropogenic land use in the catchment area. The latter is also referred to as the **reference condition**.

Hluhluwe, Mzinene and Nyalazi catchments has been somewhat greater (17.1-23.1%). The main land-use, water demands and operational features for current day flows in the uMfolozi, Hluhluwe, Nyalazi, Mzinene and Mkuze River are presented in Table 4.2.

Table 4.1. Catchment area, mean annual precipitation (MAP) and natural mean annual runoff (MAR) for the rivers supply water to the Lake St Lucia estuary system (Stretch 2013, Görgens *et al*. 2014, DWS 2015).

Name	Catchment area (km^2)	MAP (mm)	Natural MAR (Mm^3/a)	Present MAR Mm^3/a)	% of natural
Mkuze	5 983	731	271.8	248.7	91.5%
Hluhluwe	910	773	61.5	48.1	78.2%
Mzinene	728	686	26.4	20.3	76.9%
Nyalazi	648	846	123.8	102.6	82.9%
uMfolozi	10 085	21 934	1054.4	952.2	90.3%

Table 4.2. Main land-use, water demands and operational features for current day flows in the uMfolozi, Hluhluwe, Nyalazi, Mzinene and Mkuze river (Source: DWS 2015).

Item	uMfolozi	Hluhluwe	Nyalazi	Mzinene	Mkuze
Domestic demand (10^6 m^3)	7.4	3.1	-	-	-
Industrial demand (10^6 m^3)	11.0	-	-	-	-
Dam Capacity (10^6 m^3)	6.0	-	-	-	-
Afforestation (km^2)	65.0	13.9	251.3	18.2	29.7
Domestic return flows (%)	25	-	-	-	-
Irrigation (km^2)	39.0	13.8	-	21.6	4.7
Irrigation efficiency and distribution losses (%)	75	75	-	75	75

The actual flow data used as an input for the Drift estuary model is shown in Figure 4.7.

Figure 4.6. **Lake St Lucia estuary and its catchment area.**

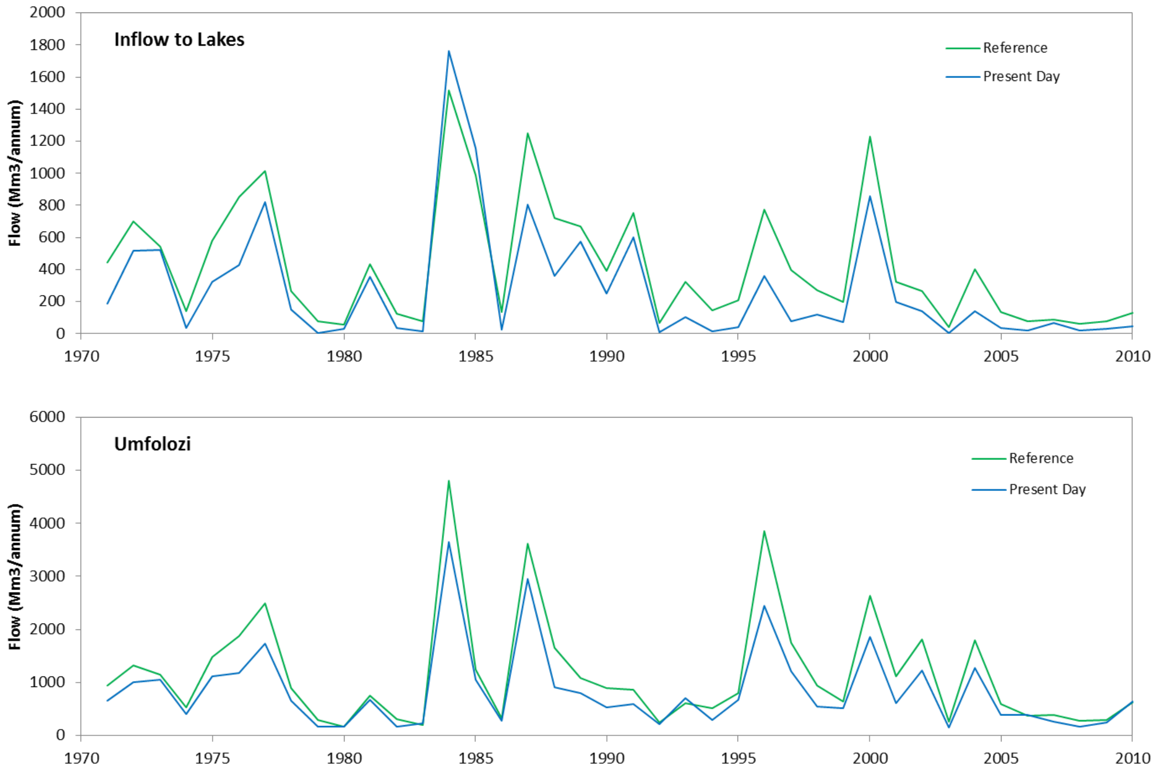


Figure 4.7. Inflows directly to the Lakes (top) and down the uMfolozi (bottom) for the Reference and Present Day. Note that inflows directly to the St Lucia Lakes are the same for all scenarios.

4.2.1.2 Present hydrological health

Hydrological health scores for the Lake St Lucia estuary were calculated in accordance with methods prescribed for estuaries in DWA (2012). Individual scores were calculated for two parameters – Mean Annual Runoff (MAR) and Flood frequency (weighted average of Class 1, 2, 3, and 4 floods) - for each of the three components of the system - the St Lucia lakes, Narrows and the uMfolozi (Table 4.3). Final scores for each component were taken as the minimum score for the three parameters and the overall score for the Lake St Lucia system was a whole calculated as a weighted average for the three components, taking their relative sizes into account. Inflows to the Lakes and Narrows included both that from the rivers that discharge directly into the St Lucia side of the system and inflow from the uMfolozi up the Narrows when the mouth was closed. Flow from the uMfolozi directly into St Lucia during large (>1:10 year) floods was not considered as this is not expected to change between scenarios.

The hydrodynamic health score assigned for the system as a whole under Mouth A (Beach channel, 78.9 = B class) were marginally higher than Mouth B (after Phase 1 excavation, 75.1 = B class) owing to the fact that the estuary mouth is closed for a greater portion of the time under Mouth A and thus allows for more uMfolozi water to enter the Narrows and Lakes offsetting reduction in inflows from the other rivers. Note that for the purposes of this study it has been assumed that there is no artificial breaching of the estuary mouth.

Table 4.3. Hydrological health scores for the Lake St Lucia system under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

Component	Parameter	Present Day - A	Present Day - B
Lakes	1.1.a. MAR (%Nat; St Lucia + uMfolozi)	79.6	75.4
	1.1.b. Flood frequency (weighted ave Class 1, 2, 3, 4)	99.6	99.6
	1.1. Hydrology (min a-b)	79.6	75.4
Narrows	1.1.a. MAR (%Nat; St Lucia + uMfolozi, % Nat))	79.6	75.4
	1.2.b. Flood frequency (weighted ave Class 1, 2, 3, 4)	99.6	99.6
	1.2. Hydrology (min a-b)	79.6	75.4
uMfolozi	1.3a. MAR (%Nat, uMfolozi)	72.7	72.7
	1.3.b. Flood frequency (weighted ave Class 1, 2, 3, 4)	99.7	99.7
	1.3. Hydrology (min a-b)	72.7	72.7
All	**1. Hydrology (Lx0.6+Nx0.3+Mx0.1)**	**78.9** **B**	**75.1** **B**

Confidence in the hydrological health score assigned to the estuary was low (40%) owing to the poor quality of flow gauging data available from the catchment and the need to scale the rainfall data from the catchment to achieve a reasonable water and salinity mass balance in the lakes. The need for improved rainfall monitoring and flow gauging in the Lake St Lucia catchments cannot be over-emphasised.

4.2.2 Geohydrology

Although it is undisputed that groundwater makes an important contribution to the hydrological functioning of the Lake St Lucia system (Kelbe *et al*. 2013), it was not assessed or evaluated in any detail as part of this study, as it was considered to be beyond the scope of the study. However, a brief summary of the state of knowledge on groundwater resources in the study area, the use thereof and their contribution to the water balance of the Lake St Lucia is provided below.

In their review of groundwater hydrology of the St Lucia area, Kelbe *et al*. (2013) refer to three main aquifer systems: secondary porosity aquifers, a Cretaceous aquiclude, and a primary porosity aquifer. The distinction between these aquifer systems is based on lithostratigraphy and associated geohydrological differences. Secondary porosity aquifers are found in Jurassic basalts and rhyolitic rocks, which overly older sedimentary rocks. Most of the groundwater in this aquifer system occurs in extensive fracture and fault systems, and is released where they intersect features such as rivers and wetlands. Contribution to surface water resources in the study area from this aquifer is considered to be very limited.

The Cretaceous aquiclude occurs in Cretaceous claystones and siltstones that overlie the extrusive Jurassic rocks. The sediments in this formation have very low hydraulic conductivities and porosities and were laid down when the area was below sea level and thus has a high salt content. Contribution to surface water resources in the study area from these to aquifer systems is considered to be low (secondary porosity aquifers) or negligible (Cretaceous aquiclude). The last of the three aquifer systems in the study area, the primary porosity aquifer is found in mainly Miocene, Pliocene, Pleistocene and Holocene unconsolidated to consolidated sedimentary deposits, which overlie the Cretaceous rocks. This aquifer is thought to play the most important role in controlling the groundwater dynamics in the coastal sections of the St Lucia catchment. The rise and fall of the water table in this aquifer is influenced by recharge from rainfall and the hydraulic properties of the soil (Kelbe et al. 2013). Where the water table intersects the land surface it forms a seepage or drainage boundary such as a stream, wetland or shoreline. Groundwater from this aquifer provides the base-flow for the rivers that flow into the Lake St Lucia System system as well as the direct seepage into the lakes along shoreline. Although the contribution to the overall water balance of the estuary is considered to be small under average conditions (6-7%, Hutchison 1976, Kelbe *et al.* 1995, Van Niekerk 2004, Taylor *et al.* 2006, Været *et al.* 2009) it becomes much more important under drought conditions, where it may be as high as 80% (Kelbe and Germishuyse, 2010, Kelbe *et al*. 2013). The slow and consistent release of the groundwater from this aquifer extends the period of river flow after rainfall events, and the persistent seepage of groundwater creates stable and consistent habitats for freshwater-dependent ecosystems around the margins of the estuary. These habitats are important refugia for a variety of fauna and flora during periods of lake hypersalinity, and are also important nodes from which recolonisation of the lake can occur once conditions have improved (Vrdoljak and Hart 2007, Kelbe *et al*. 2013).

Parsons and Associates (2009) report that there is little reliable information on direct groundwater use in the Lake St Lucia area. They cite figures of between 3.5 to 37 Mm/a of water being abstracted from the entire Usutu to Mhlathuze Water Management Area in reports by DWAF (2004b and 2004c), equivalent to about 0.6% and 4.7% of estimated recharge, and an estimate of 3.5 Mm/a being abstracted from the Zululand Coastal Aquifer from DWAF (2004c). Parsons and Associates (2009) estimate of direct groundwater use from aquifers in the St Lucia area was only 0.51 Mm/a, and is thought to have a negligible impact of water balance in the St Lucia system. These estimates do not include the use of groundwater by plantations, however, which is considered to have an important influence on the water balance of a region. Plantations increase evapotranspiration rates, reduce runoff and lower the water table (Kelbe et al. 1995; Forsyth et al., 1997; Scott and Smith, 1997; le Maitre et al., 1999; Meyer et al. 2001; Gush et al., 2002; Gush, 2006). Parsons and Associates, (2009) report that there is little locally measured groundwater level data available to corroborate and quantify impacts of this nature, but they do present a summary of available data on the estimated increase in evapotranspiration losses associated with plantations in the St Lucia area. Lindley and Scott (1987), for example, estimated that plantations on the Eastern Shores resulted in additional evapotranspiration losses of about

210 mm/a, and that this reduced groundwater seepage into the St Lucia Estuary from the Eastern Shores by about 22.4% (equivalent to 1.8% of the total freshwater input into the St Lucia Estuary system). These authors indicated that they felt that this would have negligible influence on general lake salinity, and that it would be misleading to indicate afforestation was a major cause of high salinities observed in the St Lucia Estuary during dry periods. They were also of the opinion the maximum recorded decline in groundwater levels would not reduce seepage by more than 30%. Rawlins (1991) used groundwater levels measured over a period of 17 years on the Eastern Shores to assess the impact of afforestation on the geohydrological regime and found that the rate of groundwater level recession increased by about 30% when landcover changed from grassland to plantation, that the rate of groundwater level recession was greater in plantation than in grasslands, and that the aerial extent of impact was limited to the immediate vicinity of the plantation. He also concluded commercial forestry in the area resulted in an "additional consumptive use of (ground)water of between 150 and 175 mm/a" and that the total forested area of 25 000 ha in the St Lucia Estuary catchment would "lower average (groundwater) inflow to the lake by between 10% and 12%". During extreme dry periods, they suggested that the reduction could be as high as 30%. Other estimates presented by Parson & Associates (2009) are of a similar magnitude. Kelbe et al. (1995), for example, estimated that forestry on Eastern Shores of the St Lucia Estuary and on the Western Shores reduced groundwater seepage into Lake St Lucia by about 26% and 29%, respectively, while Kelbe and Rawlins (1992) reported that groundwater flows had been greatly reduced between 19 and 36% by afforestation on the Western and Eastern Shores. Several other more speculative estimates on the impacts of afforestation on the water balance in the St Lucia system have also been tabled, and the reader is referred to Parson & Associates (2009) for more details on these. It must be noted that plantation on the Eastern Shores of St Lucia have been completed removed since many of these estimates were presented, and good progress has been made towards clearing plantations on the eastern shores of the Lakes. It is likely therefore that surface-groundwater interactions have now been restored to a much more natural level (Parson & Associates (2009).

4.2.3 Hydrodynamic functioning of the Lake St Lucia Estuary System

4.2.3.1 Mouth dynamics and tidal exchange – historical overview

The term "hydrodynamics" refer to all processes concerning the availability and movement of water through a system, and includes aspects like water level (and depth), flow velocity, turbidity, salinity, temperature, residence time, etc. Hydrodynamic processes in estuaries are influenced most directly by freshwater inflows derived from the catchment and exchanges between the estuary and the sea at the mouth. Mouth dynamics (the process of opening and closure of an estuary mouth) has a very profound influence on estuarine hydrodynamics. The amount, or proportion of time an estuary mouth is open, is controlled by a balance between the forces that keep an inlet open (river flow and tidal flow), and those that cause the inlet to close (wave energy within the inlet and availability of sand offshore and from the catchment). Differences between the balance of these forces allows for the identification of a number of different types of estuaries - wave-dominated, tide-dominated and river-dominated systems (Table 4.4, Cooper 1993, Cooper *et al.* 1999).

Depending on the circumstances, the Lake St Lucia estuarine system falls in the “River dominated” or “Wave dominated” group. When the St Lucia and uMfolozi mouths are combined, the Lake St Lucia estuarine systems is a river-dominated estuary, driven by the large seasonal flow of the uMfolozi River. River flow keeps the inlet open during periods of high rainfall, but the mouth closes during periods of low rainfall, and may stay closed for extended periods during droughts. The tidal prism is small under these conditions because the flood-scoured estuary channel fills quickly from upstream with sandy river sediment, so tidal currents are weak under this state (Illenberger & Clark 2014).

Table 4.4. Classification of southern African estuaries.

End-members	Characteristics	Recovery after floods
Wave-dominated	Temporarily open/closed. Typically smaller rivers or areas with higher wave energy. Rapid spit growth constricts the inlet.	Sandy flood-tidal deltas grow strongly after a flood; growth rate decreases as the inlet becomes constricted and choked. Tidal prism becomes insignificant and inlet closes.
Tide-dominated	Normally open. Larger rivers. Tidal prism remains large and keeps the inlet open.	The flood channel fills with sandy sediments, both river (from upstream; at a low rate) and marine (flood-tidal deltas), Sandy flood-tidal deltas grow strongly after a flood; growth rate decreases as the inlet becomes constricted.
River-dominated	River flow keeps the inlet open. Tidal prism is small because flood-scoured channel fills quickly with sandy river sediment. Tidal currents are weak. Estuary will close if river flow diminishes during dry season or drought.	The flood channel fills quickly with river sediments after a flood, because of high sediment load. The tidal prism decreases correspondingly.

When the St Lucia and uMfolozi mouths are separated, however, St Lucia becomes wave-dominated, while the uMfolozi remains river-dominated. For wave-dominated estuaries, the primary force controlling the mouth dynamics is the wave energy within the inlet, which depends on open ocean wave energy and beach slope. On sandy coasts with high wave energy (as is the case for Lake St Lucia), large volumes of sand are constantly in motion in the surf zone, driven by wave energy. This sand is transported into the inlet by the action of the waves, and in the process constricts the estuary inlet, which in turn createsstretch tidal asymmetry. Flood tides in such an inlet have a shorter duration and hence a faster current regime and bigger sediment-transporting power than the ebb tides. Thus, net sand movement is into the estuary. This sand is deposited inside the estuary in the form of a flood-tidal delta. The flood-tidal delta gradually extends upstream, but the rate slows down as it gets bigger and increasingly chokes the water flow. Two distinct mechanisms lead to fairly rapid closure of an inlet of this nature - the spit constricts the inlet initially, while the growth of flood-tidal delta increasingly chokes the water flow. The characteristics of the sediment in the sea off the KZN coast also contribute to rapid closure of estuary mouth in this region. According to Huizinga & van Niekerk (2002), for a given open ocean wave energy, a fine sand beach will have a lower slope than a coarse sand beach, so wave energy is dissipated across the wide surf zone and less wave energy will reach the inlet, and the inlet will tend to stay open. Thus, there are many permanently open estuaries along the south and southeast coast where fine sand predominates. Sand is coarser along the northeast coast, with beaches correspondingly steeper, so wave energy within the inlet is often higher, and estuaries in this region display a greater tendency to close.

Riverine floods flush sediments out of all estuary types. The estuarine channel is scoured deep and wide during a flood, and the mouth is left wide open. Sediment infilling then starts again, in a cyclical, dynamic equilibrium process. The scoured channel fills with sandy sediments, both river (from the upstream end) and marine sand (flood-tidal deltas) from the inlet. Suspended river sediments (silt and clay) settle out as they mix with sea water and flocculate. This muddy sediment tends to accumulate in the middle reaches of the estuary where it is typically deeper and where bottom water currents are weaker. Muddy sediment can also be trapped by vegetation, e.g. mangroves or reeds along the margins of the estuary, or seagrass (*Zostera* spp.) in subtidal areas.

Stretch *et al.* (2013) put together a timeline of important events and changes recorded for the Lake St Lucia system and the impacts these have had on mouth dynamics. Of these, the decision to maintain separate uMfolozi and St Lucia mouths and the consequent diversion of uMfolozi flows away from Lake St Lucia had the most dramatic impact on mouth dynamics of the latter system. Prior to 1952, if the combined mouth closed during dry periods uMfolozi flow was diverted into St Lucia. This helped to maintain water levels in the lake and ultimately drove overtopping and rebreaching of the frontal sand berm, and restored the link with the sea (Lawrie & Stretch 2011, Stretch *et al*. 2013). After separation of the two mouths it rapidly became clear that the St Lucia mouth has a natural tendency to close and that active interventions were required to keep the mouth open, which was considered desirable to enable marine species to continue using the system as a nursery area. Various interventions were implemented following this time in an effort to keep the mouth open including dredging, artificial breaching, and the construction of groynes at the St Lucia inlet (Taylor 2006, Whitfield & Taylor 2009, Taylor 2013a, Stretch *et al*. 2013). Dredging was the most successful of these and continued up until 2002 after the onset of dry conditions which ultimately led to extreme hypersaline condition and desiccation of 90% of the lake in 2006. The mouth opened briefly in 2004 as a result of the uMfolozi River overtopped its banks, flooding the system, and again in 2007 during Cyclone Gamede (a result of large storm waves coupled with high water levels in the sea, Pillay and Perrisinotto, 2009; Whitfield and Taylor, 2009). Other than these events, Lake St Lucia system remained closed until a decision was made by iSimangaliso to excavate the beach channel between the uMfolozi mouth and St Lucia, after the uMfolozi mouth had migrated a considerable distance northwards, through which Lake St Lucia was finally reconnected with the sea.

The process followed in the excavation of the beach channel is documented in a press release issued by the iSimangaliso Wetland Park Authority (iSimangaliso 2012) while subsequent changes in the mouth status and flows between the uMfolozi and St Lucia are documented in a series of reports by Taylor *et al*. (2012a, b, 2013a, b, c, d, 2014, and 2015). The beach canal was opened on 6 July 2012, at a time when the uMfolozi and St Lucia mouths were both closed. Water levels in the uMfolozi were higher than those in St Lucia and this allowed for a considerable volume of water to flow up through the Narrows into the St Lucia Lakes. Water continued to flow from the uMfolozi into St Lucia until the uMfolozi mouth breached naturally some two months later on 11 September 2012. For a period of time following this, there was some limited tidal exchange between the St Lucia Narrows and the sea through the beach channel until this silted up in late 2014. The uMfolozi mouth subsequently closed in January 2015 but the beach channel was re-opened in February 2015 again permitting water to flow across from the uMfolozi into St Lucia. Subsequent to this, the iSimangaliso Wetland Park Authority announced in another press release (iSimangaliso 2016) that it had appointed a contractor to remove some 100 000 m^3 of dredge spoil (sand, silt and vegetation) that had been placed in the natural course of the uMfolozi River impeding its flow into Lake St Lucia in accordance with recommendations that were tabled by Clark *et al*. (2014b). The amount of material to be removed is shown on Figure 4.1.

The process of removing the dredge spoil is expected to commence very soon. Thus, for the purposes of this study, **two options were considered for the hydrodynamic modelling** – **Mouth A** included the beach channel as at 2013-15 and **Mouth B** corresponds with the situation being created in 2016, where accumulated dredge spoil material has been removed as indicated on Figure 4.4 (Phase 1 of the rehabilitation effort) .

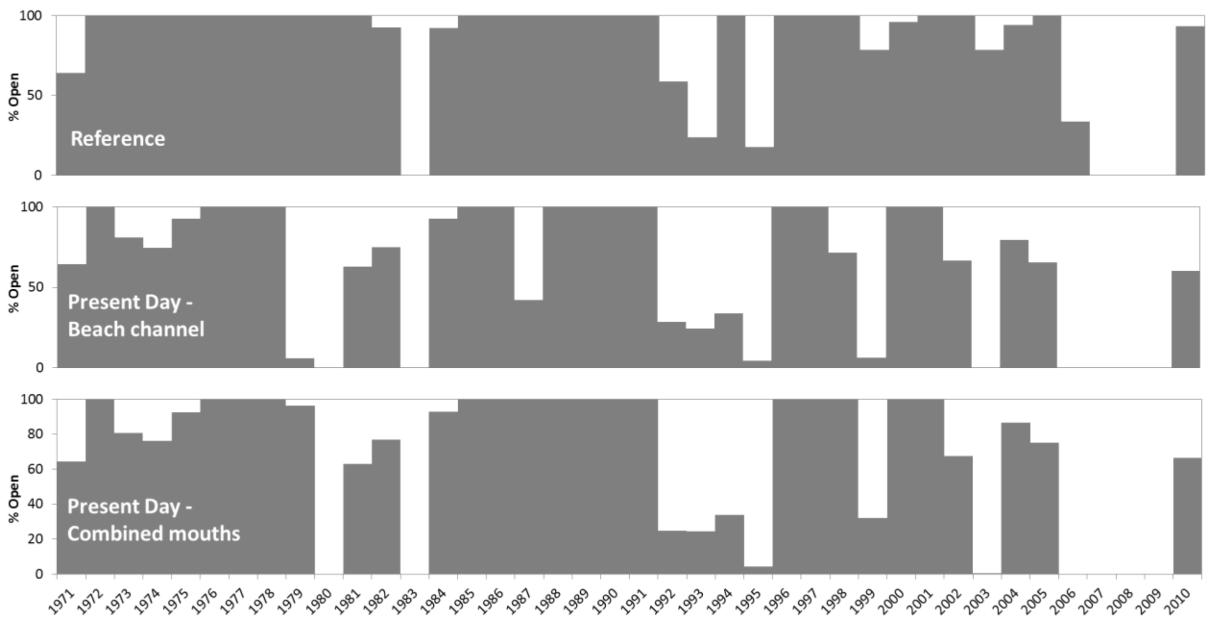


Figure 4.8. Mouth state (% open) for the Lake St Lucia estuarine system under Reference and Present Day (PD) conditions. Note that PD has been modelled as two separate scenarios – Mouth A (with beach channel as existed in 2012-15) and Mouth B (after Phase I excavation).

According to model simulation data, the estuary mouth was open for 80.6% of the time under Reference conditions but this drops to 60.8% of the time under present-day conditions with the Beach channel in place, but is slightly better under the after Phase 1 excavation configuration (66.5% open). Note that for the purposes of this study, it has been assumed that there will be no artificial breaching of the estuary mouth.

Very little information is available on tidal flows into and out of the Lake St Lucia system, either under the separated or common mouth scenarios. Lindsay *et al.* (1996) estimated a tide prism of 0.32 Mm^3 for the uMfolozi mouth under neap tide conditions and 0.65 Mm^3 during spring tide at a time when the mouths were joined. Hutchison (1976), Chrystal *et al.* (2011) and Stretch (*et al*. 2013) used data from a water level gauge and in situ flow measurements to gain some insights into tidal exchanges through the separated Lake St Lucia mouth. They reported that the tidal prism has a range of 0.3-0.6 Mm^3 over neap tides, rising to 1.0 to 2.0 Mm^3 over spring tides. Numerical model simulations undertaken as part of this study were used in an effort to estimate the magnitude of tidal inflows under "Reference" conditions and under "Present Day" conditions both as the system is at the moment (Mouth A - with beach channel) and at a time when Phase 1 of the dredge spoil removal phase has been completed and the uMfolozi River was again linked with Lake St Lucia (Mouth B - after Phase 1 excavation). Under Reference conditions, tidal inflows up the St Lucia Narrows and the uMfolozi channel were estimated to be around 34.5 and 52.3 Mm^3/annum, respectively. Tidal inflows are projected to be very much lower for the Narrows at least under present-day conditions with the Beach channel (Mouth A: 0.7 and 45.1 Mm^3/a, respectively) but are very similar to the Reference condition under the combined mouths configuration (Mouth B: 29.8 and 51.0 Mm^3/annum, Table 4.5 and Figure 4.9). Tidal inflows up the uMfolozi channel are very similar to Reference for both mouth configurations.

Table 4.5. Simulated mean tidal inflow up the Narrows and up the uMfolozi channel for the period 1971 to 2010 for Reference and present-day conditions with Present Day flows.

Hydrological scenario/mouth configuration	Mean tidal inflow volume (m^3)	
	Narrows	uMfolozi
Reference	34.5	52.3
Present (Mouth A - with beach channel)	0.7	45.1
Present (Mouth B – after Phase 1 excavation)	29.8	51.0

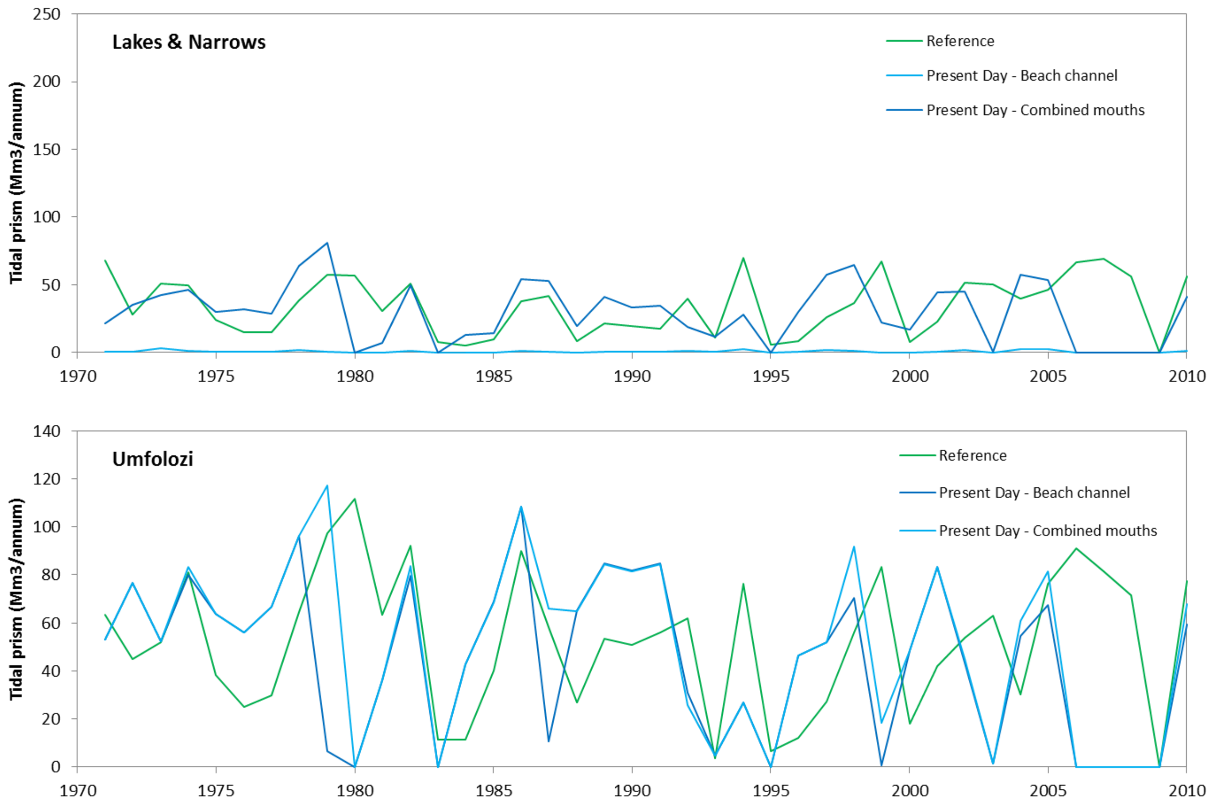


Figure 4.9. Tidal flows up the Narrows and uMfolozi channels for the Reference and Present Day. Note that Present Day conditions have been modelled as two separate scenarios – Mouth A with the existing beach channel in place and Mouth B after Phase 1 of the dredge spoil removal process has been completed.

4.2.3.2 Sediment dynamics – historical overview

Studies on composition and distribution of sediments in the Lake estuarine system indicate that there are a number of different modes or types of sediment in the system and that these are unevenly distributed within the system. Two distinct modes (or types) of sediment are found in the St Lucia lakes (Fortuin 1992) - fine-medium sand with a modal grain size of 250 microns occurs in the shallow parts of the lake (<1 m depth) while fine silt to clay (mud) with a modal size of 2 microns predominates wherever the water is deeper than 1 m and in the northern lakes. This has been confirmed by other authors (e.g. Hutchinson 1976, Stretch *et al.* 2013) and by Basson *et al.* (2014) (Figure 4.10), and is considered to be linked to the continual suspension of fine sediments by wave action in shallow waters and subsequent settlement in deeper parts of the lake where wave induced turbulence is lower. Medium sand predominates in the flood-tidal delta at the mouth of the system while the Narrows above Honeymoon Bend and the uMfolozi channel is mostly lined with mud (Wright 1995, Basson *et al.* 2014). Some coarse sediment also exists on the uMfolozi floodplain, deposited there during the Demoina floods (Van Heerden & Swart 1986a, b).

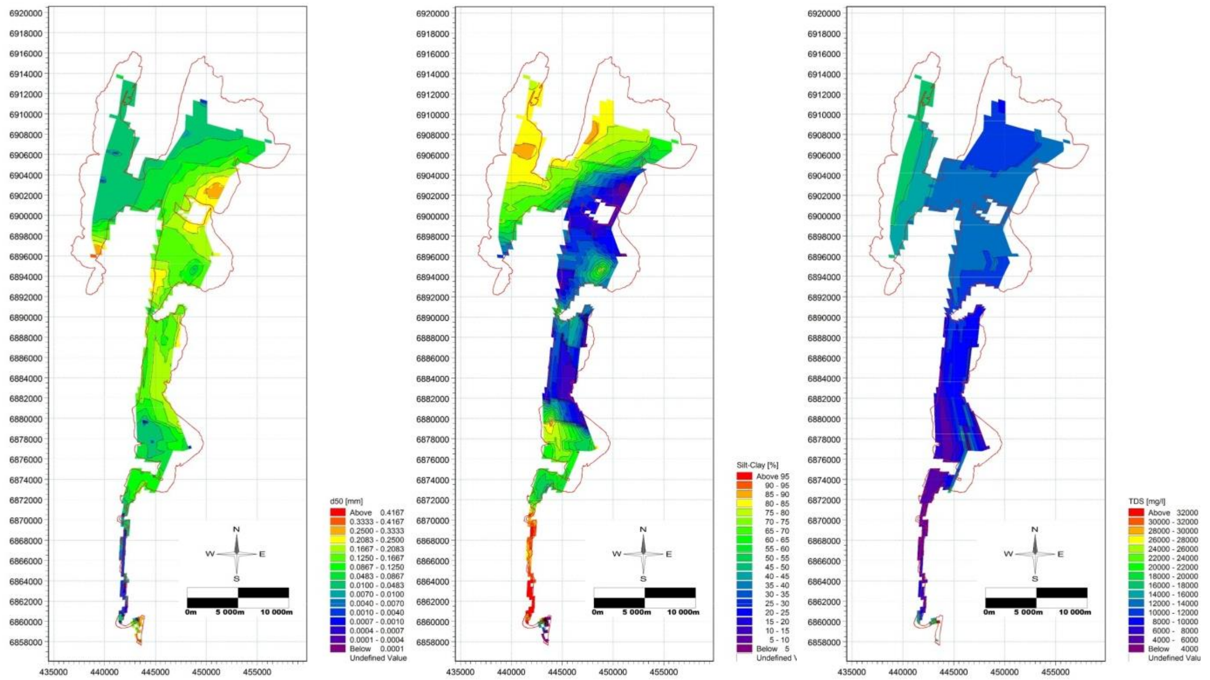


Figure 4.10. Spatial distribution of the median diameter of bed sediments (left) and percentage clay, silt (middle) and near surface TSS concentrations (right) as measured during March 2013 (Source: Basson *et al.* (2014).

The present St Lucia lake basin developed in an incised river valley that extended to at least 40 m below present day sea level during the Holecene period (> 12 000 years BP) when sea levels were very much lower than they are at present. The valley was flooded when sea levels rose towards present day levels and gradually filled with sediment over a period of about 5 000 years. Sediment yields from the catchment of the various influent river and rates of infilling have been the focus of a good deal of research over the last few decades but there seems to be little agreement on how these have changed over time and indeed if they have changed at all. This is naturally a very important issue given that this was the primary motivation for separating the uMfolozi from Lake St Lucia system in the first instance.

There has been a greater focus on the uMfolozi catchment than the other smaller influent rivers, and a number of authors have attempted to estimate current sediment yields of this catchment. Estimates vary from 0.68 Mt/a (Grenfell & Ellery 2009) to 1.24 Mt/a (Lindsay *et al.* 1996), 2.36 Mt/a (Rooseboom 1975); and over 4 Mt/a (Fleming & Hay 1983). More recently, Rountree (2012) assessed the sediment yield for the catchment using an updated sediment yield methodology for South Africa (Rooseboom *et al.* 1992; in Rountree, 2012), and also with the sediment yield data embedded in the national DWA database. These two methods indicated sediment yields of 2 and 1.4 Mt/a respectively. Stretch & Maro (2013) used WR2005 data and calculated a sediment yield of 2.67 Mt/a for the whole of the Lake St Lucia catchment. Estimates of sediment yields derived for the uMfolozi system by Basson *et *al.* (2014) are similar to Rooseboom's estimate of 2.12 Mt/a, and suggest that sediment yields from the uMfolozi (and the other influent catchments) have increased dramatically in recent times (by as much as 600%, Table 4.6).

Studies on rates of sediment deposition in the marine environment off the KZN coast suggest that the increasing sediment yield is not restricted to the Lake St Lucia system. Martin & Flemming (1986, 1988) compared modern sediment yields from KwaZulu-Natal rivers to the paleo-yield derived from offshore sedimentation in the Natal valley of the Indian Ocean. Seismic profiles showed the modern sediment yield of 322 t/km^2/a to be 12-22 times higher than long term rates averaged over 5 Ma and 130 Ma (14-27 t/km^2/a). Flemming and Hay (1988), in a similar study, described modern sediment yield as exceeding long-term averages by 12 and 30 times.

Table 4.6. Estimates of the change in sediment yield for the various catchments feeding into the Lake St Lucia estuary system under Reference and Present day inflows based on simulations prepared using the ACRU model (Source: Görgens *et al*. 2014).

River	Reference	Current	% increase
uMfolozi	0.449	2.264	404%
uMkhuze	0.217	1.214	459%
Mzinene	0.032	0.224	600%
Nsimane	0.007	0.052	643%
Nyalazi	0.024	0.352	328%

While there is little doubt that sediment yield from the Lake St Lucia catchment has increased substantially in historical times (last 100 years), it is less clear if this has actually contributed to infilling of the St Lucia lakes. A range of estimates regarding changes in the rates of infilling are available, but these are not all in agreement. Kriel *et al.* (1966) and Orme (1974) for example, estimate that the present day rates of infilling are 2 to 3.3 times faster than historical rates, while Stretch *et al.* (2013) estimates that sediment yields from the Lake St Lucia catchment has increased by no more than 50% relative to Reference conditions. Work by Lawrie *et al.* (2011), however, suggest that increases in sediment input may not necessarily be contributing to infilling of the estuary very much at all. They collected core samples from several locations using vibra-core techniques (typically 2 m depths) and dated these using Pb-210 isotopes. Results obtained suggested that sedimentation rates for Charters Creek (Catalina Bay) and Esengeni in the upper Narrows had not changed significantly during the last century, apart from evidence of an exceptional depositional event in the Charters Creek core sample during the 1920s which they suggested was probably linked to the 1925 floods.

Results of hydrodynamic simulations and the hydrological assessments undertaken for the St Lucia GEF study (Görgens *et al*. 2014), as well as earlier work, has shown that the uMfolozi and Mkuze River both carry large sediment loads and pose a significant risk in terms of deposition of sediment in the Lake St Lucia estuary system. The Mkuze floodplain (Mkuze River swamp) remains largely intact while most of the indigenous vegetation on the lower uMfolozi floodplain has been cleared, and the area converted for sugar production. There is also some evidence to suggest that the uMfolozi floodplain has subsided significantly (by as much 1 m in places) due to the straightening of the river channel, flood diversion and loss of alluvial soils and compaction through agriculture (van Heerden & Swart 1986a, b, van Heerden 2011). Many studies in the past have speculated on the potential sediment trapping capacity that could possibly be restored if the wetland/swamp areas were rehabilitated. This was investigated as part of the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" that was commissioned by the iSimangaliso Wetland Park Authority (Basson *et al*. 2014). In the case of the Mkuze Swamps, model simulation data indicated that these have a large sediment trapping efficiency corresponding to around 46% of the inflowing peak hydrograph suspended sediment concentration (Figure 4.11).

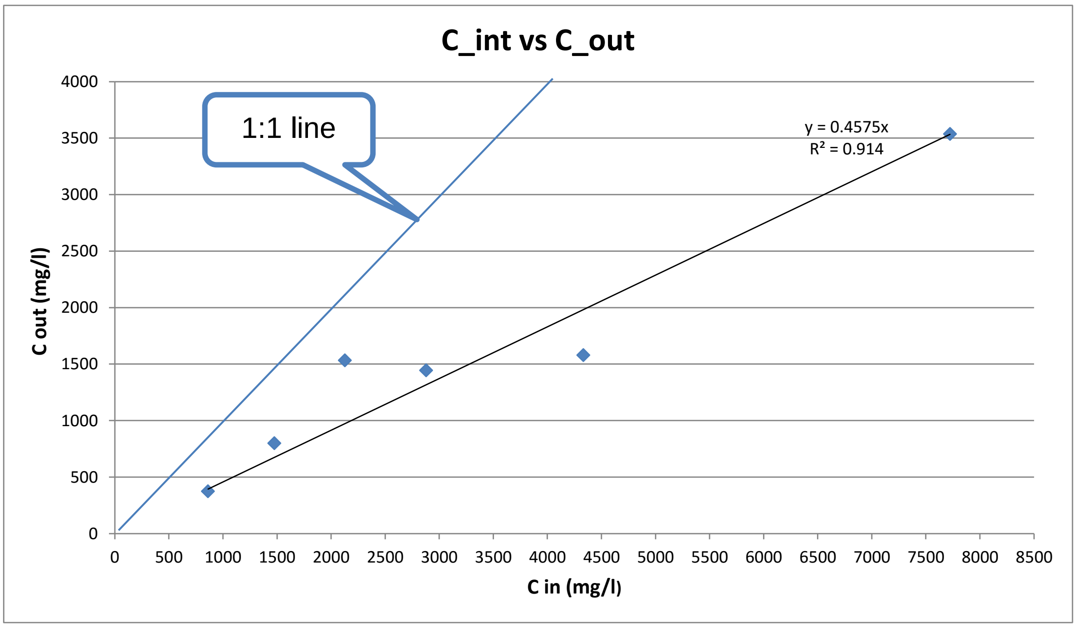


Figure 4.11. Simulated sediment transport from upstream to downstream of the Mkuze Swamps by the 2D hydrodynamic model for different flood hydrographs (Source: Basson *et al.* 2014).

By contrast, model simulation data suggest that the sediment trap efficiency of the uMfolozi floodplain in its present state is relatively small (Figure 4.12). However, restoration of the natural vegetation on the floodplain may go a some way towards rectifying this situation.

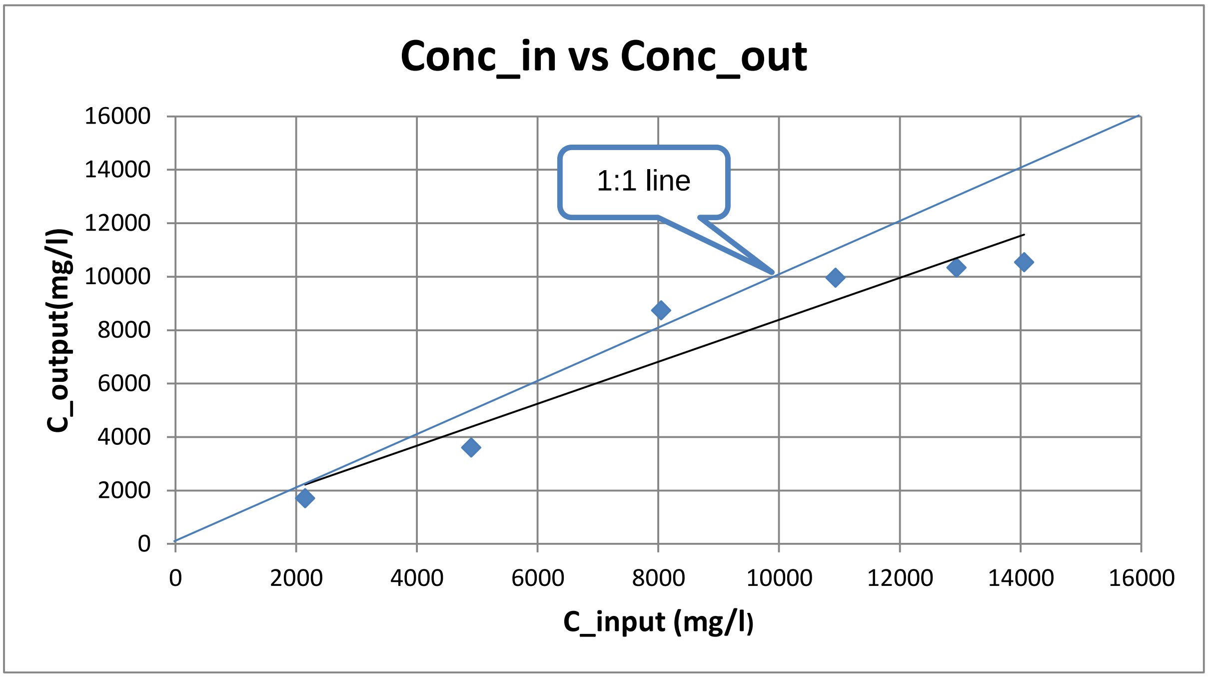


Figure 4.12. Simulated sediment transport from upstream to downstream of the uMfolozi floodplain by the 2D hydrodynamic model for different flood hydrographs (Source: Basson *et al.* 2014).

4.2.3.3 Historical changes in channel morphology

As part of a review of hydro- and sediment dynamics of the Lake St Lucia estuarine system, Illenberger & Clark (2014) assembled an impressive collection of maps and photographs depicting changes in the morphology of the estuary mouth and channels from 1852 to present as well as historical and anecdotal accounts of major events and observations on the system. Interpretation of changes in channel morphology from these photographs was to some extent confounded by variation in water levels. This is because dates and times at which the photographs were taken were not always available and owing to the fact that data on water levels in the system is patchy and none exist prior to the 1960s. It was nonetheless possible to extract a good deal of useful information from this resource, a brief summary of which is presented below.

The earliest maps of the Lake St Lucia estuarine system date back to 1852 (map by Cato presented in Taylor 2011) but many of the features on the maps are presented in a schematic fashion only. The earliest accurately surveyed map was only produced in 1905 (Crofts 1905). Analysis of these maps and other anecdotal reports led Illenberger & Clark (2014), and others (Methven 1903, Wearne, 1966, van Heerden & Swart 1986a, Taylor 2013a) to conclude that the St Lucia Lakes and uMfolozi River historically shared a common mouth, that closed seasonally or intermittantly, and that this mouth took the form of a large shallow lagoon (termed “St Lucia Bay”), roughly the size of Port Natal. The size of this embayment was later reportedly reduced to about a third of this as a result of infilling during a major flood in 1856.

The first aerial photograph of the Lake St Lucia system dates back to 1937. According to Illenberger & Clark, features evident on this photograph (notably the common mouth and the west and east forks of the uMfolozi River) still existed and match closely with those recorded by Crofts (1905), and suggest that little had changed in the intervening period. By 1957, however, the morphology of the Lake St Lucia mouth had changed quite markedly. The western fork of the uMfolozi had been all but eliminated, a "deep silt deposit" had developed around Honeymoon Bend with a narrow channel "no more than a few feet wide" running through the inside edge, a new mouth had been breached on the southern edge of the sandbar spanning the original mouth region, the construction of a levee across the floodplain designed to divert uMfolozi waters directly to the sea away from the Narrows, and the process of dredging a channel through this silt deposit had begun. Other developments in the intervening period not evident on these photographs include efforts to artificially straighten and canalize the uMfolozi River, the final part of which, "Warner's Drain" (a canal that straightened the middle section of the floodplain), was completed in 1936. Several authors (Kriel *et al.* 1966, Wearne 1966, van Heerden & Swart 1986a; van Heerden 2011; Rountree 2012, Taylor 2013a) attribute the narrowing of the uMfolozi and St Lucia channels and accumulation of silt in the mouth of the estuary to farming activities and denudation of uMfolozi floodplain and catchment. Illenberger & Clark (2014) also note that there is little or no evidence for any siltation having taken place in the Narrows upstream of Honeymoon Bend, or of any siltation having taken place in the southern Lakes.

Subsequent aerial photographs taken between the 1960s and the 1980s provide evidence of further straightening and canalization of the uMfolozi channel, construction of additional levees between the uMfolozi mouth and the Narrows (1957-1960, Figure 4.15), dredging of the Narrows, deposition of dredge spoil collected from the Narrows onto the area between the Narrows and uMfolozi mouth, construction of a "Back Channel" in 1970-71 designed to bring uMfolozi water into St Lucia to alleviate high salinities resulting from the drought of the 1970s (Figure 4.16), armouring of the lower St Lucia estuary banks with cement-sand bags and dolosse (1975-1984, Figure 4.16) and the excavation of the Link Canal in the period 1975-1983 (Figure 4.17), all of which was destroyed by Cyclone Demonia in 1984.

Figure 4.13. 1937 aerial photograph of the mouth region of the Lake St Lucia estuarine system (Source: Illenberger & Clark 2014).

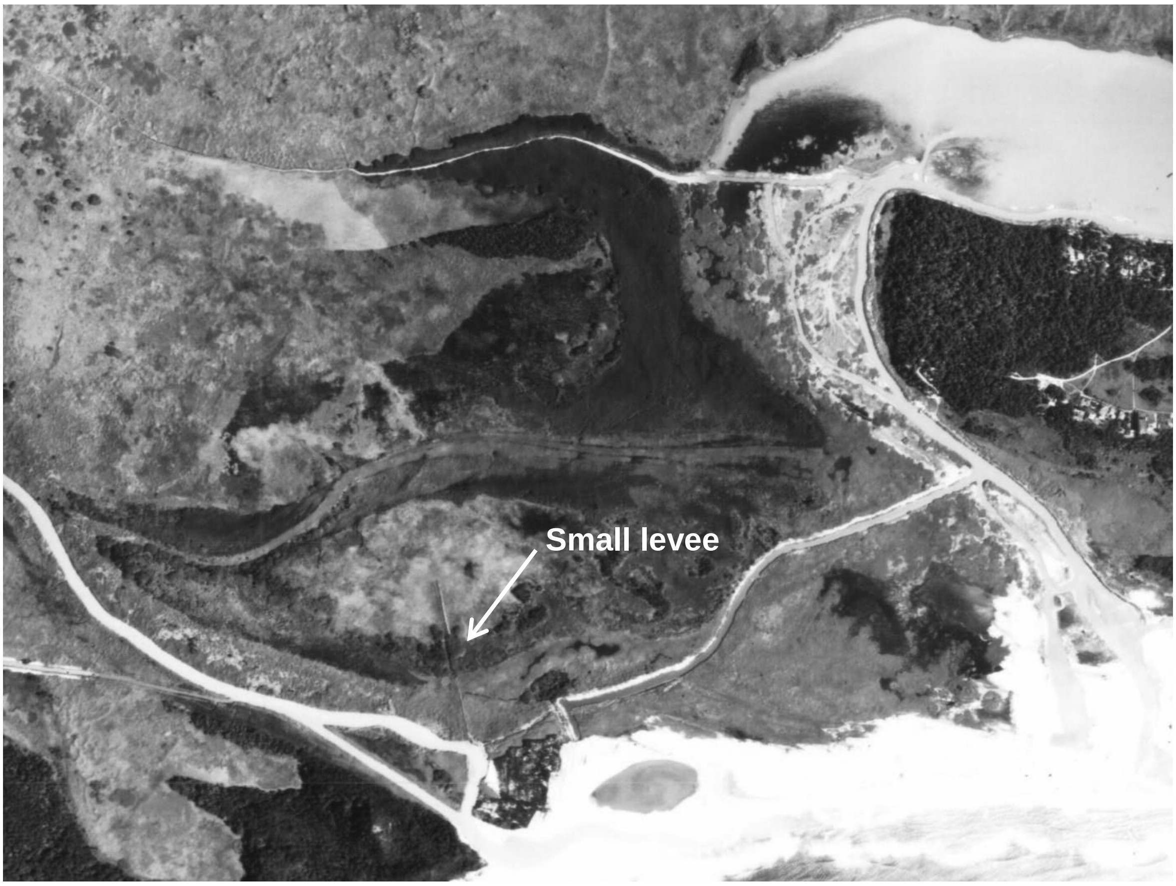


Figure 4.14. Aerial photograph from May 1957 (Source: Illenberger & Clark 2014).

Figure 4.15. Aerial photo from June 1960 showing the larger levee (constructed in 1957-1960) and further straightening of the uMfolozi channel. (Source: Illenberger & Clark 2014).

Figure 4.16. Armouring of the lower St Lucia estuary banks with cement-sand bags and dolosse (left, 1976) and the back channel excavated in 1970-71 (aerial photo from 1976) (Source: Illenberger & Clark 2014).

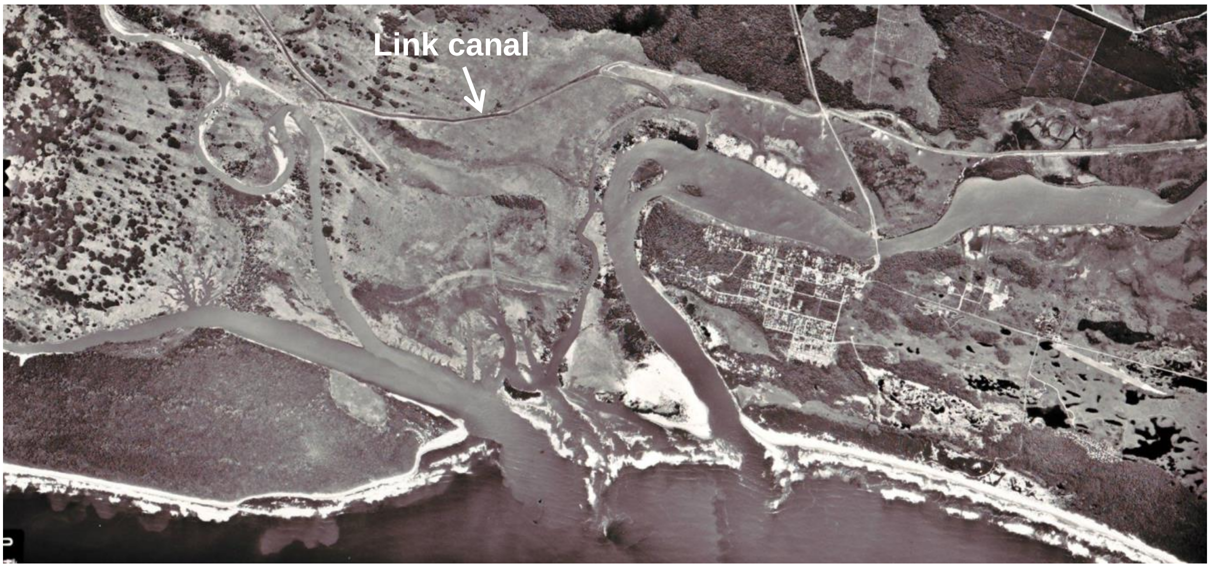


Figure 4.17. Aerial photograph from 1984 (Source: Illenberger & Clark 2014).

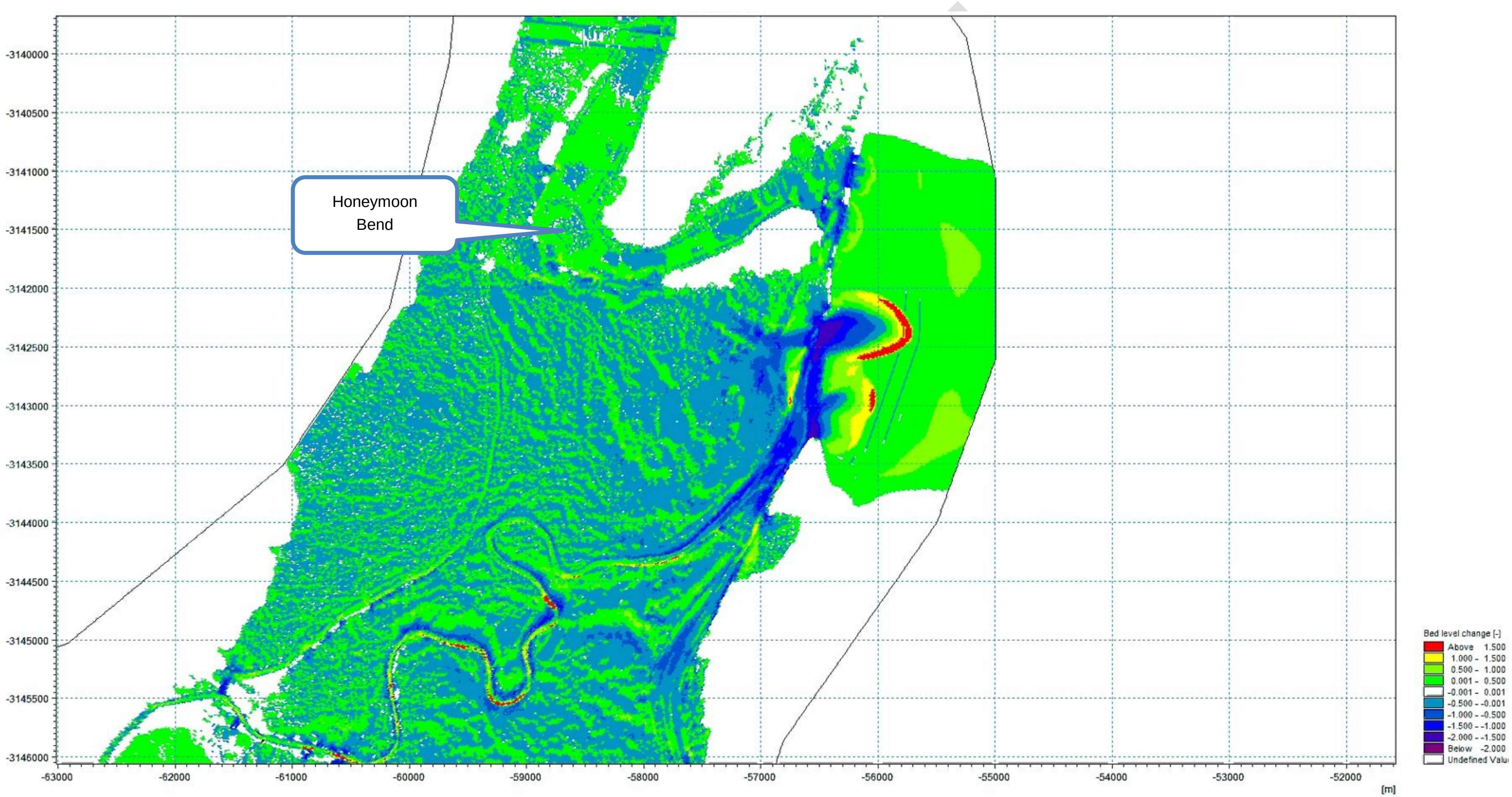
Also evident from the aerial photography is the propensity for the uMfolozi mouth to migrate northwards towards St Lucia town, a process that was frequently interrupted by breaching of the mouth near Maphelane until 2002 where after the mouth migrated northwards to a position opposite the St Lucia narrows, and the beach channel was excavated by iSimangaliso in 2012 linking the two systems again (Figure 4.18).

Figure 4.18. Aerial photograph from 2013 (Source: Illenberger & Clark 2014).

One of the key reasons why the uMfolozi and St Lucia mouths were kept apart in the past was the fear that Lake St Lucia would silt up when floods in the uMfolozi River transported fine sediment northwards along the Narrows into the Lakes. Basson *et al*. (2014) used 2D hydrodynamic model simulations to evaluate evidence of sedimentation in the Narrows from historic aerial photographs and also to assess risks from this source in future.

Model simulations (Figure 4.19) data provided clear evidence of sedimentation patterns at Honeymoon Bend of a similar nature to that observed on aerial photographs in the period 1937-1960 (Figure 4.14 and Figure 4.15) following a 1:100 year flood. Sediment deposition in the model simulations was around 0.5 to 1 m deep, with sedimentation occuring first at the right bank (western side) and then gradually moving over to the eastern bank.

Some of the results of Basson *et al.*'s 2D hydrodynamic model simulations of short and long term sediment deposition patterns in the St Lucia Lakes for 1:5 and 1:100 year floods are shown in Figure 4.20 and Figure 4.21. Penetration of sediment laden water into the lake from the different catchment occurs in sequence rather than in concert, with peak penetration from the Mzinene River into the northern part of False Bay taking place first, followed by peak penetration from the Hluhluwe and Nyalazi rivers into False Bay from the south, then peak penetration into North Lake from the Mkuze River, and finally peak penetration into South Lake from the uMfolozi River via the Narrows last. Importantly, sediment from the 1:5 year flood did not reach South Lake at all and only barely penetrated the lakes during the 1:100 year flood. Sediment mainly settles in the Narrows during these extreme events, as is evident from Figure 4.19. Long term simulations for the period 1963 to 2010 (Figure 4.22) indicate a maximum bed level change of 0.1 m to 0.2 m under Present day flow scenarios.


Honeymoon
Bend
-3140000
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[m]
Bed level change [-]
Above 1.500
1.000 - 1.500
0.500 - 1.000
0.001 - 0.500
-0.001 - 0.001
-0.500 - -0.001
-1.000 - -0.500
-1.500 - -1.000
-2.000 - -1.500
Below -2.000
Undefined Valu

Figure 4.19. Model simulations showing change in bed level around Honeymoon Bend following a 1:100 year flood (Source: Basson *et al*. 2014).

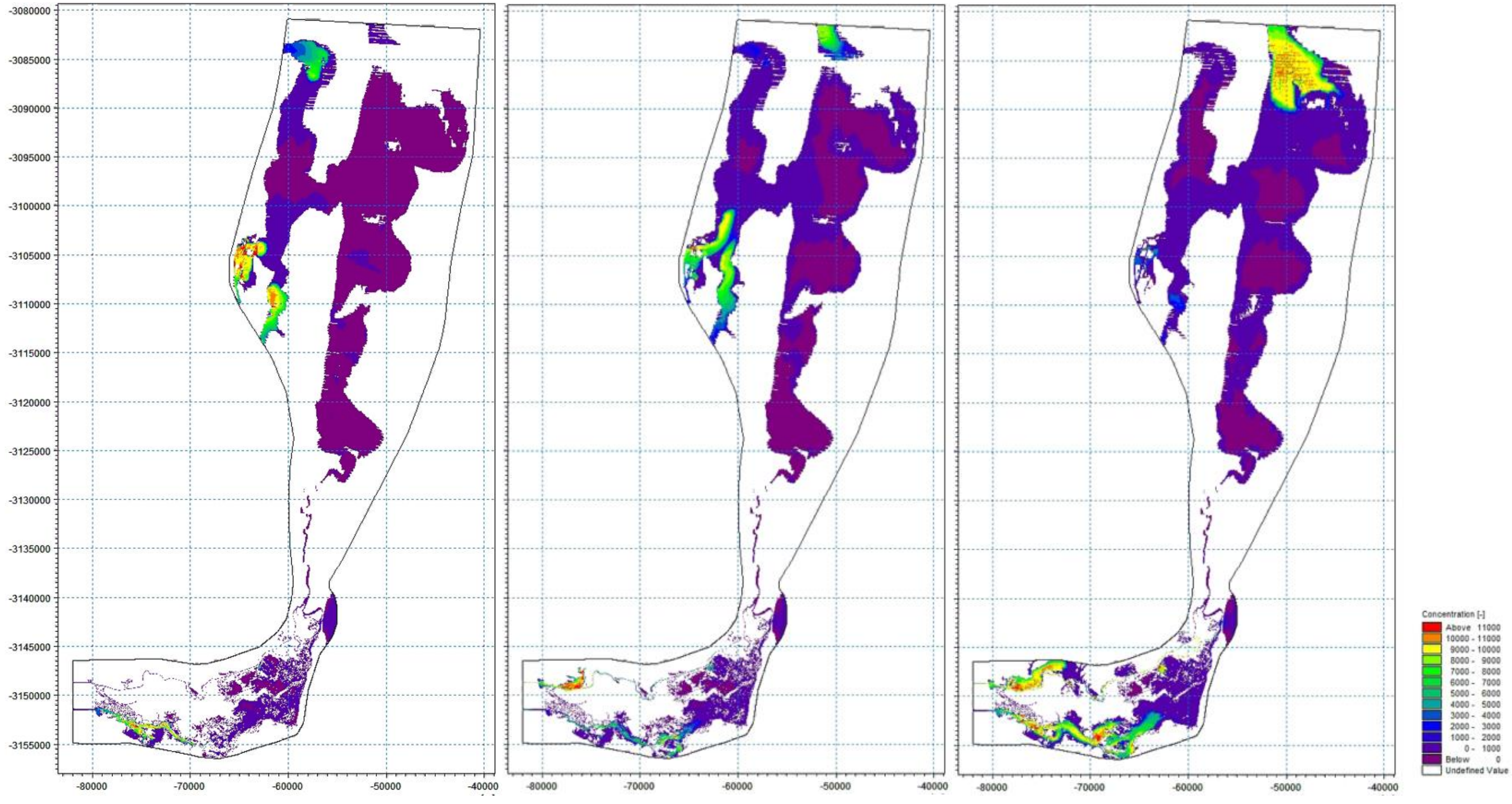


Figure 4.20. Simulated 1:5 year flood sediment concentrations showing maximum extent of penetration into False Bay from the Mzinene River in the north (left), into False Bay from the Hluhluwe and Nyalazi rivers in the south (middle), and into North Lake from the Mkuze River (right). (Note that uMfolozi River flood sediment did not reach the Southern Lake via the Narrows). (Source: Basson *et al*. 2014).

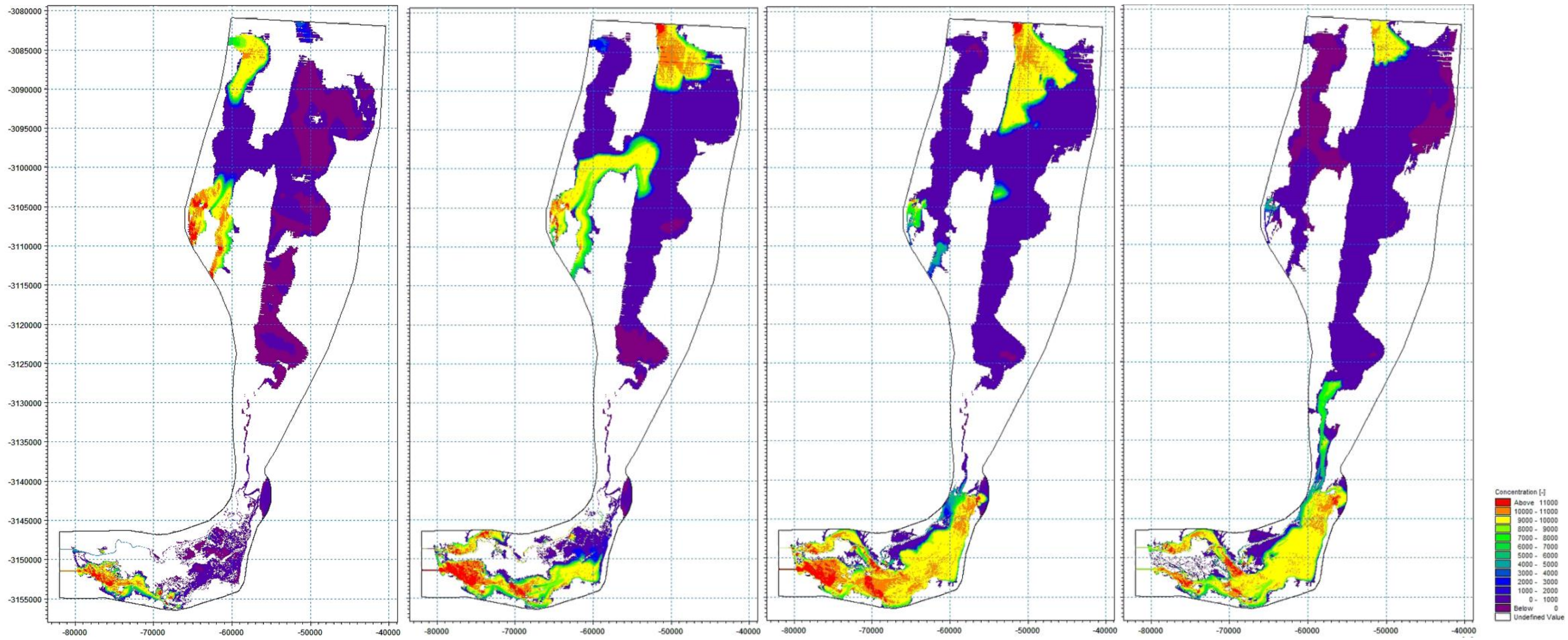


Figure 4.21. Simulated 1:100 year flood sediment concentrations showing maximum extent of penetration into False Bay from the Mzinene River in the north (left), into False Bay from the Hluhluwe and Nyalazi rivers in the south (2nd from left), and into North Lake from the Mkuze River (3rd from left), and into South Lake from the uMfolozi River via the Narrows (right). (Source: Basson *et al*. 2014).

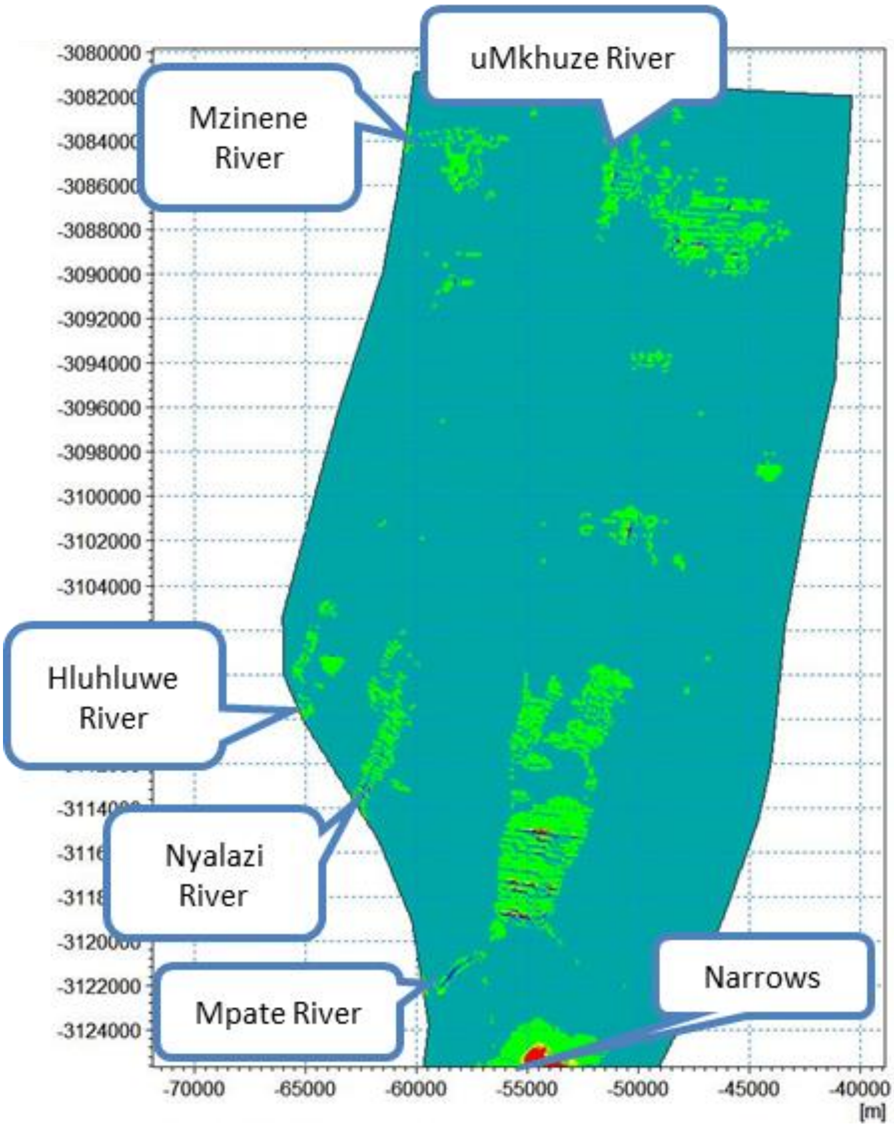


Figure 4.22. Simulated bed level change (1963 to 2010) in Lake St Lucia under Present Day flows (Source: Basson *et al*. 2014).

4.2.3.4 Water level

Changes in freshwater inflows to the St Lucia lakes from both the smaller catchments feeding directly in as well the loss of inputs from the uMfolozi under the separated mouths condition together with the changes in mouth dynamics have had a dramatic impact on water levels in the system. The extent to which the St Lucia lakes dried up, fragmented and became physically separated from one another during the most recent drought (2002-2012) is considered unprecedented (Perissinotto *et al*. 2013, Basson *et al.* 2014). Model simulations undertaken for this study certainly supports this presumption. Data on mean water level in the Lakes, Narrows and uMfolozi are presented in Table 4.7 and Figure 4.23. Mean lake level under Reference condition was estimated at 0.515 m MSL, was marginally higher under present-day conditions with the beach channel in place (Mouth A: 0.594) but was slightly lower under the combined mouths configuration (Mouth B: 0.507 m MSL, Table 4.7 and Figure 4.23). The fact that mean water level is higher than Reference with the beach channel in place is linked to the fact that the mouth is closed for a greater portion of the time under this configuration, while the drop in mean water level under the combined mouths configuration is likely linked to the interplay between this and the reduction in freshwater inflow under present-day conditions. Changes in mean water level in the Narrows and uMfolozi follow a similar pattern to that observed in the St Lucia lakes, but if anything are more exaggerated due to the closer proximity to the sea.

Table 4.7. Simulated mean water in the Lakes (at Lister's Point), Narrows (at Honeymoon Bend) and the uMfolozi for the period 1971 to 2010 for Reference and present-day conditions.

Hydrological scenario/mouth configuration	Mean water level (m MSL)		
	Lakes	Narrows	uMfolozi
Reference	0.515	0.226	0.210
Present (Mouth A - with beach channel)	0.594	0.678	0.433
Present (Mouth B – after Phase 1 excavation)	0.507	0.425	0.352

4.2.3.5 Present hydrodynamic health

Hydrodynamic health scores for the Lake St Lucia estuary were calculated in accordance with methods prescribed for estuaries in DWA (2012). Individual scores were calculated for three parameters – mouth condition (% time open relative to Reference), size of the tidal prism (% of Reference) and mean water level (as a % of Reference) – for each of the three components of the system - the St Lucia lakes, Narrows and the uMfolozi (Table 4.8). Final scores for each component were taken as the minimum score for the three parameters and the overall score for the Lake St Lucia system was a whole calculated as a weighted average for the three components, taking their relative sizes into account. The hydrodynamic health score assigned for the system as a whole under Mouth A (with beach channel) was extremely low (6.7 = F class) but was very much improved under Mouth B (71.4 = C class).

Most of the change in hydrodynamic health was attributed to non-flow related influences (i.e. historic efforts to separate the St Lucia and uMfolozi mouths, 90% for Mouth A and 70% for Mouth B). Removing the effects of these non-flow related influence resulted in the scores rising to >90% for the Present state for both mouth options – i.e. = A class. The implication of this is that restoring flow to the Lake St Lucia system would have little impact on hydrodynamic health. The focus should rather be on addressing non-flow related issues (i.e. completion of the dredge spoil removal process).

Confidence in the hydrodynamic health scores assigned to the estuary from this study are rated as "medium-low" (60%) owing to good historic data available on mouth dynamics, water level and salinity for the St Lucia Lakes and Narrows that allowed for calibration of the hydrodynamic models used in this study but was limited by the poor quality of the flow data.

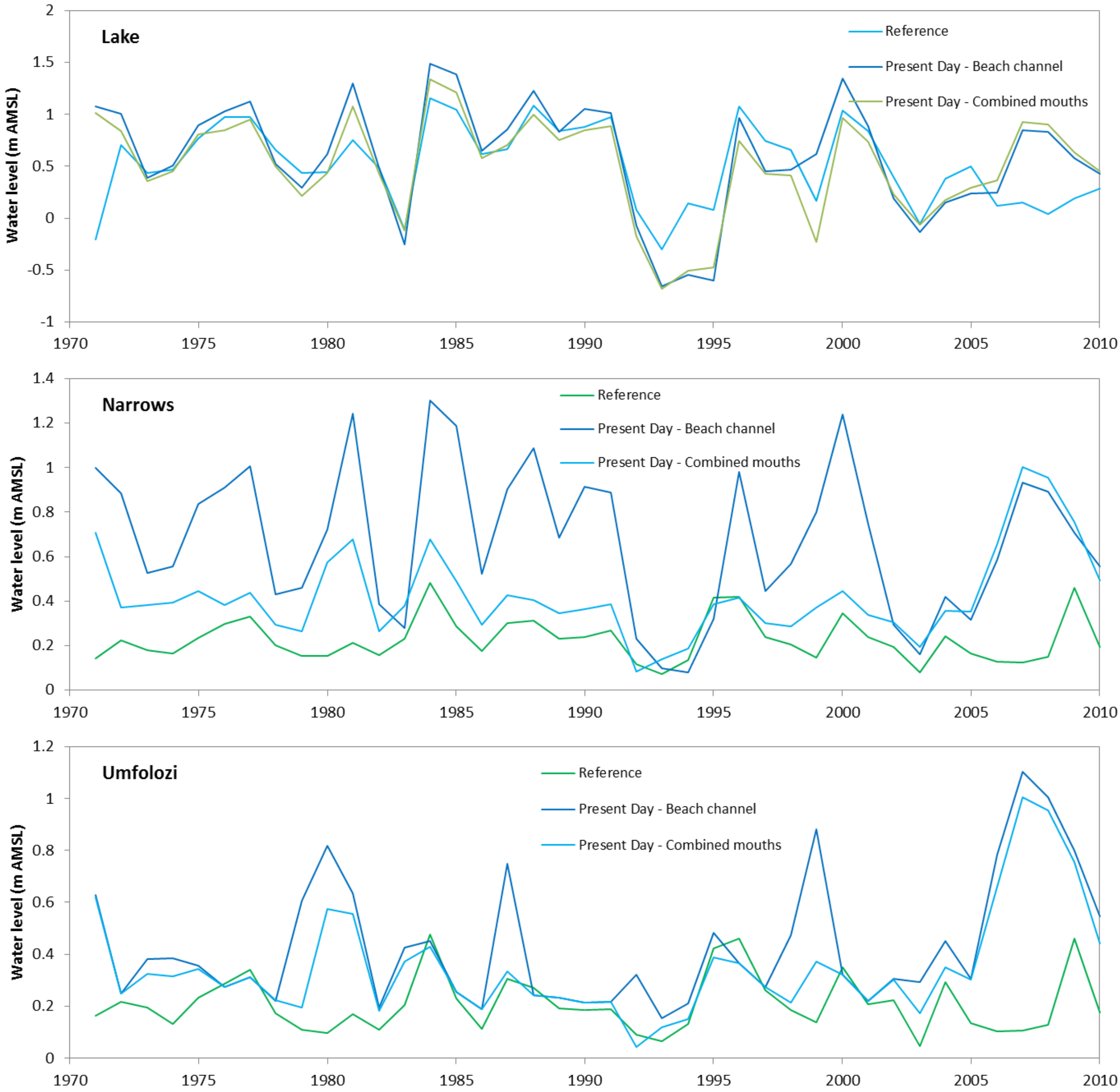


Figure 4.23. Mean water level in the Lakes, Narrows and uMfolozi for the Reference and Present Day. Note that present-day conditions have been modelled as two separate scenarios – Mouth A with the existing beach channel in place and Mouth B after Phase 1 of the dredge spoil removal process has been completed.

Table 4.8. Hydrodynamic health scores for the Lake St Lucia system under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

Component	Parameter	Present Day - A	Present Day - B
Lakes	1.a. Mouth condition (% time open, %Nat)	75.5	82.5
	1.b. Tidal prism (ave, %Nat)	2.0	86.2
	1.c. Water level (ave, %Nat)	86.7	98.5
	Hydrodynamics (min a-c)	2.0	82.5
Narrows	2.a. Mouth condition (% time open, %Nat)	75.5	82.5
	2.b. Tidal prism (ave, %Nat)	2.0	86.2
	2.c. Water level (ave, %Nat)	33.4	53.2
	2. Hydrodynamics (min a-c)	2.0	53.2
uMfolozi	3.a. Mouth condition	75.5	82.5
	3.b. Tidal prism (ave, %Nat)	86.2	97.5
	3.c. Water level (ave, %Nat)	48.4	59.6
	3. Hydrodynamics (min a-c)	48.4	59.6
All	**Hydrodynamics (Lx0.6+Nx0.3+Mx0.1)**	**6.7** **F**	**71.4** **C**
% non-flow related	Hydrodynamics adjustment	90	89
Adjusted score	Hydrodynamics adjusted	90.7	96.9

4.2.4 Water quality

4.2.4.1 Salinity

4.2.4.1.1 Current situation

The Lake St Lucia system is very shallow (mean depth <1 metre; Hutchison & Midgley 1978), and consequently has a very large surface area-to-volume ratio. Thus it is highly sensitive to the balance between evaporative water losses and fresh/sea water inflows (Perissinotto *et al.* 2013). This is evident in the range and fluctuation of salinities recorded in the system (Figure 4.24). Historically, freshwater deprivation (principally brought on by the diversion of the uMfolozi flows away from St Lucia) has had a profound impact on salinity, particularly during periods of low rainfall. During these periods, the lakes can become hypersaline (i.e. salinity >35) sometimes to the extent that a reversed salinity gradient develops within the system. Although hypersaline conditions are believed to have occurred in the Reference condition (supported by modelling studies undertaken as part of this project and earlier work - Basson *et al.* 2014, Hutchison 1976, DWAF 2004, Lawrie & Stretch 2011a, b, Stretch *et al.* 2013), the salinity levels recorded in the recent drought (2002-2012, in excess of 200) are believed to be unprecedented (Perissinotto *et al*. 2013, Basson *et al.* 2014).

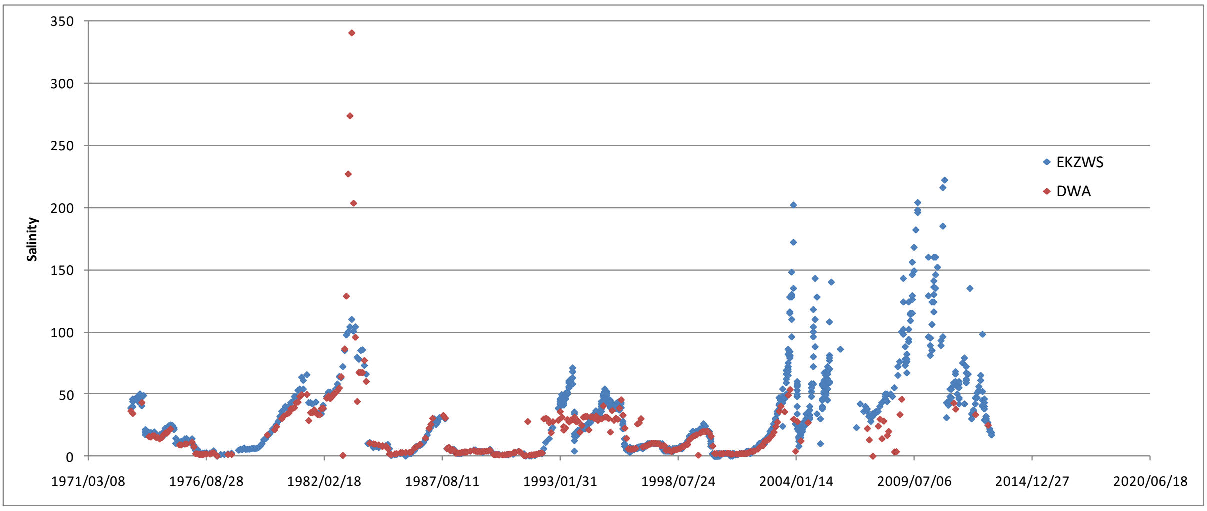


Figure 4.24. Salinity at Lister's Point (False Bay) from the early 1970s to present, based on data collected by Ezemvelo KZN Wildlife and DWA. Note that the data from DWA have been converted from conductivity to salinity using the formulae of UNESCO (1983) and IOC, SCOR & IAPSO (2010) which are only valid for the salinity range 2-42.

Conditions in the Narrows and mouth region are typically less extreme than those in the Lakes, but have also been significantly affected by anthropogenic influences on the system. When the mouth is open, salinity in the Narrows and mouth region tends to be similar to that of seawater because of the tidal influence (Perissinotto *et al*. 2013, Basson *et al.* 2014), though salinities will drop to low levels during periods of heavy rain and freshwater run-off, even if tidal action persists. During periods of extreme drought and mouth closure (as has happened in the period 2002 to 2012) this part of the system does not become hypersaline due to freshwater inflows from the Mpate and uMfolozi rivers (via the back channel in the case of the latter).

4.2.4.1.2 How salinity conditions have changed as a result of human interventions

Historically, the Lake St Lucia system has experienced quasi-decadal wet and dry cycles, with development of hypersaline conditions alternating with return to limnetic (fresh, lake-like) states at regular intervals (Perissinotto *et al*. 2013), and is likely to have done so even under Reference conditions. Major peaks in hypersalinity (salinity > 100) in the lakes were recorded during the periods 1970-1971, 1983-1984, 2003-2006 and 2009-2010 (Day *et al.* 1954, Whitfield and Taylor, 2009; Cyrus *et al*. 2011), while oligohaline to limnetic conditions (salinity < 5) reportedly occurred in 1964, 1976-1978, 1984-1986, 1988-1992, and 2000-2001 (Whitfield and Taylor 2009; Figure 4.24). Periods of hypersalinity in the lakes are, however, considered to have been greatly exacerbated relative to Reference conditions both in terms of their duration and magnitude. Under reference (natural) conditions, it is thought that hypersalinity seldom occurred for long periods at a time and that salinity is unlikely to have exceeded 45 (Hutchison 1976, DWAF 2004a). Salinity levels in excess of 200 (and with a maximum of 308), as were recorded during the period 2002-2012, are considered to be unprecedented and are likely to be a function of artificially depriving the system of freshwater while at the same time promoting open mouth conditions and hence allowing the influx of seawater into the system. The presence of weirs on the Nyalazi, Hluhluwe and Mpate rivers also inhibit the formation of a zone of saltwater dilution during periods of hypersalinity (DWAF 2004a). This would result in a salinity change in these areas that is more abrupt than would naturally be expected, as well as serving as a barrier to animal movement, and effectively negating the refuge value of these rivers.

Lawrie & Stretch (2011a, b) used hydrodynamic modelling simulations to investigate how human developments have affected the water and salt budgets of Lake St Lucia as well as the occurrence and persistence of water levels and salinities at St Lucia during wet and dry cycles, and the broad implications for the biological functioning and management of the system. Their results show a good congruence with salinity data that have been collected by Ezemvelo KZN Wildlife at a number of stations in the Lake St Lucia system, and confirmed that prior to its diversion in 1952, the uMfolozi was both an important source of fresh water to the lake during dry conditions and played a pivotal role in providing a more stable mouth state regime for the system. Their results suggest that the Lake St Lucia system has changed from one that was primarily fresh/brackish (≤12, estimated to be around 40% of the time) or "estuarine" (13-45, estimated to be around 51% of the time) in nature, with a low incidence of hypersalinity (>46, 9% of the time), to a system that has become primarily "estuarine" or hypersaline (50% and 32% of the time, respectively).

Data on salinity in the St Lucia Lakes derived from the 1D numerical modelling studies undertaken as part of this study are presented in Figure 4.25 and Table 4.9. Average salinity levels in the St Lucia Lakes under the Reference conditions were expected to be low

(7.4). Levels were projected to be moderately elevated under present-day conditions with the Beach channel (Mouth A: 9.9) but rise to much higher levels under the after Phase 1 excavation option (Mouth B: 17.4). These differences are linked to reduced freshwater inflow (both Mouth A and B) and increased seawater inputs at the mouth (Mouth B). The situation is similar in the Narrows and uMfolozi, as might be expected (Table 4.9).

Figure 4.25. Mean salinity in the Lakes, Narrows and uMfolozi for the Reference and Present Day (Mouth A with the existing beach channel in place and Mouth B after Phase 1 of the dredge spoil removal process has been completed).

Table 4.9. Simulated mean salinity in the Lakes (at Lister's Point), Narrows (at Honeymoon Bend) and the uMfolozi for the period 1971 to 2010 for Reference and present-day conditions.

Hydrological scenario/mouth configuration	Mean salinity		
	Lakes	Narrows	uMfolozi
Reference	7.4	14.3	6.8
Present (Mouth A - with beach channel)	9.9	8.4	11.2
Present (Mouth B – after Phase 1 excavation)	17.4	14.1	12.7

4.2.4.2 Nutrients

Very little information exists on nutrients in the Lake St Lucia estuarine system. The primary sources of inorganic nitrogen and phosphorous to the estuary are river inflows and remineralisation occurring within the estuary (Johnson 1976, DWAF 2004a, Perissinotto *et al.* 2013). The extent to which contributions from these sources have changed over time is not clear as there is limited information on nutrient loading for the Lake St Lucia system prior to 1973.

Monitoring of nutrient inputs (Dissolved Inorganic Nitrogen, DIN, and Dissolved Inorganic Phosphorus, DIP) into the Lake St Lucia system from the major influent rivers and in the estuary itself has been undertaken by the Department of Water and Sanitation (DWS) intermittently since 1973 (weekly or monthly but with extended gaps in the records). More recently (since 2004 and 2007, respectively), both the University of KwaZulu-Natal (UKZN) and the Coastal Research Unit of Zululand (CRUZ) have been collecting data on water quality in St Lucia (UKZN, CRUZ), the lower uMfolozi (CRUZ) and lower uMsunduzi (CRUZ). Samples from St Lucia have been collected at quarterly intervals (UKZN) or twice per annum (CRUZ, May and Nov) and up to four times per annum in the uMfolozi and uMsunduzi (Mar, Jun, Aug, Nov). The DWS and CRUZ data sets were analysed for the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" that was commissioned by the iSimangaliso Wetland Park Authority (Clark et al. 2014a), in an effort to understand changes in nutrient levels in the system over time and also key drivers affecting nutrient levels in the system. Key finding from this assessment indicated that the concentration of Dissolved Inorganic Nitrogen (DIN) had increased dramatically in the St Lucia Lakes and Narrows (up from around 0.2-0.3 mg/L in the period 1973-1996 to 1.7-3.5 mg/L in the period 2007-2012), while Dissolved Inorganic Phosphorous (DIP) has changed little over the same period (around 0.03-0.11 mg/L in the period 1973-1996 and around 0.02-0.06 mg/L in the period 2007-2012). No clear change over time was evident for either DIN or DIP in any of the influent rivers, however, in spite of these data spanning an extended time period for some catchments (1977-2012). It was concluded therefore that much of the DIN (and probably much of the DIP as well) in the water column of the St Lucia Lakes at present is derived from remineralisation (breakdown of accumulated organic matter in the system – autochthonous source) rather than an increase in the influx of nutrients to the system *per se* (allochthonous source). (Note that this does not imply that these nutrients are not ultimately derived from river inflow, simply that these nutrients enter the system in the form of organic matter rather than dissolved in the influent fresh water). This was observed to be consistent with the fact that nutrient concentrations (particularly DIN but also DIP) measured in the St Lucia Lakes in recent years (DIN: 2.93-4.25 mg/L, DIP: 0.03-0.06) were much higher than in any of the influent rivers including the uMfolozi (DIN: 0.20-1.43, DIP: 0.02-0.07).

Annual variations in DIN and DIP in the Lakes, Narrrows and uMfolozi under and Present-day conditions - Mouth A with beach channel and Mouth B with dredge spoil removed were simulated using the DRIFT estuary model and are presented as a percentage of Reference in Table 4.10 and Figure 4.26 and Figure 4.27. In all cases, levels of DIN and DIP are markedly lower and closer to the Reference state under Mouth B (combined mouth) relative to Mouth A (with beach channel) due to the increase in the tidal prism and hence increased dilution with oligotrophic sea water.

Table 4.10. Simulated mean levels for DIN and DIP (% of natural) in the Lakes (at Lister's Point), Narrows (at Honeymoon Bend) and the uMfolozi for the period 1971 to 2010 for Present-day conditions.

Hydrological scenario/mouth configuration		% of Reference		
		Lakes	Narrows	uMfolozi
DIN	Mouth A - with beach channel	233.7	385.8	216.2
	Mouth B – after Phase 1 excavation	189.8	115.8	210.4
DIP	Mouth A - with beach channel	407.1	207.6	216.5
	Mouth B – after Phase 1 excavation	231.3	81.4	208.0

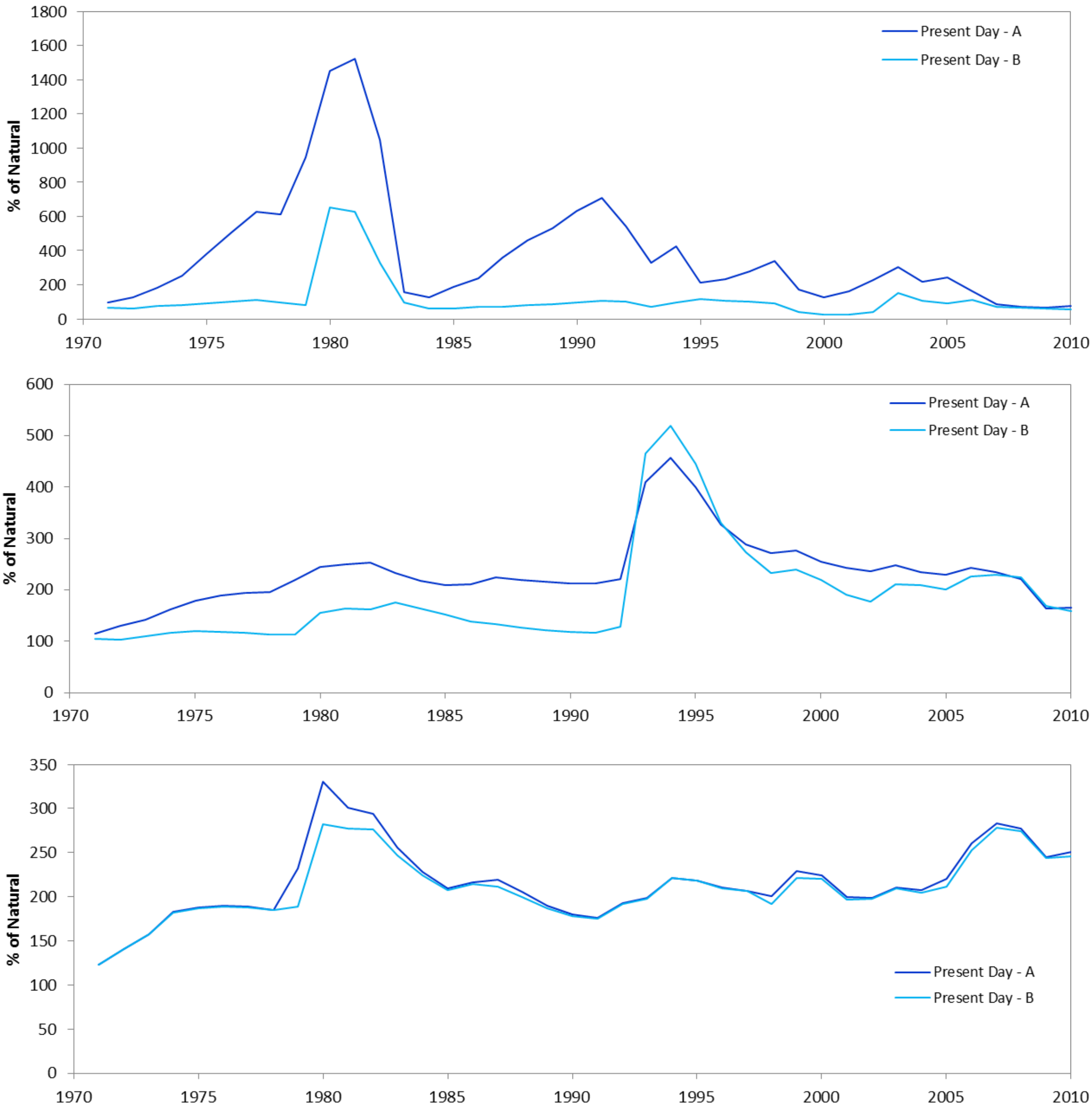


Figure 4.26. Annual variations in DIN (top) and DIP (bottom) in the Lakes, Narrows and uMfolozi under present-day conditions (Mouth A – with beach channel and Mouth B – after Phase 1 excavation) as a percentage of Reference simulated using the DRIFT estuary model.

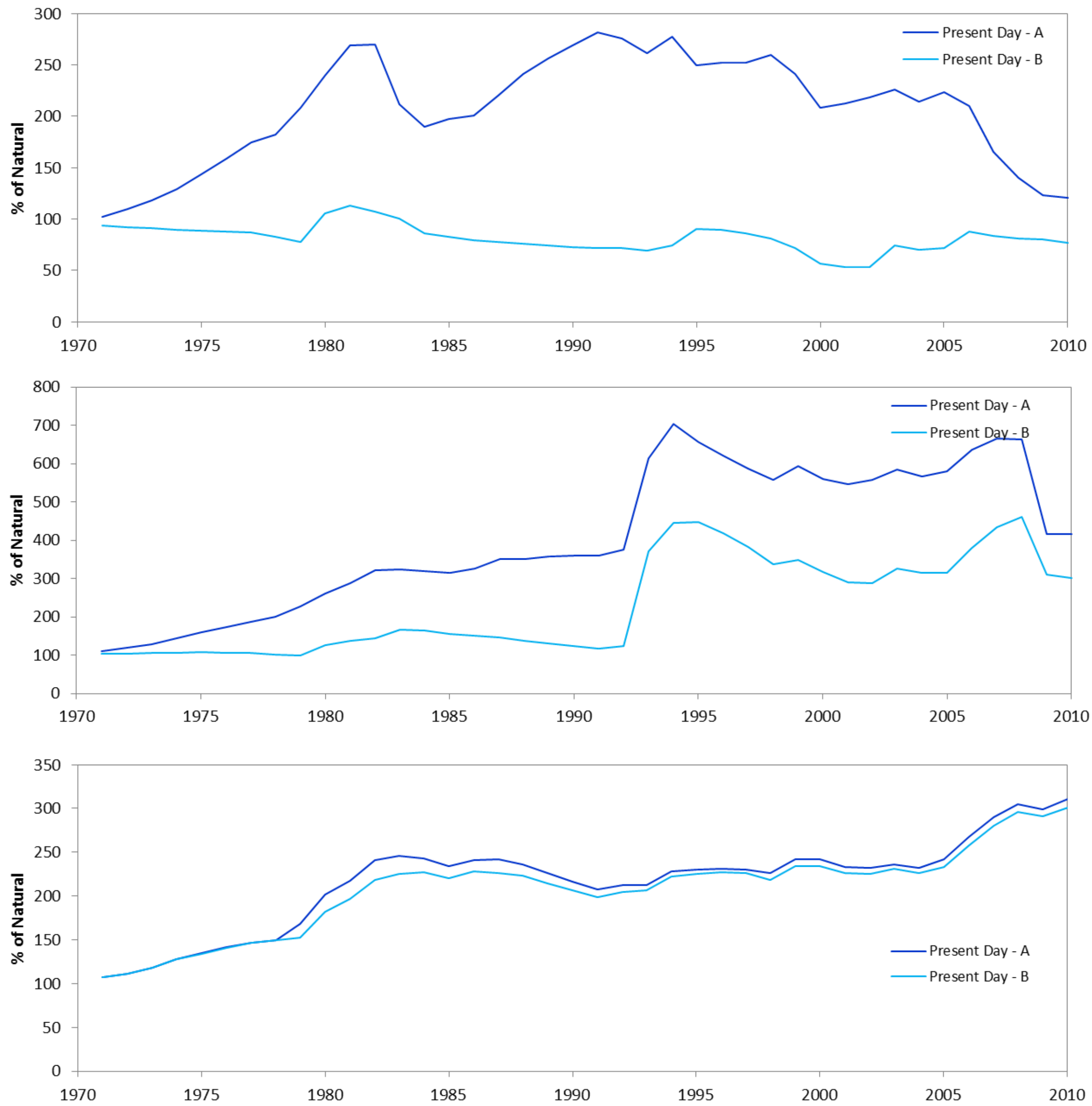


Figure 4.27. Annual variations in DIP (top) and DIP (bottom) in the Lakes, Narrows and uMfolozi under present-day conditions (Mouth A – with beach channel and Mouth B – after Phase 1 excavation) as a percentage of reference simulated using the DRIFT estuary model.

4.2.4.3 Turbidity

The concentration of suspended sediment in the water column is closely linked with turbidity, which is a measure of the amount of light that is able to penetrate through the water column. Both suspended sediment concentrations and turbidity are important for estuarine organisms. High levels of suspended sediment can interfere with or block the feeding apparatus of filer feeding organisms and can block the gills of invertebrates and fish, while light penetration through the water column is important for photosynthesis and for visually orienting predators such as fish and birds. Suspended sediment loads in the St Lucia/uMfolozi system are reportedly dominated by particles less than 60 µm in size (Maine 2011). Fine sediments of this nature are generally referred to as cohesive sediments and tend to form aggregates or flocs before they settle out of the water column. This process (known as flocculation) is accelerated when turbulence is decreased or salinity increases (Stretch *et al.* 2013). Flocs that form and settle are vulnerable to resuspension and break-up under turbulent conditions, a phenomenon which frequently occurs in the St Lucia Lakes and plays an important role in maintaining high levels of suspended sediment in the system (Stretch *et al.* 2013, Schoen *et al*. 2014).

There is very little data available on historic levels of suspended sediment or turbidity levels in the Lake St Lucia estuarine system, and it is not clear whether these have increased in response to increasing sediment yields from the catchment or not. Work by Stretch *et al.* (2013) and Schoen *et al*. (2014) suggests, however, that levels of suspended sediments in the St Lucia lakes are almost entirely dependent on the magnitude of wind-induced wave turbulence in the system and are thus dependent of wind speeds and water levels (depth) rather than catchment derived inputs of suspended sediment. 1D model simulation results from work undertaken by Basson *et al*. (2014) agree with these findings. These data suggest that the re-suspension of fine sediment by wind generated waves accounts for more than 99.99% of the sediment in suspension in the Lakes at least (Table 4.11). Flow-generated suspended sediment concentrations in the Lakes are on average very small, but some high concentrations were evident for short periods when lake levels were low Basson *et al*. (2014). This finding notwithstanding, results from the numerical modelling studies performed by Basson *et al*. (2014) and this study suggest that turbidity levels in the Lakes (Lister's Point) under Reference conditions (298.6 NTU) were markedly lower than under present-day conditions when the Beach canal was in place (Mouth A: 412.2 NTU) and under the Combined mouth scenario (Mouth B: 420.6 NTU). This is linked to differences in water level between the scenarios and also increased sediment input under Present Day relative to Reference conditions. The pattern in the Narrows and uMfolozi is the same as that observed in the Lakes.

Table 4.11. Contribution to Total Suspended Sediment (TSS) concentration in mg/ℓ at Lister's Point from flow and wind generated waves under reference and present-day conditions (Source: Basson et al. 2014, this study).

	Flow	Wind	Total
Reference	0	510	510
Present (Mouth A - with beach channel)	1	666	667
Present (Mouth B – after Phase 1 excavation)	1	673	674

Table 4.12. Simulated mean turbidity in the Lakes (at Lister's Point), Narrows (at Honeymoon Bend) and the uMfolozi for the period 1971 to 2010 under reference and present-day conditions.

Hydrological scenario/mouth configuration	Mean turbidity (NTU)		
	Lakes	Narrows	uMfolozi
Reference	298.6	15.8	20.8
Present (Mouth A - with beach channel)	412.2	35.7	53.4
Present (Mouth B – after Phase 1 excavation)	420.6	38.7	53.4

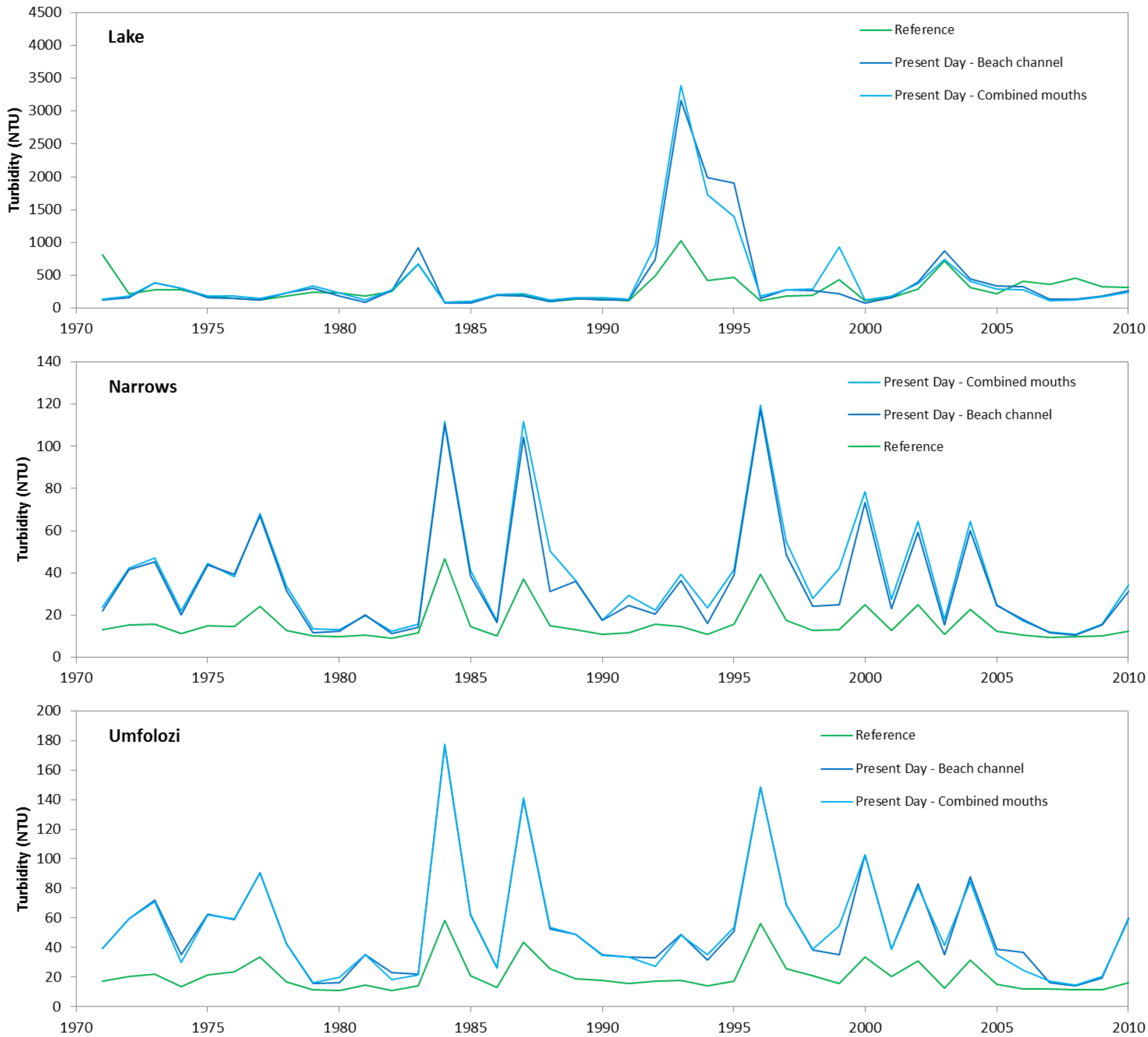


Figure 4.28. Mean turbidity in the Lakes, Narrows and uMfolozi under reference and present-day conditions (Mouth A with the existing beach channel in place and Mouth B after Phase 1 of the dredge spoil removal process has been completed).

4.2.4.4 Water quality health scores: Present Day

Water quality health scores for the Lake St Lucia estuary were calculated in accordance with methods prescribed for estuaries in DWA (2012). Individual scores were calculated for three parameters – salinity, DIN and DIP concentrations, and turbidity – for each of the three components of the system - the St Lucia lakes, Narrows and the uMfolozi (Table 4.8). Final scores for each component were taken as the minimum score for the three parameters and the overall score for the Lake St Lucia system as a whole calculated as a weighted average for the three components, taking their relative sizes into account. The hydrodynamic health score assigned for the system as a whole under Mouth A (with beach channel) was low (54.7 = D class) and was very similar under Mouth B (53.2 = D class). The effects of the change in mouth management on salinity DIN and DIP, and turbidity in the different parts of the Lake St Lucia system were very different, specifically the Lakes vs. the Narrows and uMfolozi, which accounts for this rather counter intuitive response. Salinity scores for the Lakes, for example, are lower under Mouth B (after Phase 1 excavation – 42.9%) than Mouth A (Beach channel – 75.5%) owing to the fact that the larger tidal prism combined with reduced freshwater inflow tend to drive salinity levels further from Reference conditions (i.e. higher than Natural).

Table 4.13. Water quality health scores for the Lake St Lucia system under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

Component	Parameter	Present Day - A	Present Day - B
Lakes	4.1.a. Salinity	75.5	42.9
	4.1.b. DIN + DIP (Ave-min, Sim. Coeff.)	42.9	53.1
	4.1.c. Turbidity	72.4	71.0
	4.1. Water quality (Score = (0.6*S+0.4*(min to b-c))	62.5	47.0
Narrows	4.2.a. Salinity	58.4	98.7
	4.2.b. DIN + DIP	36.9	56.7
	4.2.c. Turbidity	44.3	40.9
	4.2. Water quality (Score = (0.6*S+0.4*(min to b-c))	49.8	75.6
uMfolozi	4.3.a. Salinity	11.2	12.7
	4.3.b. DIN + DIP	58.1	59.1
	4.3.c. Turbidity	39.0	39.0
	4.3. Water quality (Score = (0.6*S+0.4*(min to b-c))	22.3	23.2
All	4. Water quality (Lx0.6+Nx0.3+Mx0.1)	54.7 D	53.2 D
% non flow related	Hydrodynamics adjustment	95	70
Adjusted score	Hydrodynamics adjusted	97.7	86.0

As was the case with the hydrodynamics scores, much of the change in water quality health was attributed to non-flow related influences (i.e. historic efforts to separate the St Lucia and uMfolozi mouths, development in the catchment and changes in the size of the hippo population). Removing the effects of these non-flow related influence resulted in the scores improving markedly for both mouth options, but more so for Mouth A (with beach channel) than Mouth B (after Phase 1 excavation). The implication of this is that restoring flow to the Lake St Lucia system under the Beach channel in place would do little to improve water quality health, but would make a big difference in the case of Mouth B. Given that iSimangaliso has already made the decision to implement Mouth B, it is extremely important that there is no further reduction in runoff to the St Lucia lakes as this would have serious impacts on water quality in the component of the system. Effort should be directed at restoring runoff to the Lakes through deforestation or other means (e.g. improvements in irrigation efficiency).

Confidence in the water quality health scores assigned to the estuary in this study was rated as medium-low (60%). Historic data was available for salinity in the St Lucia Lakes and Narrows (1960s onwards), and for DIN and DIP levels in the influent waters (1970s onwards) and in the estuary itself (2000s onwards). However, no data were available for the Reference conditions (pre-1950).

4.3 Biotic components

4.3.1 Microalgae

4.3.1.1 Brief overview of the component

Along with other primary producers, microalgae are at the base of the food web and they are therefore of major importance to the ecological functioning of every estuary. The important microalgae groups are the microphytobenthos (sediment-associated), phytoplankton (found in the water-column) and epiphytes (attached to plants). High biomass is generally dependent on stable water level and high light conditions and increases in response to nutrient inputs. Large changes in biomass are expected to occur in response to the alternation of open and closed mouth phases. Exceptionally high biomass has been reported for both phytoplankton and microphytobenthos in Lake St Lucia Estuary particularly during drought. In most cases these were blooms of cyanobacteria which formed under hypersaline conditions and thus were not necessarily utilized to sustain complex food webs. Microalgae biomass is controlled by invertebrate and fish grazing. In some temporarily open/closed estuaries, zooplankton can graze up to 70% of the available phytoplankton biomass (Kibirige & Perissinotto 2003). In the Lake St Lucia Estuary, both zooplankton and benthic macrofauna abundance and biomass have been found to be negatively correlated with microphytobenthic chl-*a* concentration on occasions (Pillay & Perissinotto 2008, Carrasco *et al*. 2010).

For the purposes of this study, microalgae will be divided into three main groups – benthic microalgae, phytoplankton and epiphytes (Table 4.14).

Key drivers (primary, secondary, tertiary drivers and other influencing factors) influencing the composition and abundance (and biomass) of microalgae in the Lake St Lucia estuarine system are listed in Table 4.15.

Table 4.14. Groups of microalgae, their dominant species and defining features

Microalgae group	Subgroups & dominant species	Defining features
Benthic microalgae	Euglenophytes, cyanophytes (blue-green algae) and bacillariophytes (diatoms).	Cyanobacteria and diatom mats occur under favourable conditions and can be important in stabilizing sediment.
Phytoplankton	Flagellates, diatoms, dinoflagellates, cyanophytes, chlorophytes, euglenophytes and coccolithophorids are dominant groups. Groups can also be identified based on size. Microplankton (20 - 200 µm), nanoplankton (2 - 20 µm) and picoplankton (< 2 µm).	Nanoplankton composed 64% of total chl-*a*, followed by microplankton and picoplankton each with about 18% of the total measured from 2004-2010 (Perissinotto *et al*. 2010). Exceptional bloom levels (> 100 mg m^{-3}) were observed on 11 occasions between August 2004 and May 2011, often formed by cyanobacteria.
Epiphytes	Extensive on submerged macrophytes and fringing vegetation.	Gordon *et al*. (2008) measured high biomass in South Lake compared with the Narrows. This was due to the growth of epiphytic filamentous macroalgae (e.g. *Cladophora* spp.) on the host submerged macrophyte *Ruppia cirrhosa.*

Knowledge of microalgae responses was obtained from studies on estuaries throughout the country, as information is limited for Lake St Lucia; this is particularly true for the benthic microalgae and epiphytes. Early published works were on phytoplankton and of a taxonomic nature (Cholnoky 1968, Grindley & Heydorn 1970, Millard & Broekhuysen 1970). Johnson (1976) investigated cell volumes and Fielding *et al*. (1991) undertook the first measurements of chlorophyll-a biomass. Some recent data are available on both phytoplankton and benthic microalgae biomass abundance and productivity (Bate & Smailes 2008, Perissinotto *et al*. 2010, Muir & Perissinotto 2011, van der Molen & Perissinotto 2011). Fewer data are available on epiphytes, which were only investigated from November 2004 to October 2005 (Gordon *et al*. 2008). A summary of information on key drivers of microalgae biomass in the Lake St Lucia estuary system is presented in Figure 4.14. These data were used to inform the design of the Drift estuary model of the estuary.

4.3.1.2 Microalgae abundance – Present Day and Reference condition

Simulation data on microalgae abundance generated from the DRIFT-Estuary model are presented in Table 4.16 and Figure 4.29-Figure 4.31. Microalgae abundance was markedly elevated above Reference levels under present-day conditions for all three parts of the estuary (Lakes, Narrows & uMfolozi), but considerably more so with the Beach channel (Mouth A) in place as opposed to the after Phase 1 excavation configuration (Mouth B). This was directly related to the fact that nutrient levels are more elevated under Mouth A due to reduced dilution by the nutrient poor seawater under this option as well as reduced inputs of nutrient rich uMfolozi water into the Narrows and Lakes under this configuration.

Table 4.15. Key drivers influencing the composition and abundance (and biomass) of microalgae in the Lake St Lucia estuarine system

Microalgae group	Key drivers			Other influencing factors
Benthic microalgae	Stable sediment Strong flow (> 5 $m^3 s^{-1}$), water movement from winds or tides will result in suspension of sediment and low biomass.	Nutrients High biomass is associated with nutrient rich conditions often indicated by muddy organic rich sediments.	High light conditions Turbid waters will limit subtidal benthic microalgae biomass. However this is not a limitation in the intertidal zone.	Grazing by zooplankton, benthic macrofauna and fish.
Phytoplankton	Water volume No water means no phytoplankton.	Nutrients Biomass increases in response to available nutrients.	High light conditions Phytoplankton biomass is higher where irradiance is high.	Grazing by zooplankton.
Epiphytes	Available host substrate Submerged macrophyte and inundated emergent vegetation area available for colonization.	Nutrients Biomass increases in response to available nutrients.	High light conditions Necessary for photosynthesis and growth.	Grazing by zooplankton, benthic macrofauna and fish.

Table 4.16. Simulated microalgae abundance (% of natural) in the Lakes (at Lister's Point), Narrows (at Honeymoon Bend) and the uMfolozi for the period 1971 to 2010 under reference and present-day (Mouth A – Beach channel and Mouth B – after Phase 1 excavation) conditions.

Mouth configuration	Microalgae component	% of Reference		
		Lakes	Narrows	uMfolozi
Present (Mouth A - with beach channel)	Benthic microalgae	1696.7	403.2	2524.0
	Phytoplankton	1707.9	933.5	1532.6
	Epiphytes	613.0	1033.1	613.0
Present (Mouth B – after Phase 1 excavation)	Benthic microalgae	1079.7	188.3	2254.0
	Phytoplankton	1075.8	349.6	1462.6
	Epiphytes	359.5	355.6	359.5

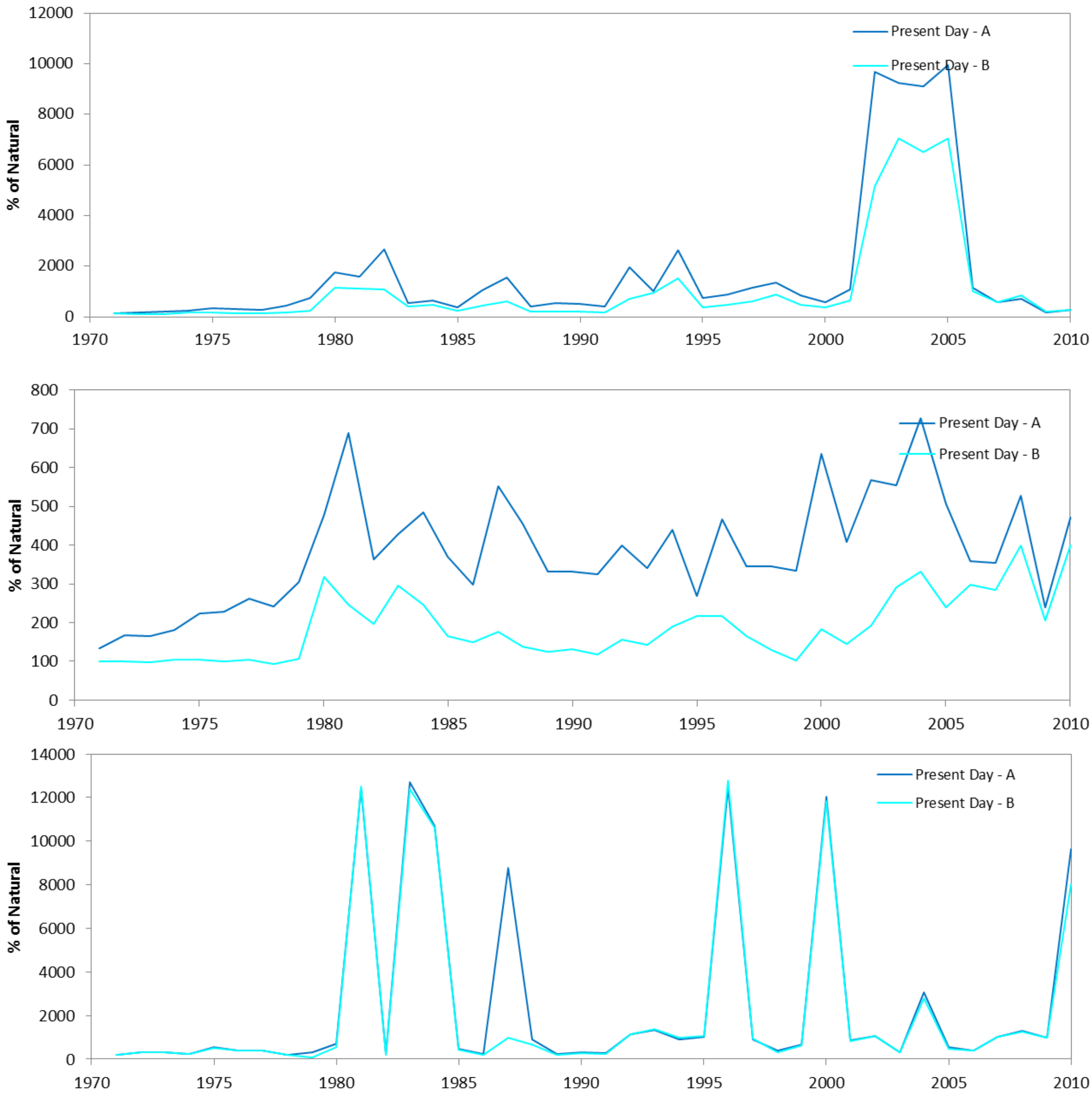


Figure 4.29. Variation in the abundance of benthic microalgae (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

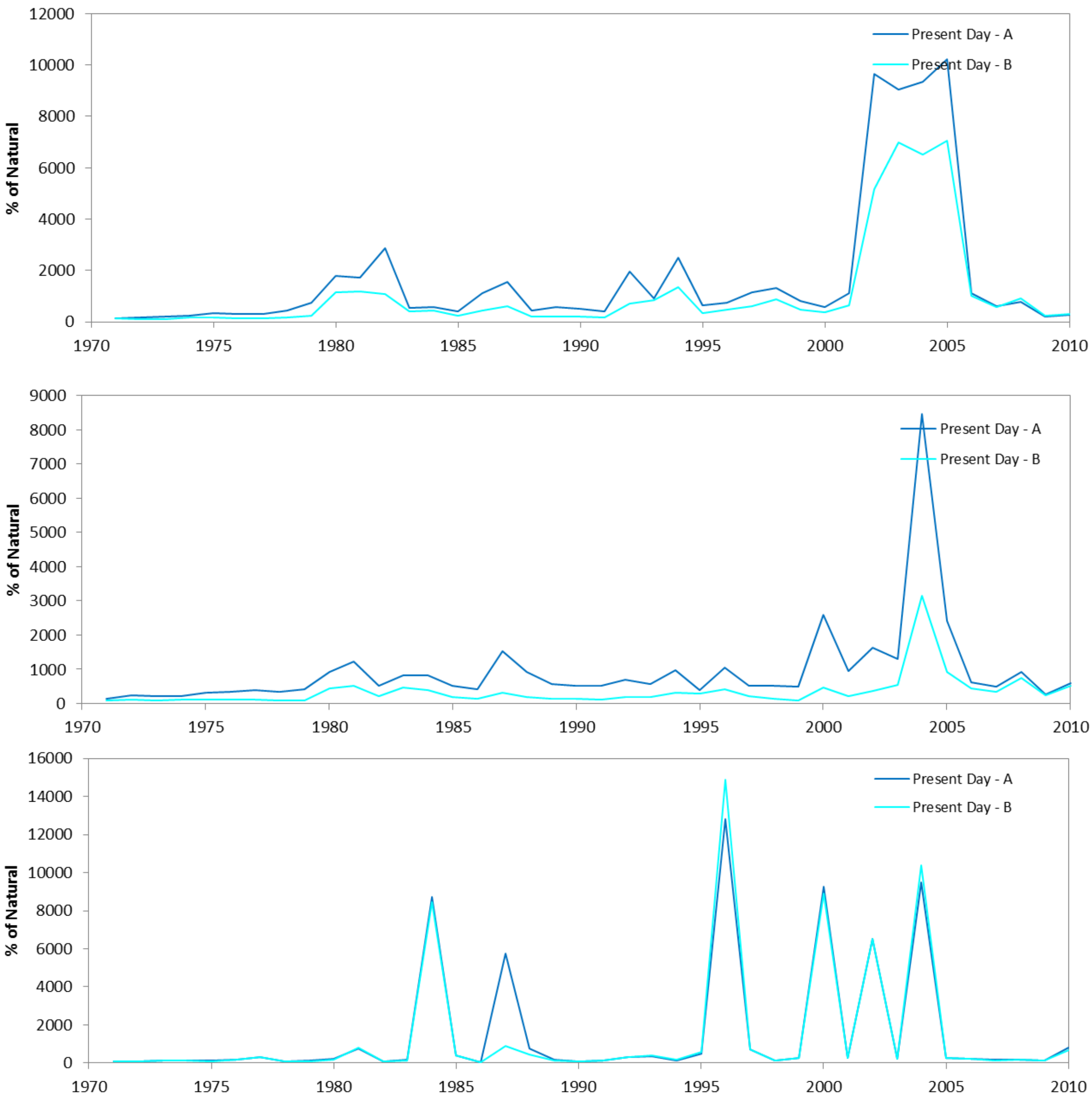


Figure 4.30. Variation in the abundance of phytoplankton (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

Figure 4.31. **Variation in the abundance of epiphytes (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

4.3.1.3 Microalgae health scores: Present Day

Microalgae health scores for the Lake St Lucia estuary system under present-day conditions for the Beach channel (Mouth A) and after Phase 1 excavation (Mouth B), calculated in accordance with methods prescribed for estuaries in DWA (2012), are presented in Table 4.17. The overall health score assigned for Mouth A (with beach channel) was very low (32 = E class) but was much improved under Mouth B (49 = D class).

Table 4.17. Microalgae health scores for the Lake St Lucia system under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

Component	Present Day - A	Present Day - B
Lakes	33	48
Narrows	28	53
uMfolozi	41	43
All	**32** **E**	**49** **D**

Confidence in the microalgae health scores assigned in this study was low (40%) owing to the fact the data available for calibration of the DRIFT estuary model was very limited.

4.3.2 Macrophytes

4.3.2.1 Brief overview of the component

Macrophytes are important as primary producers; they produce detritus, modify the physical environment and create a variety of habitats for estuarine biota. Submerged macrophytes provide a substratum for epiphytes, which in turn provide food for invertebrate fauna and refuge for juvenile fish. The extensive reed and sedge habitats stabilise banks and prevent erosion. Crabs and other invertebrates are associated with the mangrove habitat which also serves as a nursery area for juvenile fish and crustaceans. Macrophytes also play an important role in carbon sequestration, wave attenuation, bank stabilisation, shoreline protection, sediment trapping, turbidity reduction, nutrient cycling and nutrient export. The salt marsh grasses, *Paspalum vaginatum* Swartz and *Sporobolus virginicus* (L.) Kunth are grazed by a variety of animals such as antelope and hippos (Adams *et al*. 2012). Groundwater fed communities consists of reeds, sedges and grasses and occur along the eastern shoreline of Lake St Lucia. Subsurface flows support the plants associated with this habitat.

The major subgroups of macrophytes in the Lake St Lucia system are listed in Table 4.18 along with the dominant species and defining features for each group. The spatial coverage of each of these groups is shown in Figure 4.32-Figure 4.36 and approximate area for each listed in Table 4.19.

Table 4.18. Major macrophyte subgroups in the Lake St Lucia estuarine system, dominant species and defining features for each.

Subgroups	Dominant Species	Defining features
Macroalgae	*Ulva intestinalis, Chaetomorpha* sp., *Cladophora* sp., *Bostrychia* sp. and *Polysiphonia* sp.	Filamentous green algae are common throughout the system along the margins and as epiphytes. Red algae are associated with the pneumatophores and buttress roots of the mangroves.
Submerged macrophytes	*Ruppia cirrhosa, Zostera capensis* and *Stuckenia pectinata*	Variable distribution throughout the lake and estuary based on suitable abiotic conditions.
Reeds and sedges	*Phragmites australis, Juncus kraussii* and *Schoenoplectus scirpoides*	Observed at low salinity sites and those with freshwater input at the margins, sometimes inundated. *Juncus kraussii* occurs in the Narrows.
Mangroves	*Avicennia marina* and *Bruguiera gymnorrhiza*	Mangroves occur in the Narrows, mouth area and along the lower reaches of the uMfolozi.
Grass and shrubs	*Sporobolus virginicus, Paspalum vaginatum* and *Stenotaphrum secundatum*	Sedge grass and shore slope lawn, present in areas where there is no freshwater input, freshwater provided by rainfall
Salt marsh	*Sarcocornia* spp., *Salicornia meyeriana* and *Atriplex patula*	Succulent species colonize exposed saline soils in False Bay and in the mudflats of North Lake and are not tolerant to long periods of inundation
Swamp forest	*Ficus trichopoda, Barringtonia racemosa, Voacanga* spp.	Observed on the banks of uMfolozi Estuary, in the vicinity of the back channel and Narrows. Swamp forest also occurs along the Eastern Shores.

Table 4.19. Spatial coverage of macrophyte habitats (ha) in Lake St Lucia and the uMfolozi (Rautenbach 2015).

	Lake	Narrows	uMfolozi	Total:
Reeds and Sedges	6433.2	792.5	1591.8	8817.5
Mangroves	0	209.5	78.2	287.7
Grass and shrubs	2147.3	64.7	383.6	2595.6
Salt marsh	414.7	0	0	414.7
Swamp forest	0	17.4	1683.1	1700.5
Submerged macrophytes	431.5	0	0	431.5
Total	**9426.7**	**1084.1**	**3736.7**	**14247.5**

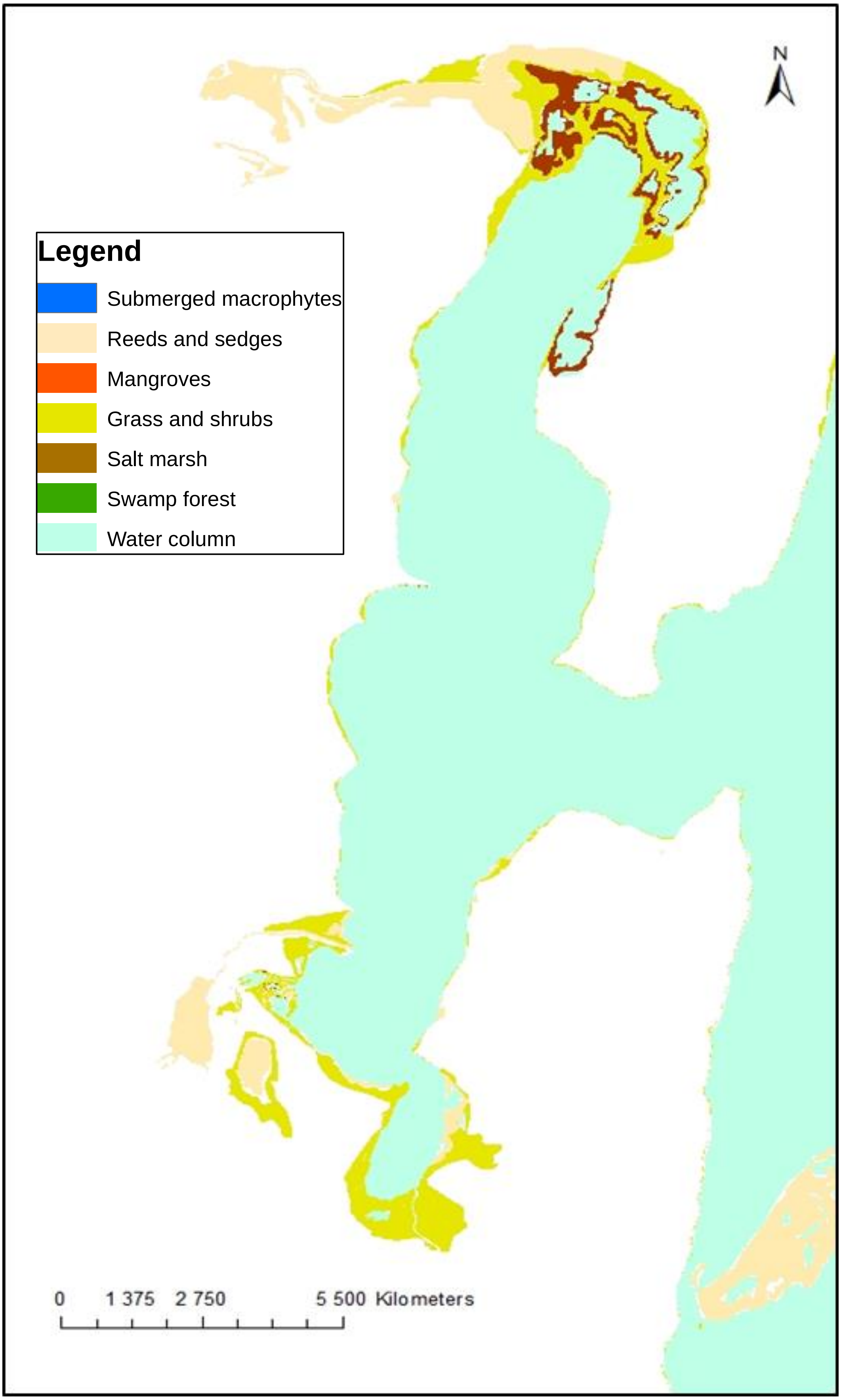


Figure 4.32. Macrophyte habitats of False Bay at Lake St Lucia (Rautenbach 2015).

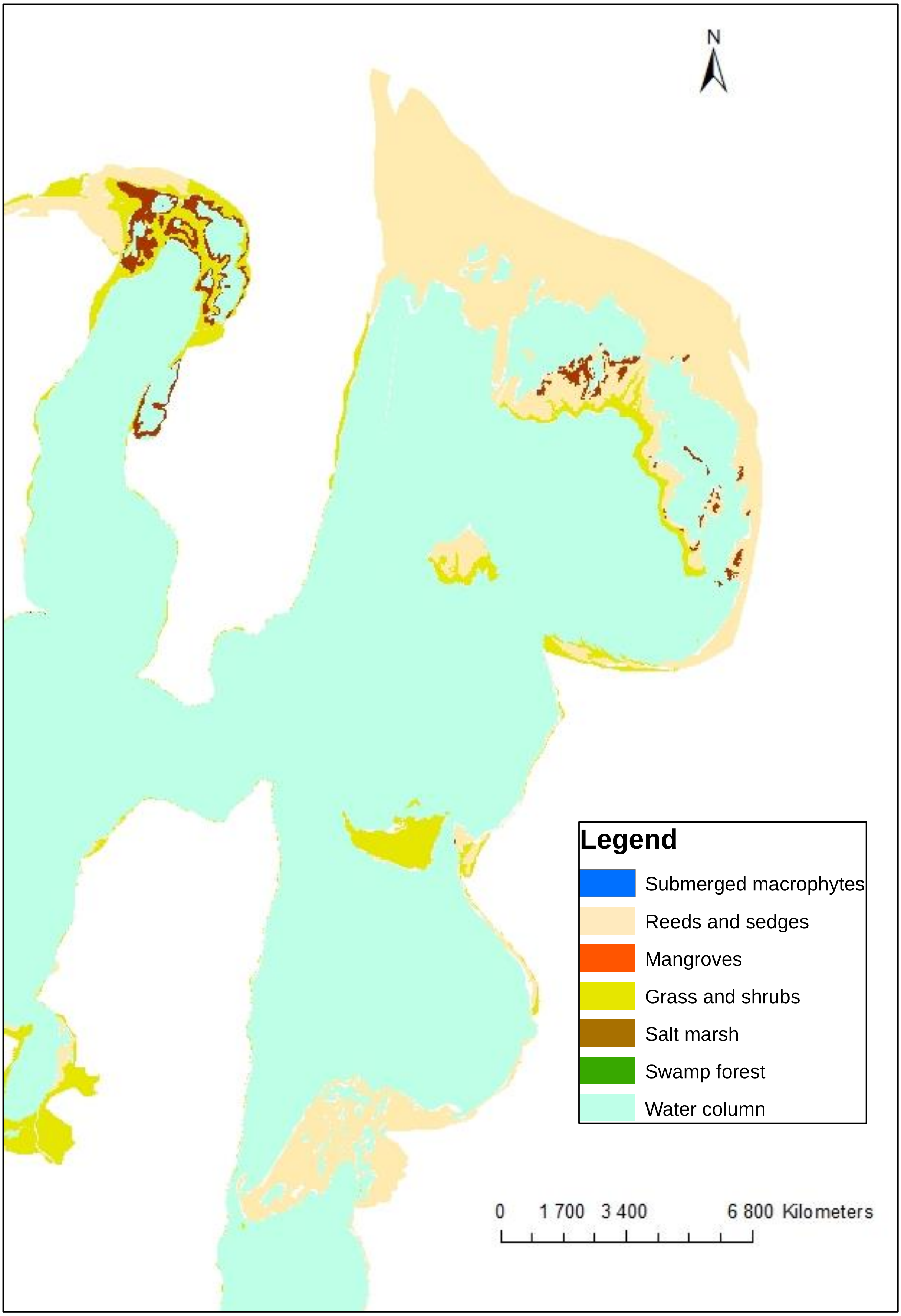


Figure 4.33. Macrophyte habitats of North Lake, St Lucia (Rautenbach 2015).

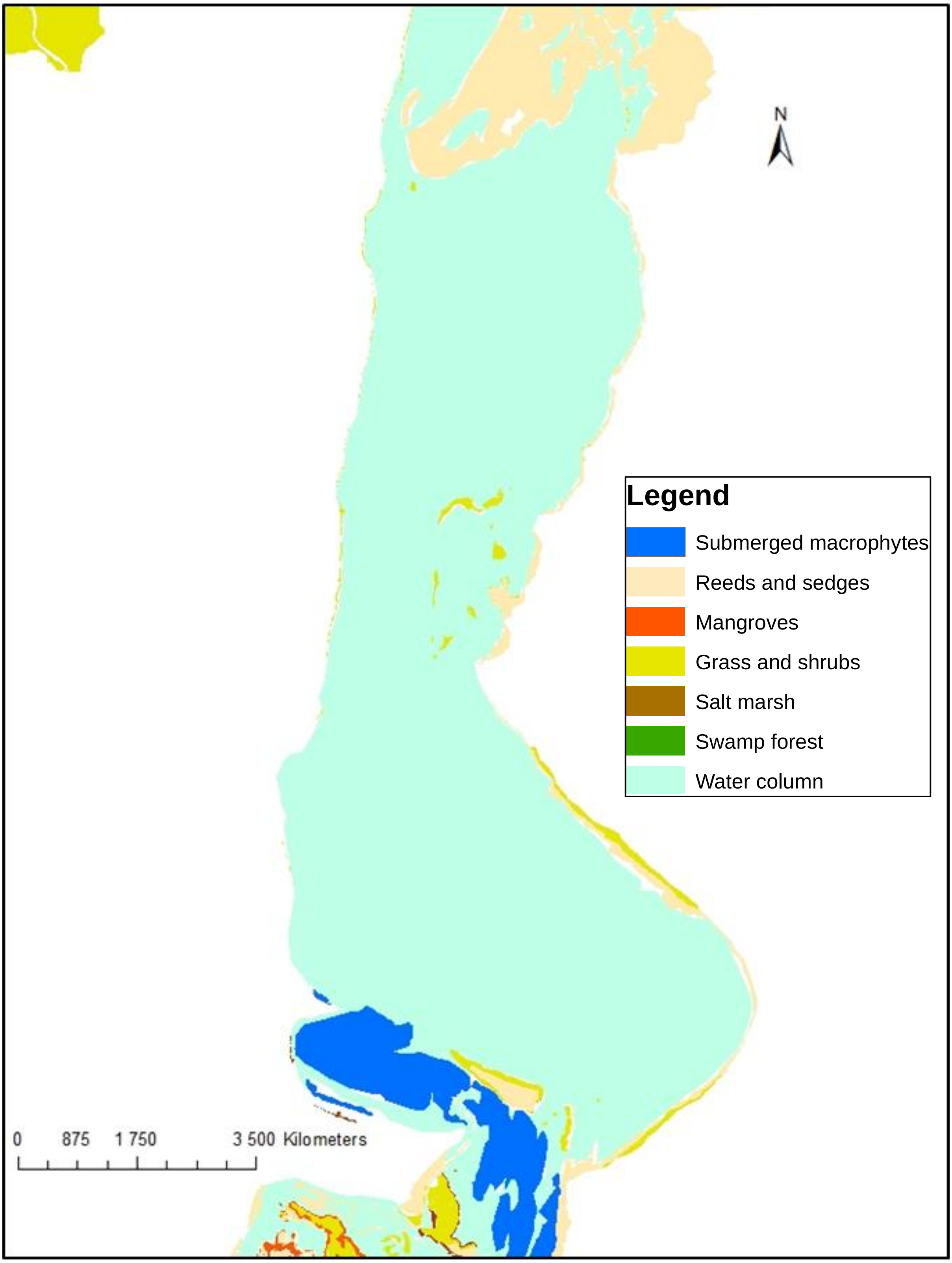


Figure 4.34. Macrophyte habitats of South Lake, St Lucia (Rautenbach 2015).

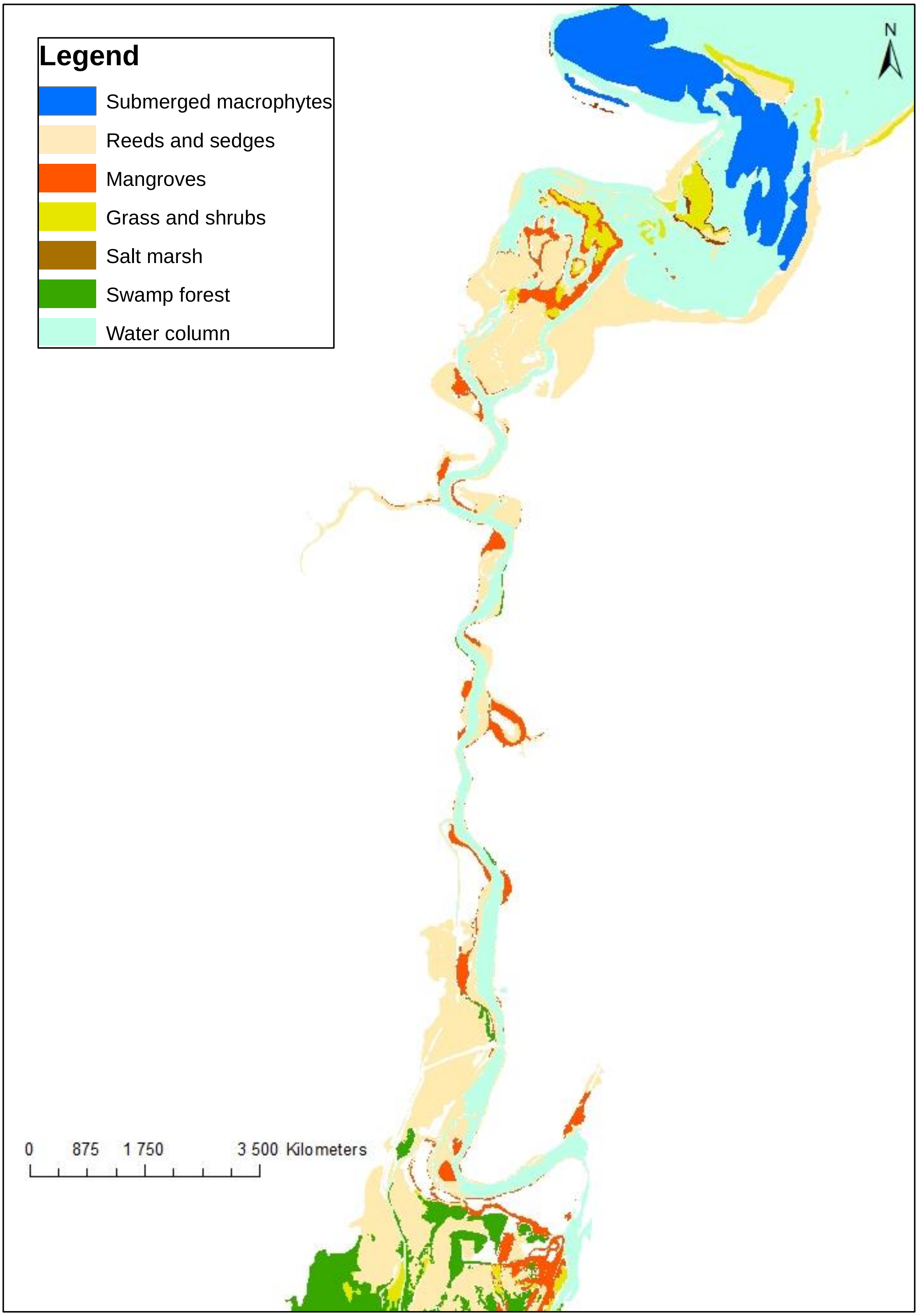


Figure 4.35. Macrophyte habitats of the Narrows at St Lucia (Rautenbach 2015).

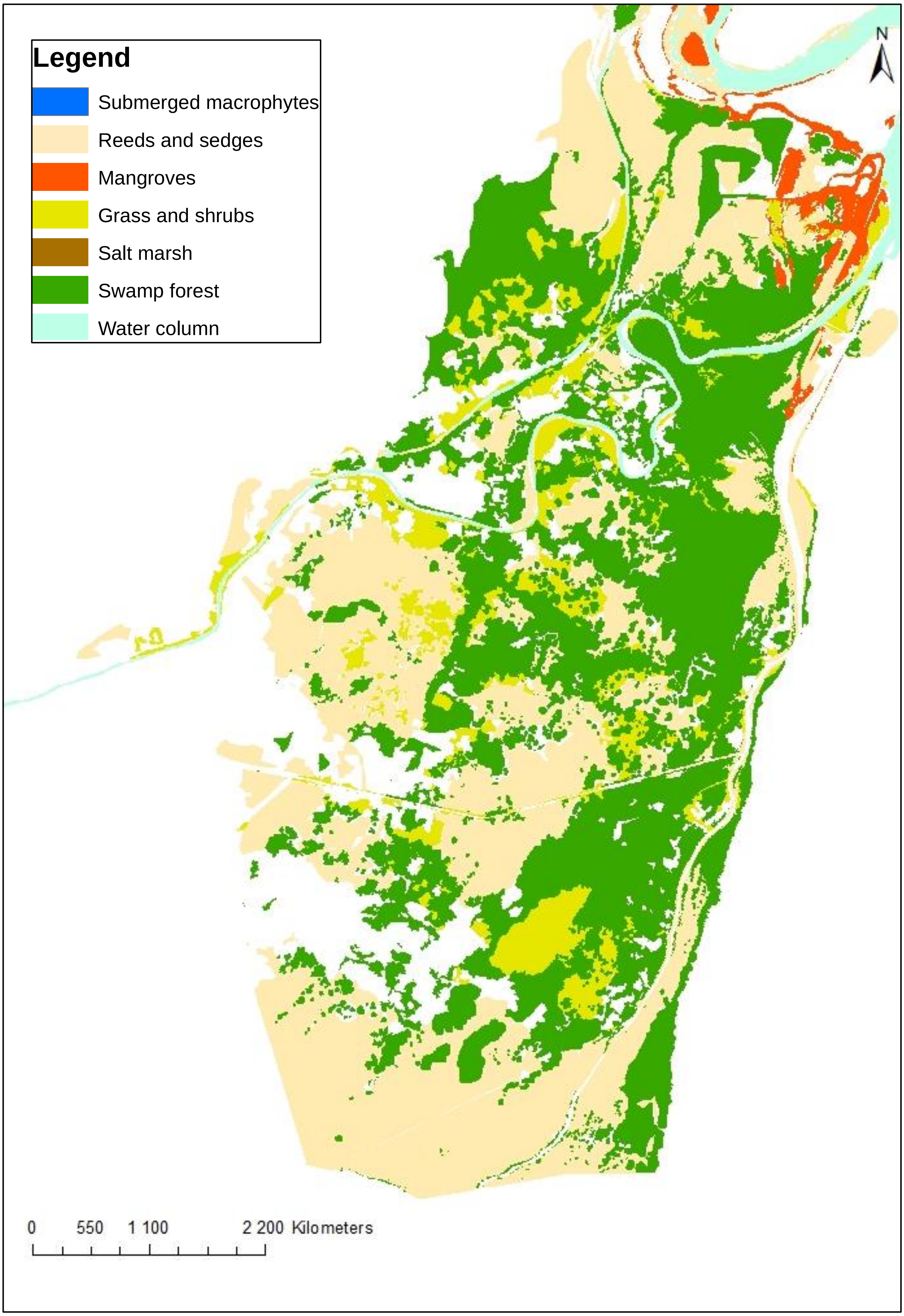


Figure 4.36. Macrophyte habitats of the lower uMfolozi (Rautenbach 2015).

4.3.2.2 Key drivers

Key drivers influencing the distribution and abundance of the various groups of macrophytes in the Lake St Lucia estuarine system are summarised below and in Table 4.20.

4.3.2.2.1 Macroalgae

Macroalgae in estuaries may be intertidal or subtidal, attached or free floating. Genera such as *Enteromorpha*, *Chaetomorpha* and *Cladophora* are common mat forming algae, although they require a firm substrate for initial cell attachment and filament growth. They have wide salinity tolerance ranges and are often indicative of non-turbulent water (closed mouth conditions) and nutrient enrichment. Inorganic nutrients (especially N and P) are known to stimulate the abundance of ephemeral and epiphytic macroalgae in shallow coastal waters. *Ulva, Enteromorpha* and *Cladophora* often form accumulations due to their filamentous nature and higher nutrient uptake rates than thicker algae (Karez *et al*. 2004). These accumulations can reduce the water quality of estuaries, not only by depleting the oxygen in the water column upon decomposition but also causing anoxic sediment conditions when large mats rest on the sediment under low flow conditions (Sfriso *et al*. 1992). Decaying mats of filamentous algae have been shown to adversely impact the social acceptability of water in estuaries and are often the reason for the manipulated opening of the mouth (Adams *et al.* 1999). In St Lucia Estuary, filamentous green algae are common along the margins and as epiphytes (*Ulva intestinalis, Chaetomorpha* spp., *Cladophora* spp.). Certain red algal species (*Bostrychia* spp. and *Polysiphonia*) are associated with the pneumatophores and buttress roots of the mangroves.

4.3.2.2.2 Submerged macrophytes

The distribution of submerged macrophytes is controlled by water depth, turbidity and velocity, salinity, nutrient and light availability, substratum and temperature. High water clarity, low sedimentation rates and low water velocity are optimum growing conditions for submerged macrophytes, hence they scarcely occur in estuaries along the coast of KwaZulu-Natal (Adams & Riddin 2005). Two types of growth forms for submerged macrophytes exist: meadows and canopies. Meadows are characterized by basal meristems and biomass is distributed equally over depth. Examples include *Zostera capensis* and *Ruppia cirrhosa*. Canopies however have apical meristems and their biomass is concentrated towards the canopy or surface (*Stuckenia pectinata*) (Madsen et al., 2001). The two forms have significantly different effects on water flow and sediments; therefore a distinction between the two is important (Madsen *et al*. 2001). A loss in substratum, refuge, the associated biota and productivity would result if there was a loss of submerged vegetation such as *Ruppia* (Tyler-Walters 2001).

Current velocity also has an effect on suspended sediments and turbidity of the water (Jha 2003). It has been shown that light is limiting to submerged macrophyte growth and turbidity is a significant factor that limits light availability. Re-suspension of sediment is caused by an increase in current velocity, which reduces the amount of light available for growth (Madsen *et al.* 2001) and prevents gas exchange (Burkholder *et al*. 2007). Macrophytes can, however, also decrease the current velocity and therefore turbidity, via sedimentation (Madsen *et al*. 2001). Silt carried in by river flow, phytoplankton blooms and the re-suspension of sediment all cause an increase in turbidity (Boardman 2003). *Ruppia* growth has been recorded in turbid waters between 17.5 and 42.5 ppm suspended solids (Kantrud 1991) and any increase in turbidity will have a significant negative effect on growth (Tyler-Walters 2001). Reductions in *Ruppia* biomass are expected when high turbidity conditions exist over long periods, however, if plant matter remains, regrowth of the species can take place once favourable conditions return (Boardman 2003). Conversely, a decrease in the suspended sediment concentration will increase water clarity and therefore growth of the submerged macrophyte (Tyler-Walters 2001). *Stuckenia pectinata* was studied by Van den Berg *et al*. (1999) and results indicated that the species colonized deeper sites in turbid water. The plant is known for its canopy forming structure and high tolerance of turbid waters; it can therefore survive in hypertrophic waters where other species cannot. The species is also more tolerant of moderate to fast currents when compared to the other two (Tyler-Walters 2002).

Nutrient sources for uptake by submerged macrophytes are possible by both sedimentary and aqueous solutions (Nichols 1991). The two most important nutrients for the maintenance of growth of *Ruppia* are nitrogen and phosphorous. The majority of nutrients are taken up in the water column by its leaves and stored for growth under favourable light conditions (Boardman 2003). *Ruppia* has been shown to benefit from low nutrient inputs (10 µM nitrate per day) (Burkholder *et al*. 1994). Nutrient enrichment may however stimulate epiphyte growth and phytoplankton blooms that will shade out light, increase turbidity and compete for nutrients, which will have negative effects on the productivity of the submerged macrophytes. *Stuckenia pectinata* grows in polluted, low oxygen waters with high nitrogen and phosphorus concentrations (Tyler-Walter 2002). The ideal salinity range for the submerged macrophyte *Zostera capensis* is 10 to 46 and 0 to 55 for *Ruppia cirrhosa* (Adams and Bate 1994a, b). *Stuckenia pectinata* grows best in salinities of less than 20 (Gordon *et al*. 2008). *Ruppia* seeds require a short period of low salinity to germinate, therefore seasonal variation in salinity is necessary for the growth of the species (Boardman 2003). *Stuckenia* species are known to replace *Ruppia* in low salinity habitats if turbidity is high (Tyler-Walters 2001) and vice versa in salinities greater than 16 (Kantrud 1990).

4.3.2.2.3 Reeds and sedges

Reeds and sedges serve as important habitats for bird, invertebrates and fish species. Their distribution is dependent on a number of factors such as water depth, salinity, light availability, sediment type and nutrients (Adams & Riddin 2005). The maximum salinity concentration that reeds and sedges can tolerate is 25. *Phragmites australis* is the dominant reed and grows optimally from 0-15 (Adams and Bate 1999) and is found at freshwater seepage sites (Adams 1994, Nondoda 2012). An increase in salinity significantly decreases shoot height and overall plant growth (Adams & Riddin 2005). In 2008, inundated *Phragmites* covered the most area (117.5 ha) in the Narrows compared to previous years (6.6 ha in 1960 and 27.6 ha 2001) (Nondoda 2012). In 2012, an expansion in emergent reed and submerged macrophyte beds (*Stuckenia pectinata*) at the Bridge at Siyabonga was observed due to lower salinities in the Narrows. It was predicted that if the mouth had to open and the concentration of seawater increased, these two vegetation types would die back (Taylor 2013).

Waterlogged conditions are necessary for growth for these emergent macrophytes and death is predicted after one month if they do not persist. Conversely, death is also inevitable if plants are completely covered for a month or more (Adams 1994). Wave action also has an effect on growth and distribution of reeds and sedges. Their adaptations to withstand wave action include flexibility (for bending), nodes which add stabilisation, strength of the plant and the formation of dense stands (Adams & Riddin 2005). Light affects the growth of reeds and sedges and many studies have shown that shading swamp forest in KwaZulu-Natal, negatively affects the growth of these emergent macrophytes (Boshoff 1983, Riddin 1999).

4.3.2.2.4 Mangroves

Five mangrove species populate the coast of South Africa in the subtropical regions; these are *Lumnitzera racemosa, Bruguiera gymnorrhiza, Ceriops tagal, Rhizophora mucronata* and *Avicennia marina*. The species that occur at Lake St Lucia are *Avicennia marina* and *Bruguiera gymnorrhiza,* which grow in the Narrows, mouth area and uMfolozi (Taylor 2006, Hoppe-Speer *et al*. 2012). Historically mangroves would have been limited when the St Lucia Estuary was fresher and closed periodically. Artificial breaching and dredging increased saline conditions and intertidal habitat where mangroves expanded.

Mangroves are able to tolerate a wide range in salinity and depending on their strategy for salt management they are divided into secretors and non-secretors. The former possess morphological adaptations such as salt hairs or salt glands used to excrete excess salt, while the latter do not (Parida *et al*. 2004). Other methods such as ultrafiltration, leaf succulence or leaf desiccation may be employed to excrete or exclude salt (Steinke 1999, Parida *et al*. 2004). *A. marina* can tolerate salinity between 5 and 35 (Downton 1982, Ball and Farquhar 1984, Burchett *et al*. 1984; Clough 1984, Naidoo 1987). Salt accumulation stunts the growth of *A. marina,* and occurs if adequate drainage does not take place and evaporation dries the area up (a closed mouth state may cause this condition) (Taylor, 2006). Breen and Hill (1969) found that after 5 months of inundation due to mouth closure of the Kosi Bay Estuary, the species *C. tagal, R. mucronata* and *A. marina* died. Historically mouth closure and high water levels in the Lake St Lucia Estuary may have limited the distribution of mangroves.

B. gymnorrhiza, the black mangrove, is also a common species in South Africa. Tree heights have been recorded at 30 to 35 m; however average height is approximately 7-20 m (Allen and Duke 2006). *B. gymnorrhiza* is not a pioneer species like *A. marina* and prefers habitats that are on higher ground, where inundation only occurs during spring tides (middle and upper intertidal zones) (Steinke 1999, Allen and Duke 2006), however, it has been found to survive better than *Avicennia marina* under periodic mouth closure conditions (Steinke 1999). *B. gymnorrhiza* prefers a salinity concentration of 10 for optimum growth and reproduction (Riddin and Adams 2007).

4.3.2.2.5 Grass and shrubs

Grass species, *Paspalum vaginatum, Sporobolus virginicus* and *Stenotaphrum secundatum* populate substratum that is more stable and conditions less extreme compared to that of the succulent salt marsh (Taylor 2006). In the Lake St Lucia system, *S. virginicus* is more tolerant of higher salinity for longer periods than *P. vaginatum* (Adams and Riddin, 2005).

The effects of inundation and salinity on *S. virginicus* were studied at False Bay (Breen *et al*. 1977). The distribution and growth was influenced by wave action, water level and salinity (Rogers 1974, Breen *et al.* 1977). *S. virginicus* can survive in high salinity as it excretes salts from its leaves. It is therefore found growing on the lower lying areas of the shore where fluctuating salinities are common. Seed germination is reduced at salinities of 15 and inhibited completely at 20 or more, but when favourable conditions return germination takes place. The older the plant, the more tolerant it is to increasing salinity conditions and inundation (Breen *et al*. 1977).

4.3.2.2.6 Salt marsh

Salt marsh plants provide numerous ecosystem services such as filtering and detoxification, nursery function for fisheries, protection from floods and sea storms and carbon sequestration (Barbier *et al.* 2011). Although it is agreed that abiotic, rather than biotic factors, are responsible for the zonation of salt marsh species, there is disagreement on the level of importance of each factor (Cooper 1982). Therefore, the eco-physiological responses of estuarine plants are important with regards to predicting their survival and growth under different scenarios (Adams & Bate 1994). Adams *et al.* (1999) reported that the two most important abiotic factors that determine distribution of salt marsh are inundation and salinity. As the soils of salt marshes are periodically inundated with seawater, causing waterlogging and changes in salinities, a physically stressful environment is created for the angiosperms which grow there (Pennings *et al*. 2005). Salt marsh plants do not survive in saline conditions over 30 and grow optimally in salinities ranging from 10-35 (Chapman 1960).

Die back of the salt marsh after three months of submergence is predicted and if the sediment dries out, the plants are only expected to survive for six months (Adams 1994). Adams *et al*. (1999) observed that dieback of *Sarcocornia natelensis* was caused by the closure of the mouth of the Great Brak Estuary, which caused inundation for more than 2 months. Reeds and sedges often take over when tidal influence stops (with mouth close) as they are more tolerable of freshwater and longer inundation conditions (Adams & Riddin 2005).

4.3.2.2.7 Swamp forest

Common swamp species include *Syzygium cordatum, Barringtonia racemosa* and *Ficus trichopoda*. The macrophyte habitat, swamp forest, grows optimally in freshwater conditions (Adams & Riddin 2005), unlike the more saline mangrove habitats.

4.3.2.2.8 Floating macrophytes

Floating angiosperms float on the water surface and can be rooted in the substrate. These plants are generally restricted to the fresh and oligohaline (<5) sections of estuaries and to zones of quiet water (Adams *et al*. 1999). An indigenous example at Lake St Lucia is the water lily *Nymphaea nouchali* Burm.f.var *caerulea* (Sav.) Verdc. This plant occurs in the surrounding freshwater wetlands but could occur in the estuary if it remained fresh. There are many exotic species that fall in this category and typically increase or appear in response to nutrient enrichment. These are *Azolla filiculoides* Lam. (water fern), *Salvinia molesta* D.S. Mitchell (kariba weed) and *Eicchornia crassipes* (Mart.) Solms-Laub. (water hyacinth) and *Pistia stratiotes* (water cabbage).

Table 4.20. Key drivers influencing the distribution and abundance (and biomass) of macrophytes in the Lake St Lucia estuary system.

Group	Key drivers			Other influencing factors
Macroalgae	**Depth/ water level** Available habitat decreases in response to drop in water level. Light availability is affected too	**Water velocity** Optimum velocities for growth are between 0.5 and 0.8 m s^{-1}	**Nutrients** Respond rapidly to an increase in nutrients	**Salinity** Occur over a wide range of salinity 0-40
Submerged macrophytes	**Depth / water level** Occur at water depth < 1.2 m and > 0.5 m but dependent on available light, sensitive to exposure and desiccation	**Water velocity / sediment stability** Unstable sediment at > 1 m s^{-1} and no colonization	**Salinity** *Ruppia cirrhosa* (<50) *Stukenia pectinata* (<20) *Zostera capensis* (15-45)	**Turbidity and nutrients** High silt load will reduce light available to the plants. Respond rapidly to an increase in nutrients
Reeds & sedges	**Salinity** Grow best at a salinity <20	**Depth/water level** Will die if permanently inundated > 3 m	**Groundwater seepage and nutrients** Groundwater provides favourable waterlogged habitats	Shading by swamp forest can reduce growth and expansion. Strong waves can reduce cover. Grazing of new shoots as well as fire can cause damage.

Group	Key drivers			Other influencing factors
Mangroves	**Intertidal habitat** Mangrove habitat will expand with an increase in intertidal habitat (typically found between mean sea level and mean high water spring tide level)	**Salinity** Grow best in seawater , can be outcompeted by reeds at lower salinity <10	**Water level** Inundation of pneumatophores for greater than 3 months will result in die-back	Physical destruction observed after cyclones. Fine silt deposited on pneumatophores detrimental to gaseous exchange. Fire, hail and browsing can all reduce growth.
Grass & shrubs	**Salinity** < 20 ideal for growth and expansion	**Water level** A water level >1.5 msl will cause die-back. Saline grasses are better adapted to submerged conditions than succulent salt marsh.	**Grazing** Grazing by mammals and aquatic herbivores	Loss of habitat due to invasive plant species.
Salt marsh (succulent)	**Salinity** Grow best in saline soils (10-35). Salt crusts prevent seedling establishment	**Water level** Inundation >3 months will kill salt marsh. Sensitive to desiccation.	**Dry sediment** Adapted to survive saline, dry soils	.
Swamp forest	**Salinity** Prefer low salinity conditions <10	**Water level** Prolonged inundation has negative effect on growth	**Water flow** Prefer flowing water to standing water	Groundwater seepage is important for maintenance of suitable conditions
Floating macrophytes	**Water velocity** Optimum velocities for growth are below 0.5 m s^{-1}	**Salinity** Restricted to areas where < 5	**Water depth** Restricted to shallow waters between 0.5 and 1.2 m	**Nutrients** Invasive aquatics respond rapidly to an increase in nutrients

4.3.2.3 Macrophyte abundance – Present Day and Reference condition

Summary statistics on the abundance of macrophytes under present-day conditions (Beach channel and after Phase 1 excavation options) are presented in Table 4.21 and time series data for the period 1971-2010 are presented in Figure 4.37-Figure 4.44. For the most part, abundance was more similar to the Reference condition under the after Phase 1 excavation option (Mouth B) than with the Beach channel. This was mostly due to differences in nutrient levels but was reversed in some cases where other drivers (such as salinity) were more important (e.g. for the mangroves and swamp forest).

Table 4.21. Simulated macrophyte abundance (% of natural) in the Lakes (at Lister's Point), Narrows (at Honeymoon Bend) and the uMfolozi for the period 1971 to 2010 under reference and present-day (Mouth A – Beach channel and Mouth B – after Phase 1 excavation) conditions.

Mouth configuration	Microalgae component	% of Reference		
		Lakes	Narrows	uMfolozi
Present (Mouth A - with beach channel)	Macroalgae	1577.1	1866.8	2423.5
	Submerged macrophytes	1756.9	1981.0	-
	Floating macrophytes	79.4	202.3	74.4
	Reeds and sedges	1721.2	876.0	1015.4
	Mangroves	-	40.3	118.7
	Salt marsh	105.1	84.2	100.0
	Swamp forest	100.0	122.2	39.0
	Grass & shrubs	97.9	100.7	70.7
Present (Mouth B – after Phase 1 excavation)	Macroalgae	1011.2	568.6	2188.2
	Submerged macrophytes	615.8	419.2	-
	Floating macrophytes	77.8	93.9	70.0
	Reeds and sedges	482.2	299.3	751.5
	Mangroves	-	91.5	183.4
	Salt marsh	102.3	60.3	100.0
	Swamp forest	-	104.2	49.4
	Grass & shrubs	82.7	97.3	70.3

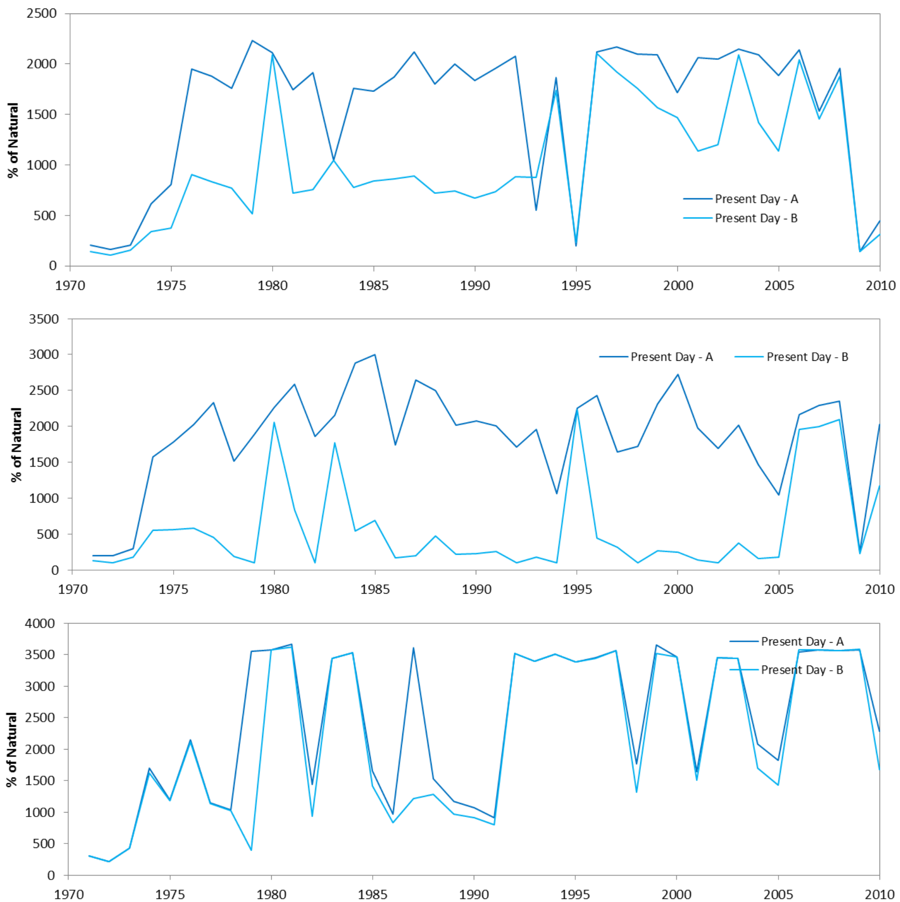


Figure 4.37. Variation in the abundance of macroalgae (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

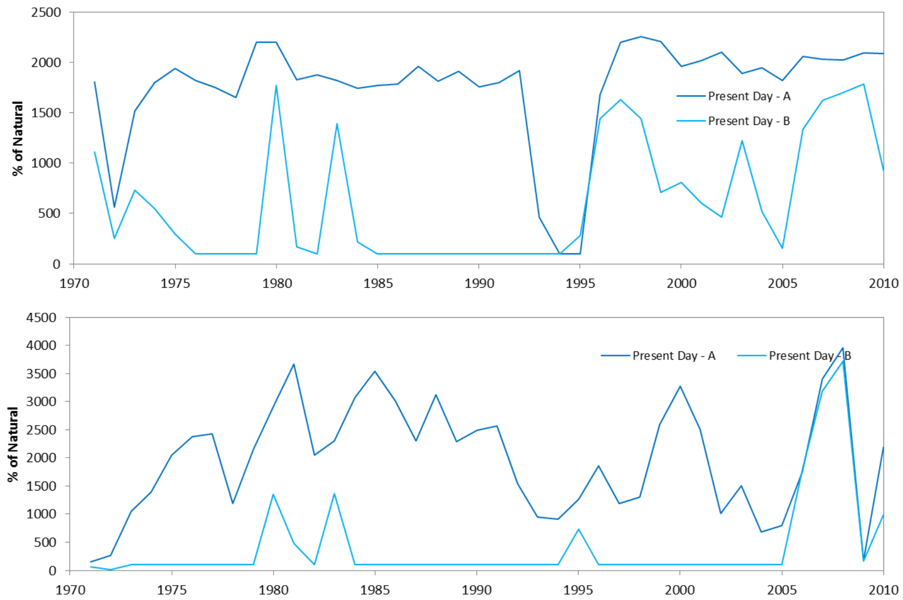


Figure 4.38. Variation in the abundance of submerged macrophytes (% of natural) in the Lakes (top) and Narrows (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

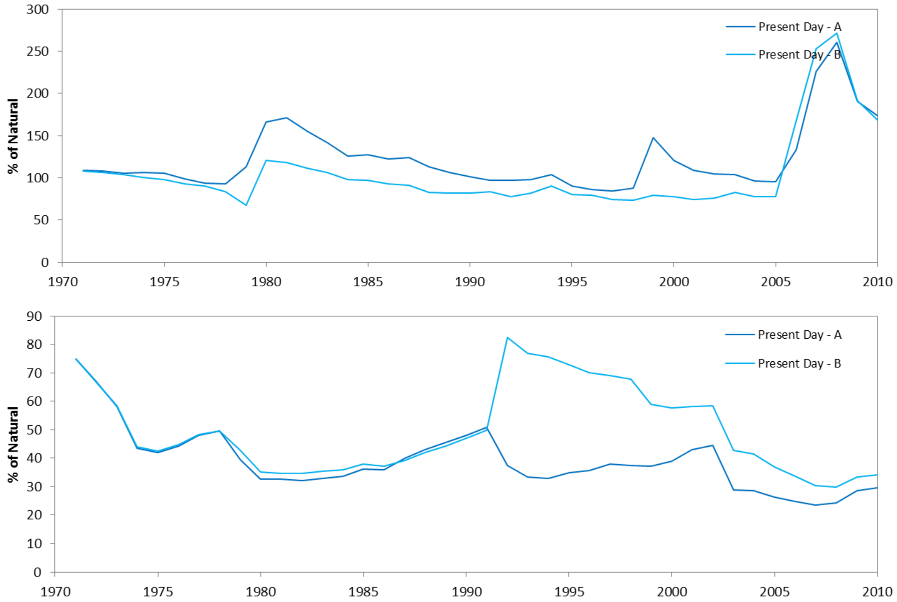


Figure 4.39. **Variation in the abundance of swamp forest (% of natural) in the Narrows (top) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

Figure 4.40. **Variation in the abundance of floating macrophytes (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

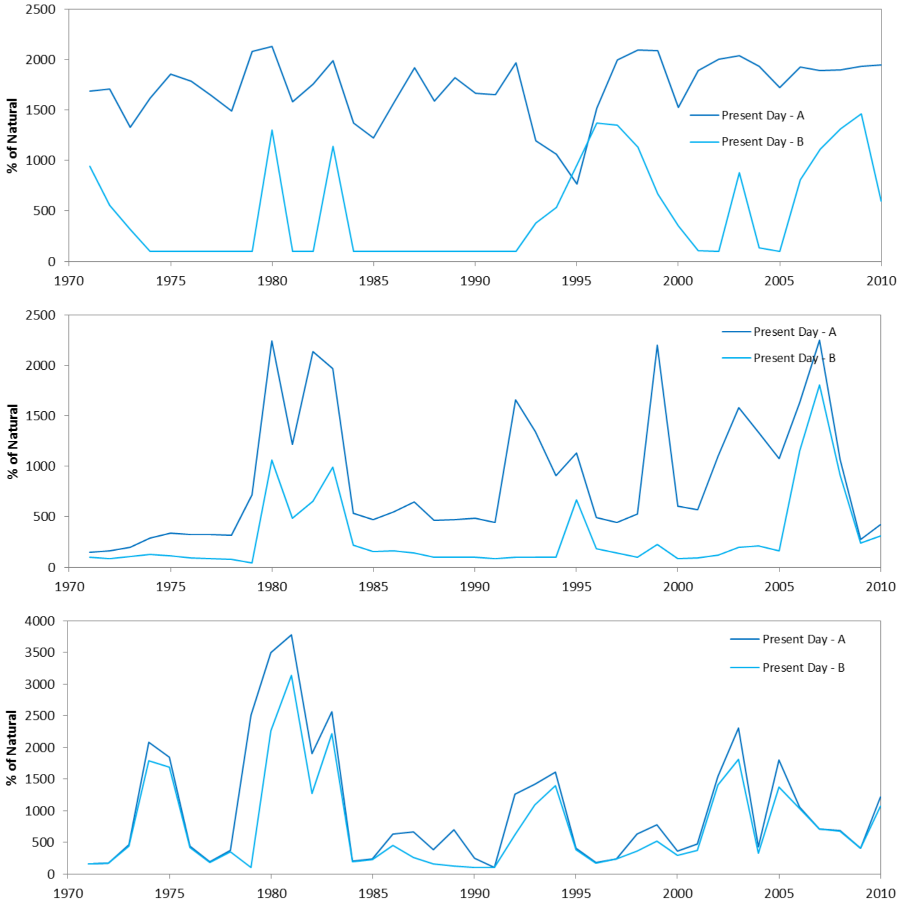


Figure 4.41. **Variation in the abundance of reeds & sedges (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

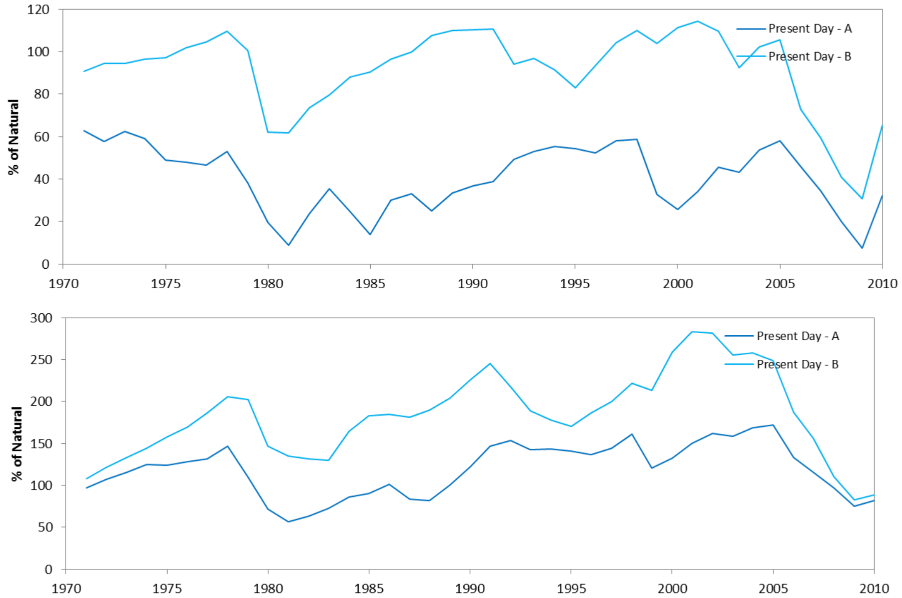


Figure 4.42. **Variation in the abundance of mangroves (% of natural) in the Narrows (top) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

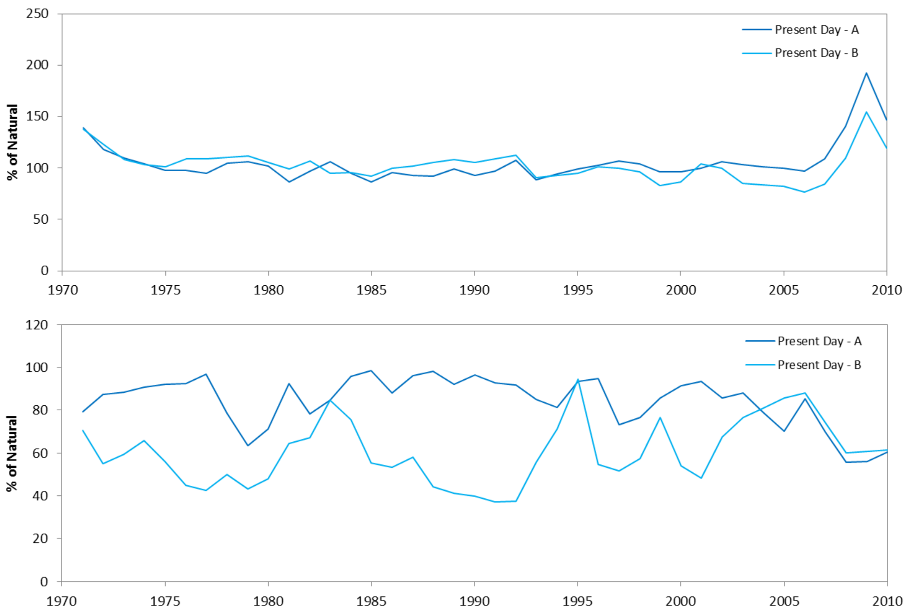


Figure 4.43. **Variation in the abundance of salt marsh (% of natural) in the Lakes (top) and Narrows (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

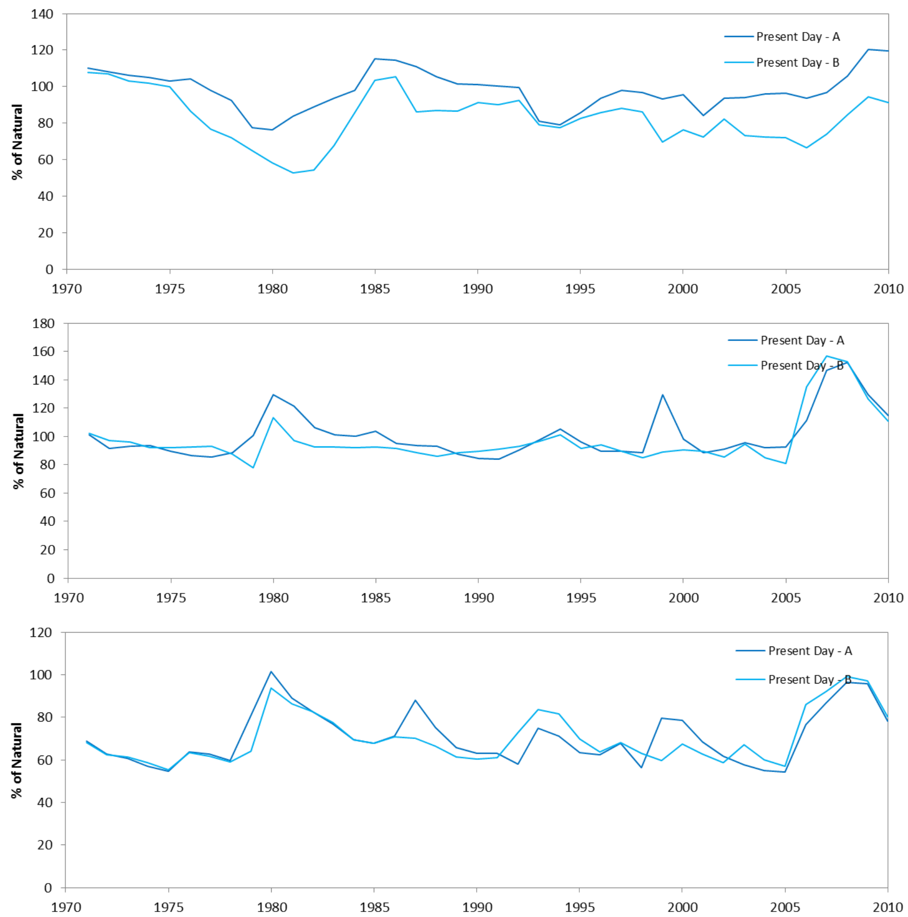


Figure 4.44. **Variation in the abundance of grass & shrubs (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

4.3.2.4 Macrophyte health scores: Present Day

Macrophyte health scores for the Lake St Lucia estuary system under present-day conditions for the Beach channel (Mouth A) and after Phase 1 excavation (Mouth B), calculated in accordance with methods prescribed for estuaries in DWA (2012), are presented in Table 4.22. The overall health scores assigned for Mouth A (with beach channel) and Mouth B (after Phase 1 excavation) were both high – 75 and 77, respectively (=B class for both). These high scores reflect a low sensitivity amongst the macrophytes to water quality changes in the Lake St Lucia system.

Table 4.22. Macrophyte health scores for the Lake St Lucia system under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

Component	Present Day - A	Present Day - B
Lakes	87	82
Narrows	61	73
uMfolozi	46	54
All	**75** **B**	**77** **B**

Confidence in the health scores assigned for macrophytes in the Lake St Lucia estuary was medium-high (80%). Moderately good historic data (mostly in the form of aerial photographs) and good present day data was available on various macrophyte groups from the estuary. Knowledge regarding the driver response relationships for estuarine macrophytes is also good.

4.3.3 Invertebrates

4.3.3.1 Brief overview of the component

Invertebrates are dominant components of both the pelagic and benthic subsystems of the Lake St Lucia estuary system. In the water column, various assemblages of planktonic and nektonic species alternate with one another in response to climatic (dry versus wet cycles) and mouth stages (closed versus open; Carrasco *et al.* 2013). The zooplankton component that spends its entire cycle in the water column (holoplankton) is, under typically estuarine conditions, dominated by two copepods, *Pseudodiaptomus stuhlmanni* and *Acartiella natalensis*, and one mysid species, *Mesopodopsis africana* (Carrasco *et al.* 2010, Jerling *et al.* 2010a, Carrasco *et al.* 2013). These are, however, temporarily replaced by other species, either of marine, freshwater or halophilic origin, whenever conditions change and their respective favourable state prevails. Those species that remain in the plankton only for the larval stages (meroplankton), are on the other hand most often dominated by bivalves, gastropods and crabs as well as polychaetes (Carrasco *et al*. 2010, Jerling *et al*. 2010a). Exceptional blooms of jellyfish have also been recorded regularly in the lake region, particularly of the rhizostomatid scyphozoan *Crambionella stuhlmanni* (Carrasco *et al.* 2013, Perissinotto *et al*. 2013).

Planktonic prawn larvae enter the Lake St Lucia system from the ocean when the estuary mouth is open, generally in the stage of post-larvae (Forbes & Forbes 2013). Once inside the estuary, they grow to juvenile and sub-adults, after which they return to the ocean to complete their growth to sexual maturity and eventually spawn. Thus, inside the estuary they are generally regarded as part of supra-benthos or the demersal nekton. Apart from the penaeid prawns, the only other prominent nektonic invertebrate that has been recorded historically (but not recently) in the Lake St Lucia system is the squid *Sepioteuthis lessoniana* (Day *et al*. 1954, Milllard & Broekhuysen 1970).

Most of the investigations on benthic invertebrates undertaken in the Lake St Lucia system have dealt exclusively with macrofauna (total body length >500 µm), however very recently some meiofaunal (63-500 µm) studies have also elucidated the critical role that smaller invertebrates play within the sediment. Among the most prominent members of the Lake St Lucia macrofauna are the polychaetes, crustaceans and molluscs, with aquatic insects also becoming important during oligohaline phases. The polychaetes are represented by a wide variety of species, among which the nereids *Ceratonereis keiskama* and *Dendronereis arborifera*, the spionids *Prionospio sexoculata* and *Polydora* sp. are very prominent, as well as the sabellid *Desdemona ornata* and the capitellid *Capitella capitata* (MacKay *et al.* 2010, Pillay *et al*. 2013). The crustaceans are most often dominated by the tanaid *Apseudes digitalis*, the amphipod *Grandidierella bonnieroides*, the cumacean *Iphinoe truncata*, the isopod *Cyathura estuaria*, the penaeid prawn *Penaeus indicus*, the caridean *Palaemon pacificus* and the brachyurans *Hymenosoma projectum*, *Paratylodiplax blephariskios*, *Scylla serrata*, *Neosarmatium africana* and *Varuna litterata* (Blaber *et al.* 1983, Pillay & Perissinotto 2008; MacKay et al. 2010; Peer *et al*. 2013). A new species of harpacticoid copepod recently described as *Nitocra taylori* (Gomez *et al.* 2012) occurs in all three lake basins under typical estuarine conditions. Under fresh/brackish water conditions, insects in the orders Coleoptera (Dytiscidae, Hydrophilidae), Hemiptera (Corixidae, Notonectidae, Nepidae, Belostomatidae) and Diptera (Chironomidae) become often dominant, with the midge *Chironomus kaffrarius*, the corixid bug *Sigara* sp. and 7-8 species of freshwater beetles having been recorded as particularly abundant on a number of occasions (Day *et al.* 1954, Grindley & Heydorn 1970, Singh 2010). The staphylinid beetle, *Bledius pilicollis*, on the other hand, was recently observed thriving under hypersaline conditions in the northern part of the system (Carrasco & Perissinotto 2012).

Among the molluscs, a wide variety of gastropods and bivalves has been reported from the Lake St Lucia system. Dominant gastropods in the Lake St Lucia system are usually *Assiminea capensis, Coriandra durbanensis, Nassarius kraussianus, Haminoea natalensis* and recently even the south-east Asian alien invasive species *Tarebia granifera* (Millard & Brokhuysen 1970; Weerts 1993; Pillay & Perissinotto 2008, Miranda *et al*. 2011a, b, Raw *et al*. 2013). The dominant bivalve species in the system have been consistently reported as *Solen cylindraceus, Brachidontes virgiliae* and *Salmacoma litoralis* (Boltt 1975, Pillay & Perissinotto 2008, MacKay *et al.* 2010), but records suggest that other species may have been very abundant within the system prior to the recent dry phase. These include the piddock *Barnea manilensis*, the oysters *Saccostrea forskahlii* and *Dendostrea sandvichensis,* as well as the recently-recorded clam *Meretrix morphina* (previously reported as *M. meretrix*) (Day *et al.* 1954; Nel *et al*. 2012). A recent census of the bivalves has shown that at least two species recorded regularly in the past within the system are actually new to science and are currently being described as *Tellinides kilburni* sp. n. (previously reported as *Tellina rousi*) and *Siliqua herberti* (previously known as *S. polita*) (Nel *et al.* 2012; Huber *et al*. in press). Another important macrafaunal species that was historically confused as “sipunculid”, has now been properly identified and described as a new, possibly micro-endemic, species of cerianthid sea-anemone, *Edwardsia isimangaliso* (Daly *et al*. 2012).

Unfortunately, the only meiofaunal surveys undertaken in the Lake St Lucia estuarine lake are very recent and cover only the period of the latest dry phase, from 2004 to 2010. During the driest part of the study, only 12 meiofaunal taxa were recorded, with nematodes, harpacticoid copepods, polychaetes and amphipods dominating total abundance (Pillay & Perissinotto 2009). Subsequent collections in the estuary showed that in the wake of the breaching event of March-August 2007 a dramatic increase in meiofaunal density and diversity occurred throughout the system. Seven additional taxa recruited into the estuary on this occasion, including two groups not previously encountered in the meiofauna of the Lake St Lucia system, the rotifers and kinorhynchs (Bownes & Perissinotto 2012, Pillay *et al.* 2013). Taxa that were identified to species and that represent new distribution records for South Africa, and for the Lake St Lucia Estuary in particular, include the kinorhynch *Echinoderes maxwelli*, the benthic rotifers *Lecane* cf. *grandis* and *Testudinella* cf. *obscura*, as well as 3 mite species: *Tyrophagus putrescientiae* (Astigmatidae); *Copidognathus africanus* and *Acarothrix umgenica* (Halacaridae). A dedicated survey of the meiofaunal Phylum Gastrotricha of the broader iSimangaliso Park was initiated in 2010 and has already led to the description of a species new to science, *Halichaetonotus sanctaeluciae,* from the Lake St Lucia Estuary mouth and possibly another four in the near future (Todaro *et al*. 2011).

Reports of invertebrate investigations in the uMfolozi section of the system are very scarce in the literature and published data has only become available recently, following the surveys undertaken during the period March 2007 to August 2008 by the University of Zululand (Jerling *et al*. 2010b, Ngqulana *et al*. 2010). The zooplankton component was dominated by a small number of species, with the copepods *Pseudodiaptomus stuhlmanni* and *Acartiella natalensis* making up 75% of the total catch. Peak densities of estuarine zooplankton occurred under closed mouth conditions, while an array of oceanic coastal species entered the estuary during open phases, reducing significantly the abundance of typical estuarine dwellers. Overall, total zooplankton abundance was lower in the uMfolozi during open mouth states (Jerling *et al*. 2010b). Invertebrate macrofaunal biomass and abundance, on the other hand, was remarkably low in the uMfolozi, both under open and closed mouth conditions. Only 17 taxa have been recorded in the recent surveys, with the polychaetes *Ceratonereis* sp., *Dendronereis arborifera* and *Capitella capitata* dominating by number along with the crab *Paratylodiplax blephariskios* and the tanaid *Apseudes digitalis*. Periodic river flooding and the unstable nature of the sediment have been suggested as the main causes underlying the low macrofaunal abundance and diversity in comparison with the much higher levels normally found within Lake St Lucia (Ngqulana *et al*. 2010).

Pelagic and benthic invertebrates can be subdivided on the basis of their broad habitat preferences and tolerance to key environmental factors into four main categories: 1) typical estuarine invertebrates; 2) marine invertebrates recruited from the ocean via tidal penetration; 3) fresh/brackish water invertebrates invading the estuarine lake during oligohaline phases; and 4) halophilic species thriving under hypersaline conditions. Defining features and typical/dominant species of/in each group are listed in Table 4.23.

Because an updated census (using worldwide group specialists and updated identification keys) of the invertebrate biodiversity of the St Lucia estuarine lake has currently been completed only for the bivalves, gastropods, copepods, brachyurans, penaeid prawns and cnidarians, the emphasis of this review was on these groups.

Table 4.23. Groups of invertebrates based on similar drivers, and their defining features

Group	Defining features, typical/dominant species
1:Benthic estuarine residents	Euryhaline species that are able to complete their life cycle within the estuary. Exhibit a wide range of feeding modes. These include: *Solen cylindraceus, Salmacoma litoralis, Tellinides kilburni, Haminoea natalensis, Nitocra taylori, Hymenosoma projectum, Neosarmatium africana, Edwardsia isimangaliso, Ceratonereis keiskama, Dendronereis arborifera, Apseudes digitalis, Grandidierella bonnieroides.*
2: Benthic marine recruits/spawners	Stenohaline species requiring periodical juvenile recruitment from the ocean. They are filter feeders, deposit feeders or detritivores. This group comprises *Paeneus indicus, Paratylodiplax blephariskios, Scilla serrata, Varuna litterata, Uca spp., Barnea manilensis* (?), *Meretrix morphina* (?), *Nassarius kraussianus* (?)
3: Benthic fresh/brackish water dwellers	Stenohaline species penetrating into the estuarine lake during periods of predominant freshwater inflow. Exhibit a wide range of feeding modes. This group is dominated by the following taxa: *Brachidontes virgiliae, Assiminea capensis, Palaemon pacificus,* chironomid midges, ditiscid beetles, corixid bugs, *Varuna litterata, Potamonautes* cf. *sidneyi.* NOTE: The alien invasive *Tarebia granifera* would also fall in this category.
4: Benthic halophilic or hypersaline obligates	Euryhaline species permanently present (?), but thriving only during hypersaline conditions when competitors are eliminated by the harsh environment. They are generally microalagal mat feeders. This group comprises *Macrostomium* sp., *Cletocamptus confluens, Coriandra durbanensis* (?) and *Bledius pilicollis.*
5:Pelagic estuarine residents	Euryhaline species that are able to complete their life cycle in the estuary. They are unselective filter-feeders. This group includes *Mesopodopsis africana, Pseudodiaptomus stuhlmanni, Acartiella natalensis, Nitocra taylori* and *Crambionella stuhlmanni* (?).
6: Pelagic marine recruits/spawners	Stenohaline species requiring periodical juvenile recruitment from the ocean. They are unselective filter-feeders. This group is normally dominated by *Paeneus indicus, Corycaeus* spp. and *Paracalanus* spp. and occasionally/locally by *Noctiluca scintillans* and *Oikopleura dioica.*
7: Pelagic fresh/brackish water dwellers	Stenohaline species penetrating into the estuarine lake during periods of predominant freshwater inflow. They are normally unselective filter-feeders and include as dominants *Moina* cf. *micrura, Diaphanosoma* cf. *excisum, Diaptomus* spp. and *Cyclops* spp.
8: Pelagic halophilic or hypersaline obligates	Euryhaline species permanently present (?), but thriving only during hypersaline conditions when their competitors are eliminated by unfavourable conditions. They are unselective filter-feeders and include *Fabrea* cf. *salina* and *Apocyclops* cf. *dengizicus.*

4.3.3.2 Key drivers

The main controlling factors of invertebrate abundance/biomass and diversity are summarised in Table 4.24.

Table 4.24. The main controlling factors of invertebrate abundance/biomass and diversity in the Lake St Lucia system

Group	Key drivers			Other influencing factors
1:Benthic estuarine residents	Mean Salinity *Most species exhibit salinity tolerance thresholds of 10-15 and 60-65*	Suspended Silt *Significant mortality occurs after prolonged exposure at silt concentrations above 2.6 g/L, equivalent to turbidity levels of approx. 1000 NTU*	Open Mouth (% time) *Prolonged open mouth leads to competitors entering from the ocean, while closed mouth may lead to desiccation and fragmentation of the system when combined with drought conditions*	Temperature; food availability as particulate organic matter (detritus, microalgae, zooplankton); gain/loss of special habitats (e.g. macrophytes, Mangroves)
2: Benthic marine recruits/ spawners	Mean Salinity *Most species exhibit salinity tolerance thresholds of 20 and 60, excluding Varuna litterata which migrates to freshwater*	Open Mouth (% time) *Success directly proportional to the amount of time the mouth remains open*	Suspended Silt *Significant mortality occurs after prolonged exposure at silt concentrations above 2.6 g/L, equivalent to turbidity levels of approx. 1000 NTU*	Temperature; food availability as particulate organic matter (detritus, microalgae, zooplankton) and habitats such as macrophytes and Mangroves
3: Benthic fresh/brackish water dwellers	Mean Salinity *Threshold levels are generally around 15-25, but the alien invasive Tarebia granifera can survive for few months up to 30*	Suspended Silt *Not much information available, but Significant mortality and depressed grazing rates are expected at turbidity levels above 1000 NTUs*	Submerged area A simple linear relationship should apply between macrobenthic density and substratum availability.	Temperature (?), Food availability as particulate organic matter (detritus, microalgae, zooplankton) macrophytes, Epiphytes and epibenthic prey
4: Benthic halophilic or hypersaline obligates	Mean Salinity *The thresholds of peak concentrations are at about 75-80 and 130. Above 130 resting stages are formed, while below 75, abundance drops dramatically*	Open Mouth (% time) *Ideal conditions are obtained under prolonged periods of mouth closure, with high evaporative losses and little freshwater inflow*	Suspended Silt *Significant mortality occurs after prolonged exposure at silt concentrations above 2.6 g/L, equivalent to turbidity levels of approx. 1000 NTU*	Temperature (?); food availability as particulate organic matter (mainly cyanobacteria mats) and mucilage
5:Pelagic estuarine residents	Mean Salinity *Tested species exhibit salinity tolerance thresholds*	Suspended Silt *significant effects on both feeding and mortality occurs after*	Open Mouth (% time) *Prolonged open mouth leads to competitors entering*	Food availability as phytoplankton & microphytobenthos abundance and

Group	Key drivers			Other influencing factors
	of about 5 and 40, but in situ survival extends to salinities of 2.5 and 65, with obvious sub-lethal effects.	*prolonged exposure above silt concentrations equivalent to turbidity of approx. 500 NTU*	*from the ocean, while closed mouth causes hypersaline or freshwater conditions to prevail*	production
6: Pelagic marine recruits/spawners	Mean Salinity *Although, no local experiments have been conducted, most species are expected to exhibit salinity tolerance thresholds of 15-20 and 60-65*	Open Mouth (% time) *Success directly proportional to the amount of time the mouth remains open*	Suspended Silt *significant effects on both feeding and mortality occur after prolonged exposure above silt concentrations equivalent to turbidity of approx. 500 NTU*	Turbidity (?); food availability as phytoplankton & microphytobenthos biomass and production as well as zooplankton prey
7: Pelagic fresh/brackish water dwellers	Mean Salinity *Threshold levels are generally around 15-25*	Suspended Silt *Decreased filtering rates in Daphnia spp. have been observed above 10 NTU and mortality in freshwater copepods above approx. 500 NTU*	Water volume A simple linear relationship should apply between zooplankton density and water volume availability.	Food availability as phytoplankton & microphytobenthos biomass and production as well as zooplankton prey
8: Pelagic halophylic or hypersaline obligates	Mean Salinity *The thresholds of peak concentrations are at about 75-80 and 130. Above 130 resting stages are formed, while below 75, abundance drops dramatically*	Open Mouth (% time) *Ideal conditions are obtained under prolonged periods of mouth closure, with high evaporative losses and little freshwater inflow*	Suspended Silt *Mortality in copepods is expected only above approx. 500 NTU.*	Turbidity (?); food availability as phytoplankton & microphytobenthos biomass and production, particularly cyanobacteria (e.g. *Cyanothece* sp.); competition with estuarine/marine species

4.3.3.3 Invertebrate abundance – Present Day and Reference condition

Summary statistics on the abundance of invertebrates under present-day conditions (Beach channel and after Phase 1 excavation options) are presented in Table 4.21 and time series data for the period 1971-2010 are presented in Figure 4.37-Figure 4.44. Abundance of marine and estuarine species were very much lower than Reference under Mouth A due to limited opportunities for recruitment under this scenario, but improved dramatically under Mouth B with increased tidal prism. Freshwater species were similar for the two scenarios while halophylic species (which are only found in the Lakes) increased above Reference level under Mouth B due to increased hypersalinity for this scenario.

Table 4.25. Simulated invertebrate abundance (% of natural) in the Lakes (at Lister's Point), Narrows (at Honeymoon Bend) and the uMfolozi for the period 1971 to 2010 under reference and present-day conditions (Mouth A – Beach channel and Mouth B – after Phase 1 excavation) conditions.

Hydrological scenario/Mouth option	Invertebrate group	% of Reference		
		Lakes	Narrows	uMfolozi
Present (Mouth A - with beach channel)	Benthic estuarine	41.4	20.8	102.8
	Benthic marine	27.5	23.0	71.0
	Benthic freshwater	93.8	109.6	80.9
	Benthic halophilic	96.9	-	-
	Pelagic estuarine	39.3	20.5	102.0
	Pelagic marine	26.3	22.9	114.3
	Pelagic freshwater	91.5	110.8	75.3
	Pelagic halophilic	99.0	-	-
Present (Mouth B – after Phase 1 excavation)	Benthic estuarine	81.5	85.6	105.6
	Benthic marine	80.0	83.4	75.2
	Benthic freshwater	89.2	78.4	67.5
	Benthic halophilic	139.1	-	-
	Pelagic estuarine	78.1	85.9	108.3
	Pelagic marine	78.2	89.9	125.3
	Pelagic freshwater	76.9	83.1	64.7
	Pelagic halophilic	179.8	-	-

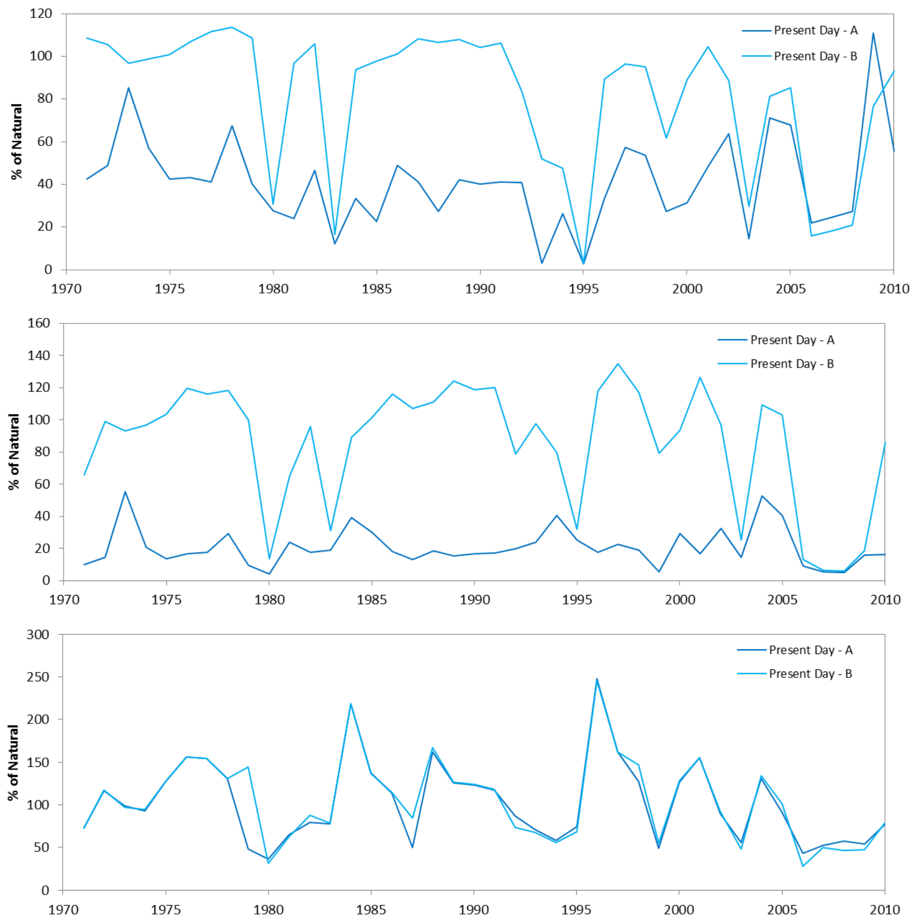


Figure 4.45. **Variation in the abundance of benthic estuarine invertebrates (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

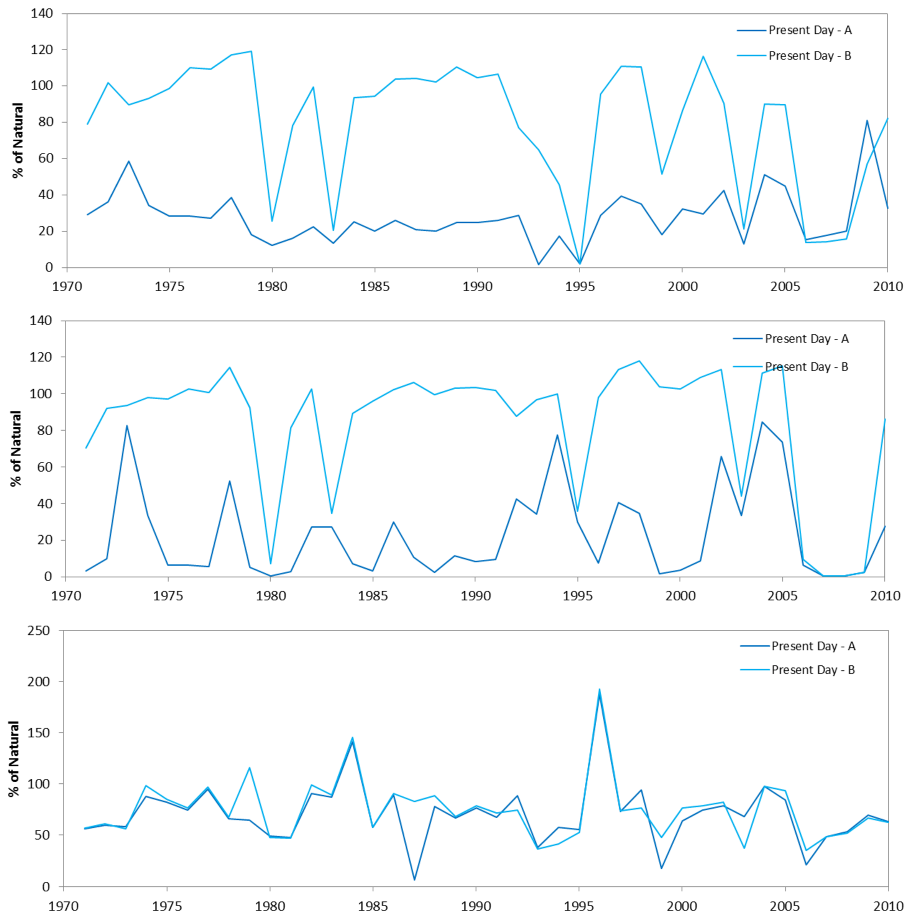
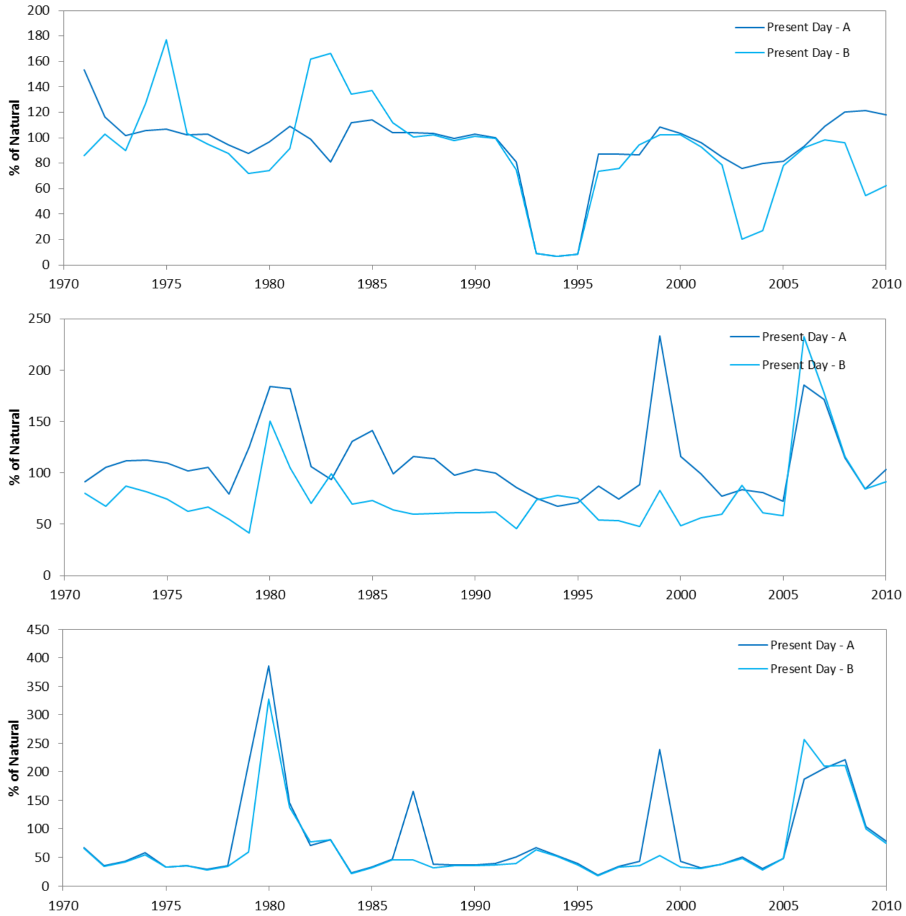


Figure 4.46. **Variation in the abundance of benthic marine invertebrates (% of natural) in the Lakes (top) and Narrows (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**



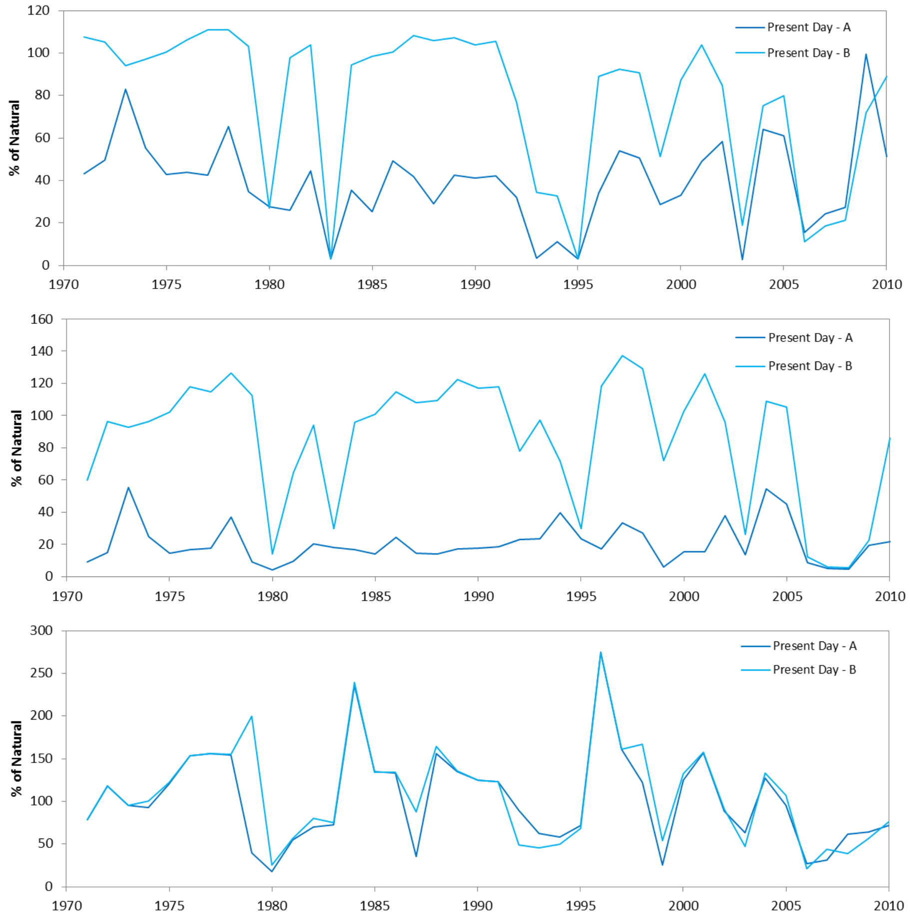


Figure 4.47. **Variation in the abundance of benthic freshwater invertebrates (% of natural) in the Narrows (top) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

Figure 4.48. **Variation in the abundance of pelagic estuarine invertebrates (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

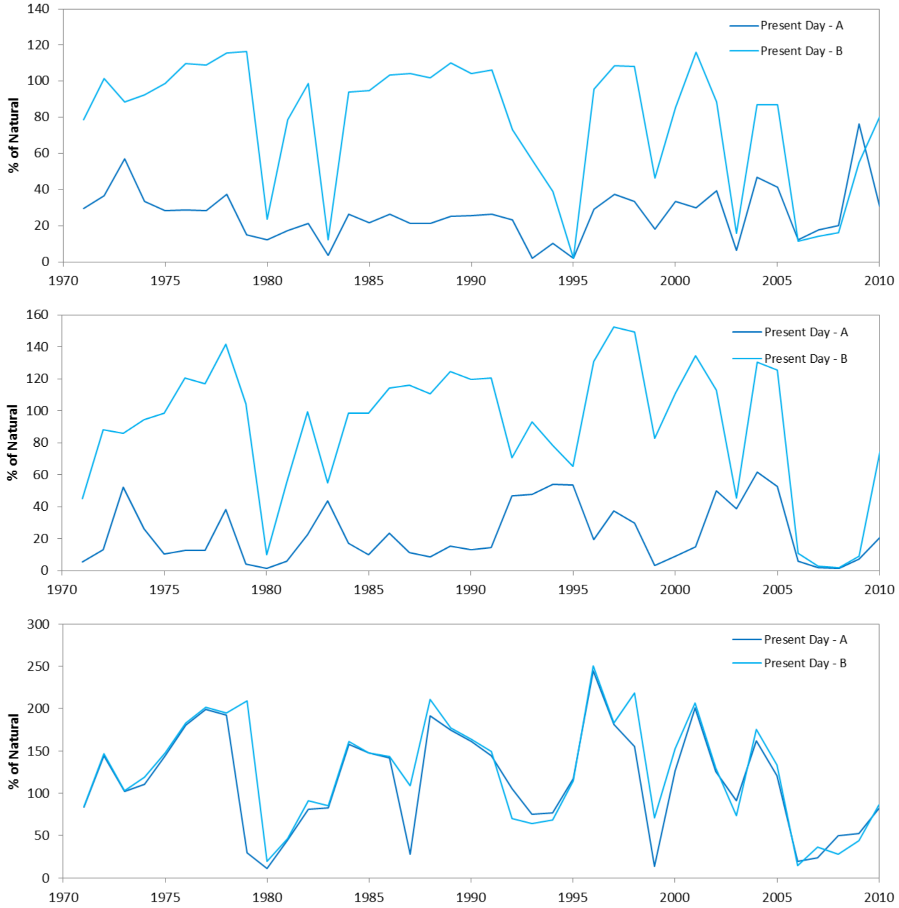


Figure 4.49. **Variation in the abundance of pelagic marine invertebrates (% of natural) in the Narrows (top) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

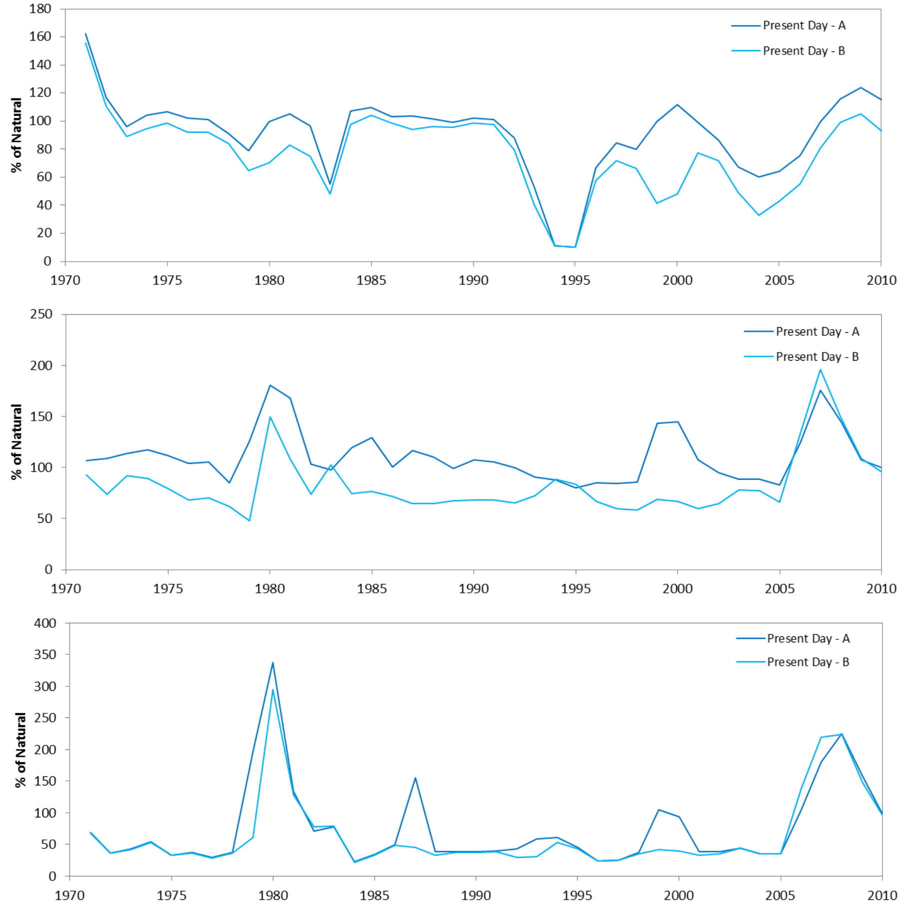


Figure 4.50. **Variation in the abundance of pelagic freshwater invertebrates (% of natural) in the Lakes (top) and Narrows (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

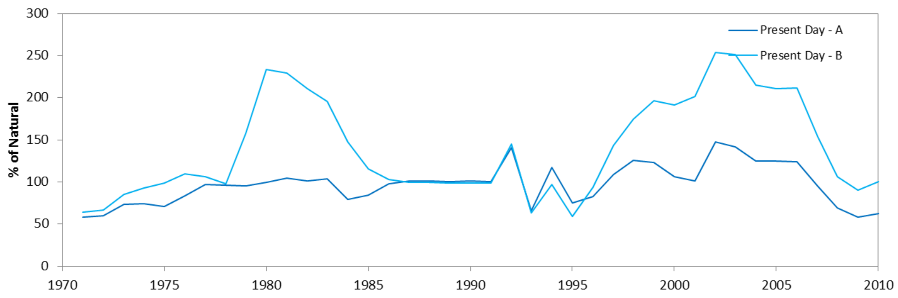


Figure 4.51. **Variation in the abundance of benthic halophilic invertebrates (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

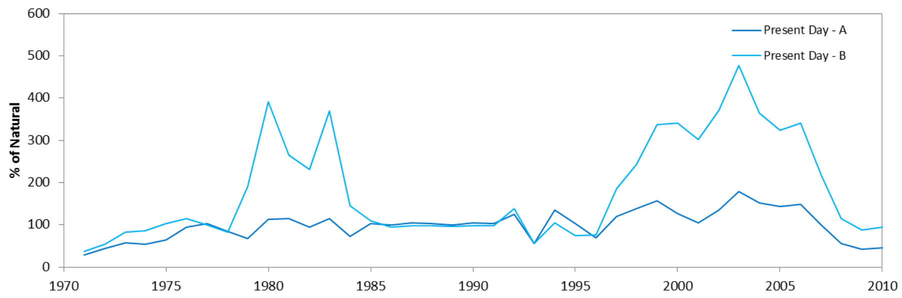


Figure 4.52. **Variation in the abundance of pelagic halophylic invertebrates (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

4.3.3.4 Invertebrates health scores: Present Day

Invertebrates health scores for the Lake St Lucia estuary system under present-day conditions for the Beach channel (Mouth A) and after Phase 1 excavation (Mouth B), calculated in accordance with methods prescribed for estuaries in DWA (2012), are presented in Table 4.26. The overall health score assigned for Mouth A (with beach channel) was low (31 = E Class) but was somewhat better (46 = D class) for Mouth B (after Phase 1 excavation). These low scores reflect a high sensitivity amongst the invertebrates to changes in hydrodynamic functioning (mouth state and tidal prism) and changes in water quality (salinity and turbidity) in the Lake St Lucia system.

Table 4.26. Invertebrates health scores for the Lake St Lucia system under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

Component	Present Day - A	Present Day - B
Lakes	32	45
Narrows	23	46
uMfolozi	52	56
All	**31** **E**	**46** **D**

Confidence in the health scores assigned for invertebrate communities in the Lake St Lucia estuary under present day conditions was medium-low (60%) owing to the paucity of data available on abundance and community composition of these organisms in the system as a whole, especially for the earlier periods (i.e. pre-1980).

4.3.4 Fish

4.3.4.1 Overview

Historically the Lake St Lucia Estuarine System and the uMfolozi-uMsunduzi estuary both shared a common mouth to the sea via St Lucia Bay (Whitfield *et al*. 2013). However, they have been anthropogenically separated for more than 50 years and most researchers who have studied the fish in this system present information for the St Lucia Narrows and Lakes separately from the uMfolozi system which is the convention that has been followed here. It is important to recognise though that the Lake St Lucia estuarine lake system is ultimately one greater estuarine system, the parts of which are integrally linked to one another (or certainly were in the past).

Lake St Lucia is classified as an “estuarine lake’, one of only four of its kind in South Africa (Whitfield, 1992). The generalized physical characteristics of estuarine lakes are that they have a negligible tidal prism, mixing within these systems is wind driven, and salinities range from 1 to 35. However, spatial and temporal salinities within estuarine lakes vary from oligohaline to hypersaline (Cyrus *et al*., 2011, Taylor, 1982). Their fish fauna is dominated by marine and estuarine species, although some freshwater species increase in abundance during prolonged oligohaline periods (Whitfield, 1980).

A research assessment of Lake St Lucia undertaken by Cyrus (1989) indicated that fish were the most studied group and that the level of understanding of this group was excellent. Since then this has been added to, particularly over the last decade, during which time the mouth has been closed for an extended period. Salinities in the system reached beyond 200 in False Bay during December 2003, this being an all-time high, while lake levels dropped to an all-time low in July 2006, when only 10% of the 350 km^2 surface area of the lake was covered by water.

The uMfolozi was classified by Whitfield (1992) as a River Mouth Estuary, one that has high freshwater outflow and which remains permanently open to the sea. However changes in flows from the catchment have resulted in winter mouth closures being of regular occurrence. In addition, an extremely high sediment load is brought down by the river to the estuary and this has a profound influence on this component of the greater Lake St Lucia estuarine system. Limited data are available on the biota of the system, most emanating from 2007 onwards (Cyrus *et al.*, 2010b).

4.3.4.2 Species diversity

Earliest studies on the fish fauna of the Lake St Lucia were undertaken by Day *et al.* (1954) and Millard and Broekhuysen (1970) and the first checklist for the system was produced by Whitfield (1980). To date a total of 155 species of fish (Cyrus 2013) have been recorded in Lake St Lucia, but their occurrence and distribution within the system changes according to the salinity state that it is in at the time. This can cycle from virtually fresh to hypersaline over a period of years. In addition, due to its large size, a wide range of salinities can be present within the system at any one time. As a consequence, diversity and density of fish species is extremely variable. Furthermore, restriction of the connection to the sea and reduced river inflow also influence occurrence and distribution within the lake.

Species diversity in the uMfolozi is nowhere near that of the Lake St Lucia system, with only some 60+ species having been recorded. Density of fish in the system is also low (Vivier *et al*. 2009 & 2010a & b).

4.3.4.3 Species origins and fish assemblages

Whitfield (1994) has classified fish species occurring in estuaries based on their origins and life cycle linkages to estuaries. His classification comprises five categories. Of the 155 fish species recorded in the Lake St Lucia system, 43% are marine species which are not dependent on estuaries for any specific part of their life cycle (Category III) and 35% are euryhaline marine species which breed at sea with their juveniles showing varying degrees of dependence on estuaries for part of their life cycle (Category II). Thirteen percent are estuarine species, which breed in these systems (Category I), 6% euryhaline freshwater species some of which may breed in estuarine as well as freshwater (Category IV), and 3% are obligate catadromous species which use estuaries as transit routes between the marine and freshwater environments (Category V).

The fish fauna of the Lake St Lucia system based on their origins and dependence on estuaries (Whitfield 1998) is as follows:-

Category I	Estuarine Resident Species which breed in estuaries (21 species),
Category II	Euryhaline Marine Species which breed at sea but with juveniles that show varying dependence on estuaries (51 species),
Category III	Marine Species which occur in estuaries in small numbers but are not dependant on these systems (69 species),
Category IV	Euryhaline Freshwater Species (10 species), and
Category V	Obligate Catadromous Species which use estuaries as transit routes between the marine and freshwater environments (4 species).

Species origins and composition of fish in the uMfolozi are very similar to those of Lake St Lucia with the same categories present (Vivier *et al*., 2010b).

4.3.4.4 Trophic levels and feeding groups

Due to the large number of habitats that occur in a system as large as Lake St Lucia, it is not surprising that a wide range of feeding groups are present. However, the bulk of species (Category II and III) coming in from the sea as larvae or post larvae, initially feed on individual zooplankters, until reaching 20 to 30 mm in size at which point they tart switching to their juvenile/adult mode of feeding (Cyrus and Blaber, 1983a & b; Blaber, 1977, 1984; Blaber and Whitfield, 1977; Martin and Blaber, 1983; Martin, 1989; Whitfield, 1985).

Whitfield (1980b) produced the first food web for Lake St Lucia based on data collected during 1975-76. Subsequently Blaber (1997) identified five major trophic groups as being present in the Lake St Lucia System, these are as follows:

1. **Benthic Invertebrate Feeders –** with the dominant species including *Pommadasys commersonni, P. kaakan, Acanthopagrus vagus* (previously *A. berda*)*, Solea turbynei* (previously *S. bleekeri*), *Gerres methueni, G. acinaces* and *Rhabdosargus sarba,* which feed on surface and subsurface benthos (Blaber, 1982a, 1984; Cyrus, 1988b, 1991a; Cyrus and Blaber, 1982, 1983a, b; Wallace 1975a).
2. **Planktivores -** there are essentially two groups present in Lake St Lucia, the pelagic planktivores that filter feed by straining the plankton out of the water through the gill rakers, and include *Hilsa kelee, Thryssa vitrirostris* and *Gilchristella aestuaria* (Blaber, 1979; Blaber *et. al.*, 1981) and those that individually select out zooplankters. This latter group, either take their prey in the water column (*Ambassis ambassis, A. natalensis, A. dussumieri* (previously *A. gymnocephalus*) and *Hippichthys heptagonus*) (Martin and Blaber, 1983) or take them whilst they are resting near or at the bottom of the estuary,

such as is done by *Leiognathus equulus*. This latter species feeds almost exclusively on the zooplankter *Pseudodiaptomus stuhlmanni,* which during the day is closely associated with the benthos (Nhleko, 2011; Nhleko *et. al.*, 2012).

3. **Piscivores –** including *A. japonicus, Caranx ignobilis, C. sexfaciatus, Platycephalus indicus, Lichia amia, Muraenesox bagio, Sphyraena jello* and *Otolithes ruber*, which feed on other fish (Blaber, 1982b; Blaber and Cyrus, 1983; Whitfield and Blaber, 1978a).
4. **Omnivorous Species –** including 10 species of mullet with *Liza macrolepis, L. dumerilii, M. cephalus, Valamugil buchanani* and *V. cunnesius* being the most abundant (Blaber, 1976, 1977; Whitfield and Blaber, 1978a, c). The freshwater tilapia *O.mossambicus*, essentially a detritivore, which dominates the system under hypersaline conditions (Cyrus and Vivier, 2006a & b; Vivier *et. al.*, 2010a; Cyrus *et. al.,* 2010a), also falls into this group, as does the milkfish *Chanos chanos* (Whitfield and Blaber, 1978d).
5. **Epiphytic grazers –** with only one species, *R. holubi* which uses this feeding mode for the first year of its life, thereafter moving out to sea and switching to a diet dominated by bivalve molluscs (Blaber, 1974).

The distribution of members of these feeding groups is determined to a large extent by substrata, with the benthic feeding species being partitioned between sandy and muddy substrata. Filter feeders are found throughout, but appear to be present in greater numbers in the more turbid areas of the system. The predators are largely partitioned based on their mode of feeding, some showing preference for the more turbid areas (chemosensory predators) and others clear water areas (visual predators).

Blaber (1997) provided a summary of the fish community food web based on percentage contribution to biomass. He found that the planktivores make up the largest component, at 38%, with the benthic invertebrate feeders and iliophagous species each contributing 21% of the biomass and piscivores 17%. *Rhabodosargus holubi,* the only epiphytic grazer, contributed the remaining 3%. The dominance by planktivores can be related to the high plankton productivity in Lake St Lucia, which is more than an order of magnitude higher than most other KwaZulu-Natal estuaries (Blaber, 1979; Blaber *et. al.*, 1981; Allanson and van Wyk, 1969). However, there are also major contributions from benthic invertebrate feeders and iliophagous species. From the data presented it can be concluded that the Lake St Lucia system fish food web is both phytoplankton and detritus driven.

Whilst a similar set of feeding groups to those found in Lake St Lucia are present in the uMfolozi, it appears that the system is unable to sustain them in any density once they have passed the post larval stage. Vivier & Cyrus (2009, 2010b) have shown that when most of the euryhaline marine feeding groups reach the size where they switch from a planktivorous mode of feeding to their adult food preference (e.g. benthos), there is a large drop off in the densities of these fish present in the system. This indicates that the successful recruitment recorded cannot be maintained through the required tenure of this part of the life cycle. The benthic fauna has also been noted to be significantly below the densities and species diversity recorded in Lake St Lucia (Ngqulana *et al.*, 2010 & Owen *et al*., 2010).

4.3.4.5 Division of the component into groups

For the purpose of this study, the species of the Lake St Lucia Estuary System were divided into four groups with subdivisions in each group as listed in Table 4.27. These groups equate to Whitfield's (1998) Categories 1, 2, 4 and 5. Whitfield's Group III was not considered as they are species that occur in very small numbers and have no real association with the estuarine environment. Table 4.27 lists the four Groups as well as the dominant species in each.

Table 4.27. Fish groups and sub-groups found in the Lake St Lucia Estuarine System.

Group & Subgroups	Key/Dominant Species
Estuarine Resident Species	
Resident Planktivores	*Gilchristella aestuaria, Ambassis ambassis, A.natalensis, A.dussumieri* (previously *A.gymnocephalus*), *Atherina breviceps, Hippichthys heptagonus* & *Leiognathus equulus* (plankton taken whilst they are resting near or at the bottom of the estuary)
Resident Benthivores	*Glossogobius callidus, G.tenuiformis, Taenioides jacksoni, Croilia mossambica Periophthalmus kalolo & P.argentilineatus*
Euryhaline Marine Species	
Marine Planktivores	*Hilsa kelee, Thrysa vitrirostris & Stolephorus holodon*
Marine Benthivores	*Pomadasys commersonni, P.kaakan, Acanthopagrus vagus* (previously *A.berda*), *Solea turbynei* (previously *S.bleekeri*), *Gerres methueni, G.filamentosus, G. longirostris* & *Rhabdosargus sarba,*
Marine Omnivores	*Liza macrolepis, L.dumerilii, M.cephalus, Valamugil buchanani, V.cunnesius* & *Chanos chanos*
Marine Piscivores	*Argyrosomus japonicus, Caranx ignobilis, C.sexfasciatus, Elops machnata, Platycephalus indicus, Lichia amia, Muraenesox bagio, Sphyraena jello, Otolithes ruber*, *Lutjanus argentimaculatus, L.fulviflamma Scomberoides lysan, Pomatomus saltatrix* & *Strongylura leiura*
Euryhaline Freshwater Species	
Freshwater Benthivores	*Glossogobius giuris, Awaous aeneofuscus, Pseudocrenilabrus philander, Barbus paludinosus* & *B.viviparus,*
Freshwater Detritivores	*Oreochromis mossambicus*
Freshwater Piscivores	*Clarius gariepinus*
Catadromous Species	
Catadromous Detritivores	*Myxus capensis & Liza alata*
Catadromous Piscivores	*Megalops cyprinoides, Anguilla mossambica & A. bicolor*

Whilst a substantial amount of information exists on the diversity and density of Lake St Lucia and uMfolozi fish there is virtually no quantitative data on biomass. As a result the species composition and density of each group was determined for each zone based on published data and converted to percentage contribution to each of the 11 sub-groups.

These groups were then weighted based on the sizes attained by members in the group and this was used as a proxy for biomass in the calibration of the response curves. The relative contribution made by each group to overall fish abundance in the lakes, Narrows and uMfolozi is listed in Table 4.28.

Table 4.28. Relative contribution (%) to overall fish biomass by the various sub-groups of fish in the Lakes, Narrows and uMfolozi

Subgroups	Lakes	Narrows	uMfolozi
Resident Planktivores	4.00	5.00	20.5
Resident Benthivores	4.00	5.00	2.0
Marine Planktivores	6.05	7.80	10.0
Marine Benthivores	18.70	24.20	20.0
Marine Omnivores	21.70	26.60	30.0
Marine Piscivores	10.90	12.00	10.0
Freshwater Benthivores	0.95	0.48	1.0
Freshwater Detritivores	30.10	16.84	5.0
Freshwater Piscivores	0.95	0.48	1.0
Catadromous Detritivores	1.70	1.00	0.0
Catadromous Piscivores	0.95	0.60	0.5

4.3.4.6 Key drivers of the fish community in the system

Six key drivers were identified as being the most important in influencing species abundance in the system. They are listed in **Error! Reference source not found.**, which also provides an indication of the influence they exert on each of the 11 fish groups that have been identified.

Table 4.29. Influence of abiotic characteristics and processes, as well as other biotic components on fish groupings (empty box = no or negligible influence) Note: Fish availability for Piscivores not built into Drift estuary model.

Group		Key drivers					
		Salinity tolerance	Tidal Prism	Food Availability	Volume	Fresh Water Inflow	Turbidity
Estuarine Resident Species	Estuarine Planktivores	*Most species exhibit salinity tolerance thresholds of 5-10 and 60-65*		*Zooplankton availability influences these species*	*Reduced lake volumes have a negative influence while increased volumes provide opportunity for increases*		*The distribution of most species is influenced at thresholds of either above or below 80-100 NTU*
	Estuarine Benthivores			*Benthic & Epibenthic food availability influences these species*			
Euryhaline Marine Species	Marine Planktivores	*Most species exhibit salinity tolerance thresholds of 10-15 and 60-65*	*Densities in the system are influenced by the extent of the connection to the marine environment. This is directly related to size of the tidal prism.*	*Zooplankton availability influences these species*	*Reduced lake volumes have a negative influence on this group*		*The distribution of most species are influenced at thresholds of either above or below 80-100 NTU*
	Marine Benthivores			*Benthic & Epibenthic food availability influences these species*			
	Marine Detritivores						
	Marine Piscivores						
Euryhaline Freshwater Species	Freshwater Benthivores	*Most species exhibit salinity tolerance thresholds of 10-15 but some up to 40*		*Benthic & Epibenthic food availability influences these species*	*Reduced lake volumes have a negative influence while increased volumes provide opportunity for increases*	*Reduced freshwater inflows have a negative effect on this group whilst increases have a small positive effect*	
	Freshwater Omnivores	*The single species exhibits an extreme tolerance to salinity*					

Group	Key drivers						
	Salinity tolerance	**Tidal Prism**	**Food Availability**	**Volume**	**Fresh Water Inflow**	**Turbidity**	
Catadromous Species	Catadromous Detritivores Catadromous Piscivores		*Densities passing through the system are influenced by the extent of the connection to the marine environment. This is directly related to size of the tidal prism.*			*Reduced freshwater inflows have a negative effect on this group whilst increases have a positive effect*	
References		Cyrus *et al.* (2010a), Forbes & Cyrus (1993), Whitfield & Blaber (1979c), Whitfield *et al.* (1981 & 2006)		Blaber (1984), Blaber & Cyrus (1983), Blaber *et al.* (1981 & 1983), Cyrus (1988a), Cyrus & Blaber 1983a & b), Jerling *et al*. (2010 & 2011), MacKay *et al.* (2010), Ngqulana *et al.*(2010), Nhleko (2011), Nhleko *et al.* (2012) Owen *et al.* (2010) Whifield & Blaber (1978a & b)		Whitfield & Taylor (2009)	Cyrus (1987, 1988b & c, 1992), Cyrus & Blaber (1987a, b & c, 1992)

4.3.4.7 Fish abundance – Present Day and Reference condition

Summary statistics on the abundance of fish under present-day conditions (Beach channel and after Phase 1 excavation options) are presented in Table 4.30 and time series data for the period 1971-2010 are presented in Figure 4.53-Figure 4.63. Abundance of marine and catadromous species was very much lower than Reference with the Beach channel in place (Mouth A) but improved dramatically under the combined mouths configuration (Mouth B) due to opportunities for recruitment. The reverse was true for the resident and freshwater species, a trend that was clearly linked to conditions being more saline under the latter scenario.

Table 4.30. Simulated fish abundance (% of natural) in the Lakes (at Lister's Point), Narrows (at Honeymoon Bend) and the uMfolozi for the period 1971 to 2010 under reference and present-day (Mouth A – Beach channel and Mouth B – after Phase 1 excavation) conditions.

Hydrological scenario	Groupo	% of Reference		
		Lakes	Narrows	uMfolozi
Present (Mouth A - with beach channel)	Resident planktivore	97.4	62.7	88.7
	Resident benthivore	36.4	45.7	91.5
	Marine planktivore	26.5	24.6	64.7
	Marine benthivore	30.6	16.5	43.5
	Marine omnivore	33.4	28.8	103.4
	Marine piscivore	32.8	46.3	78.3
	Freshwater benthivore	33.6	37.5	46.6
	Freshwater detritivore	89.5	88.8	94.9
	Freshwater piscivore	66.6	91.6	82.5
	Catadromous detritivore	26.5	32.4	75.1
	Catadromous piscivore	28.4	32.3	75.1
Present (Mouth B – after Phase 1 excavation)	Resident planktivore	85.5	85.4	89.4
	Resident benthivore	75.5	82.6	95.7
	Marine planktivore	62.3	78.1	73.2
	Marine benthivore	59.6	64.9	46.4
	Marine omnivore	69.6	42.1	114.8
	Marine piscivore	59.4	44.8	86.8
	Freshwater benthivore	60.9	66.0	46.3
	Freshwater detritivore	85.9	72.0	90.2
	Freshwater piscivore	50.2	46.8	69.0
	Catadromous detritivore	54.3	65.0	82.9
	Catadromous piscivore	57.4	64.8	82.9

Figure 4.53. **Variation in the abundance of resident planktivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

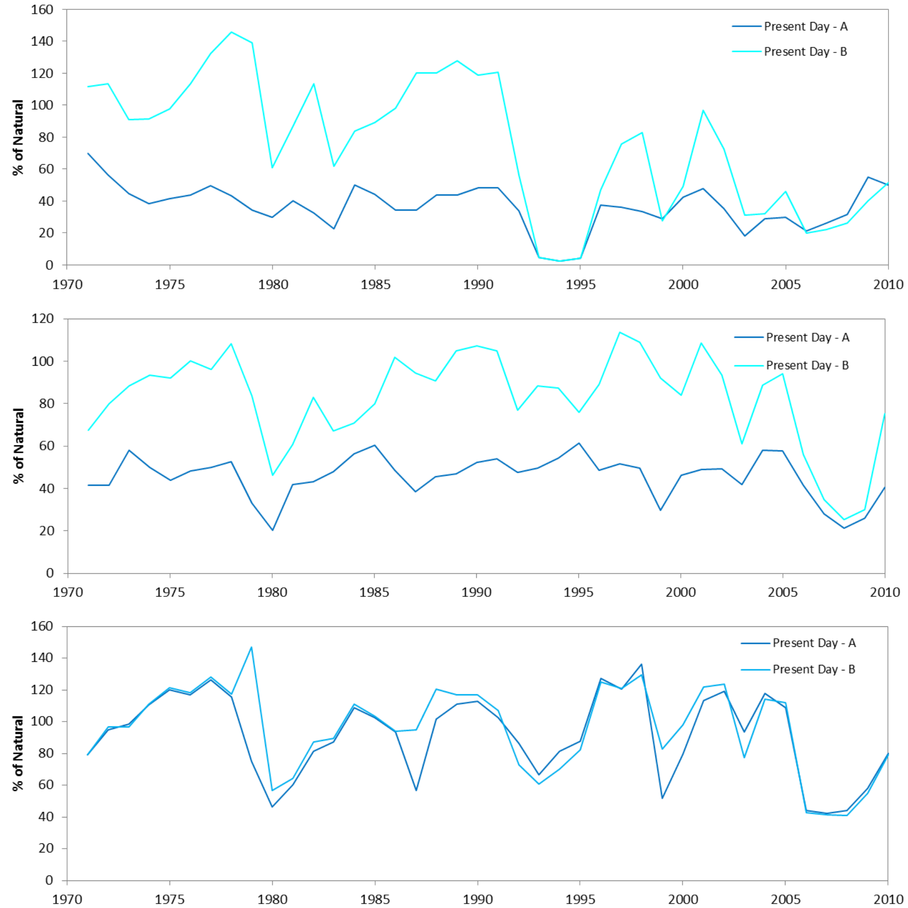


Figure 4.54. **Variation in the abundance of resident benthivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

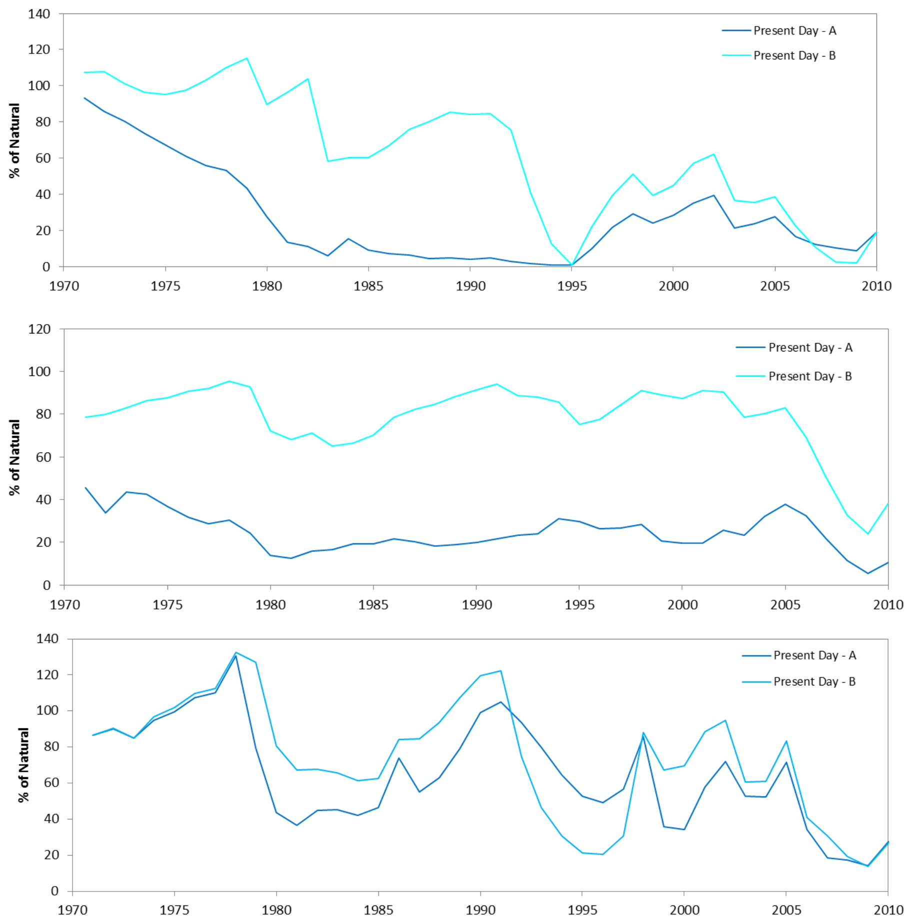


Figure 4.55. **Variation in the abundance of marine planktivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

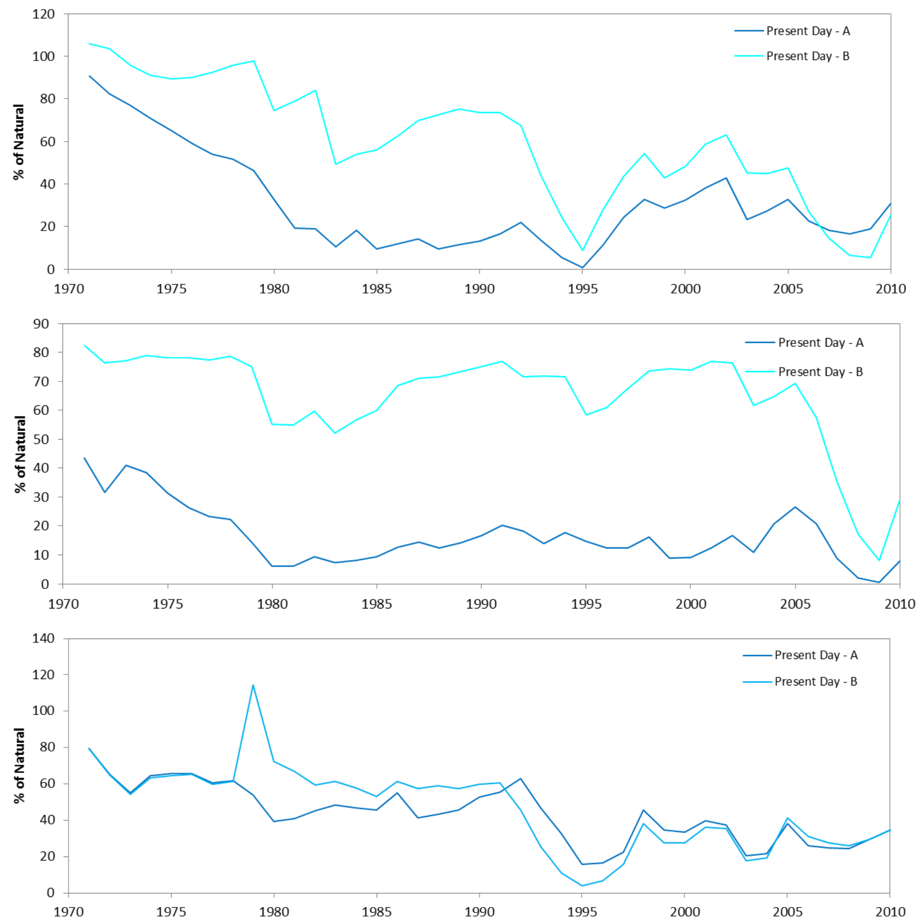


Figure 4.56. **Variation in the abundance of marine benthivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

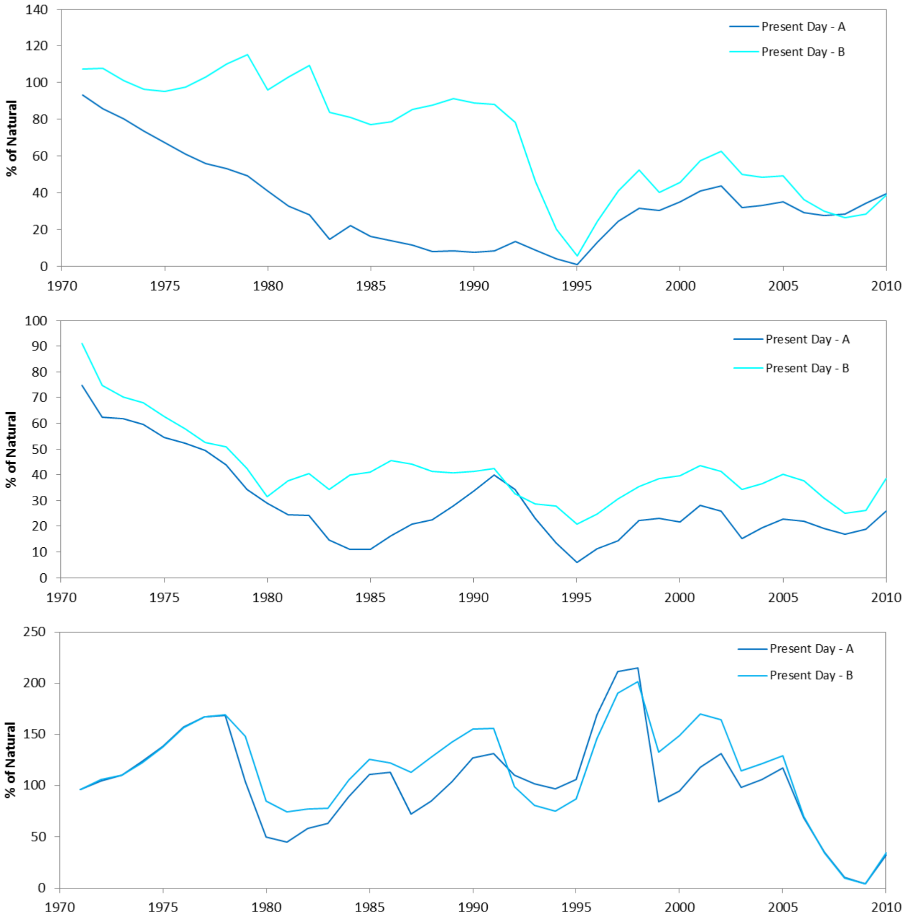


Figure 4.57. **Variation in the abundance of marine omnivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

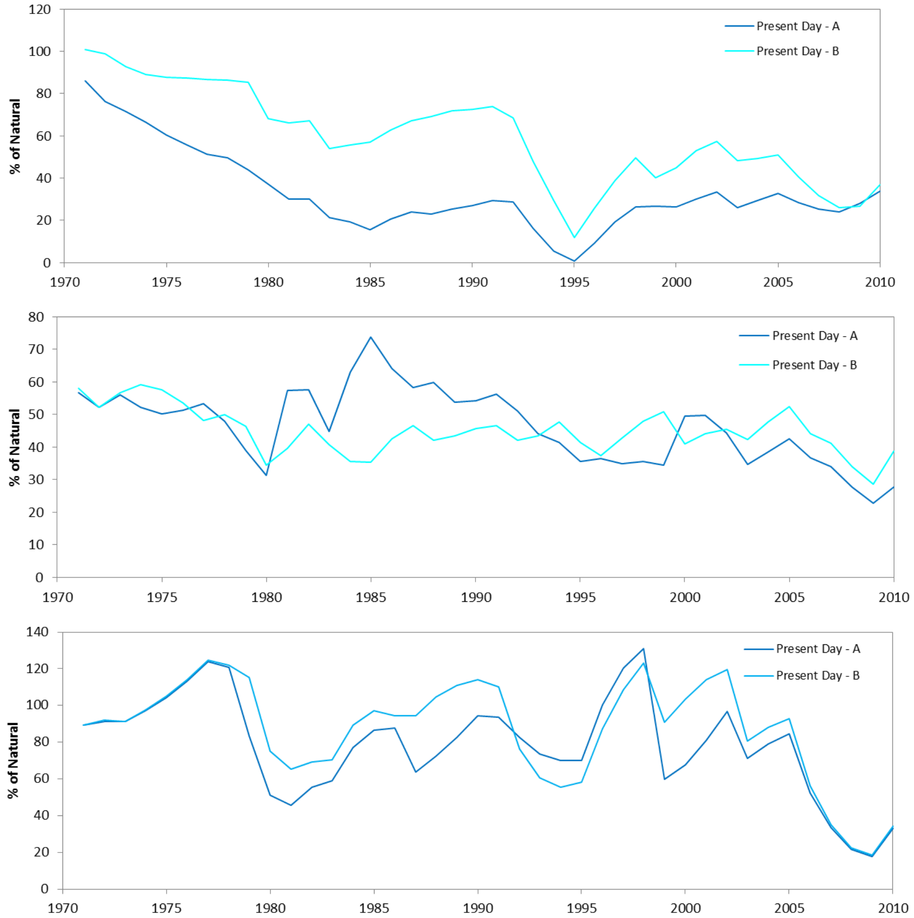


Figure 4.58. **Variation in the abundance of marine piscivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

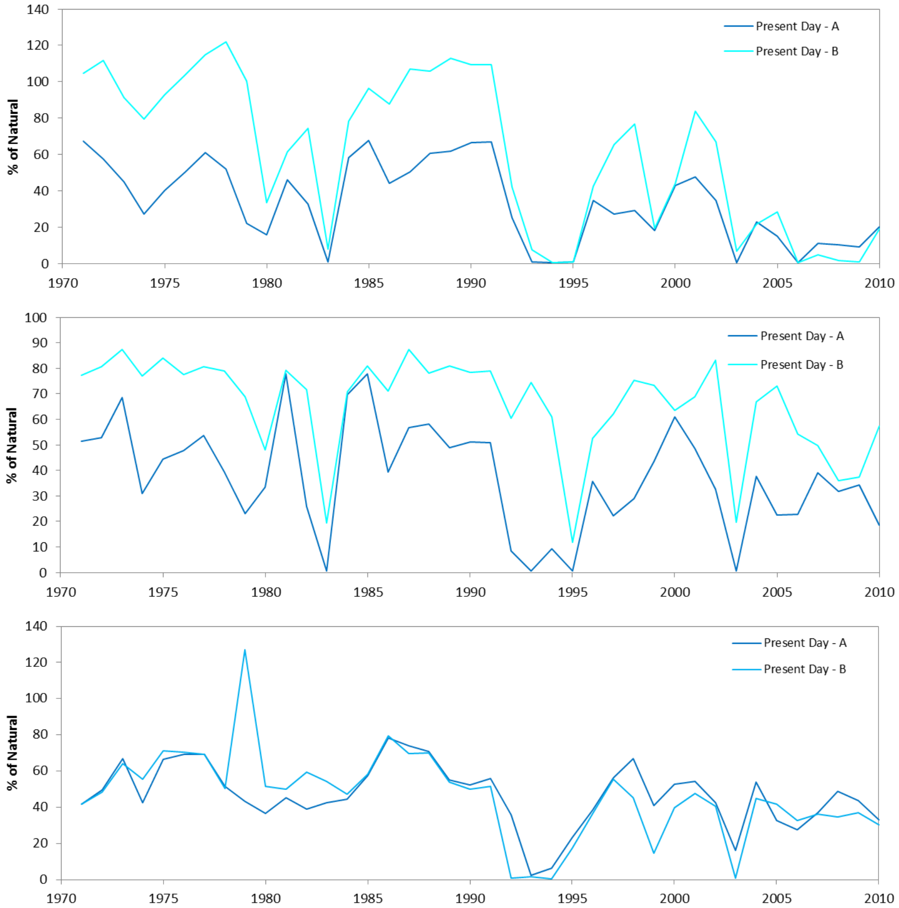


Figure 4.59. **Variation in the abundance of freshwater benthivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

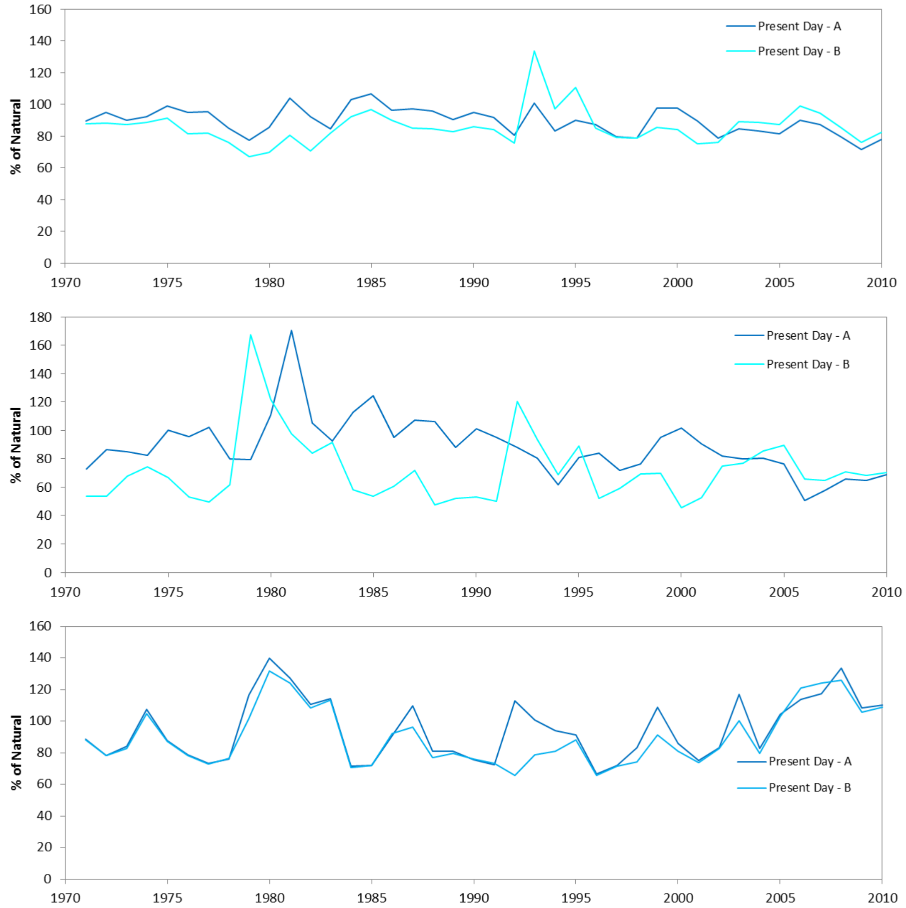


Figure 4.60. **Variation in the abundance of freshwater detritivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

Figure 4.61. **Variation in the abundance of freshwater piscivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

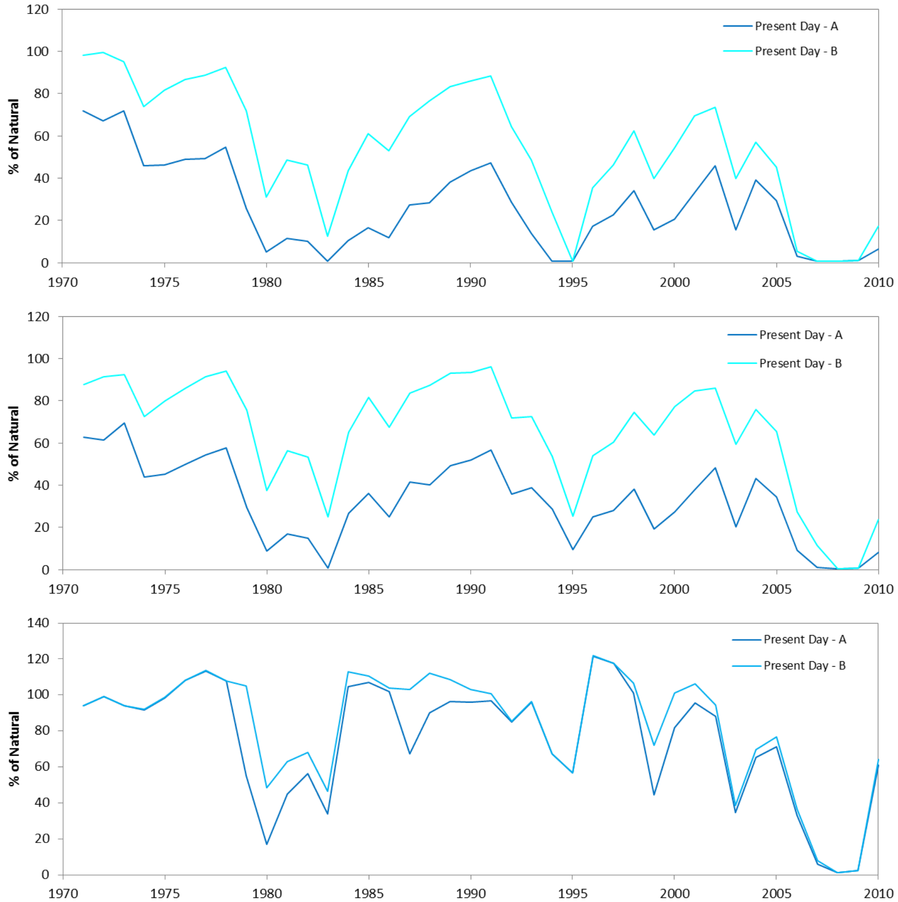


Figure 4.62. **Variation in the abundance of catadromous detrivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

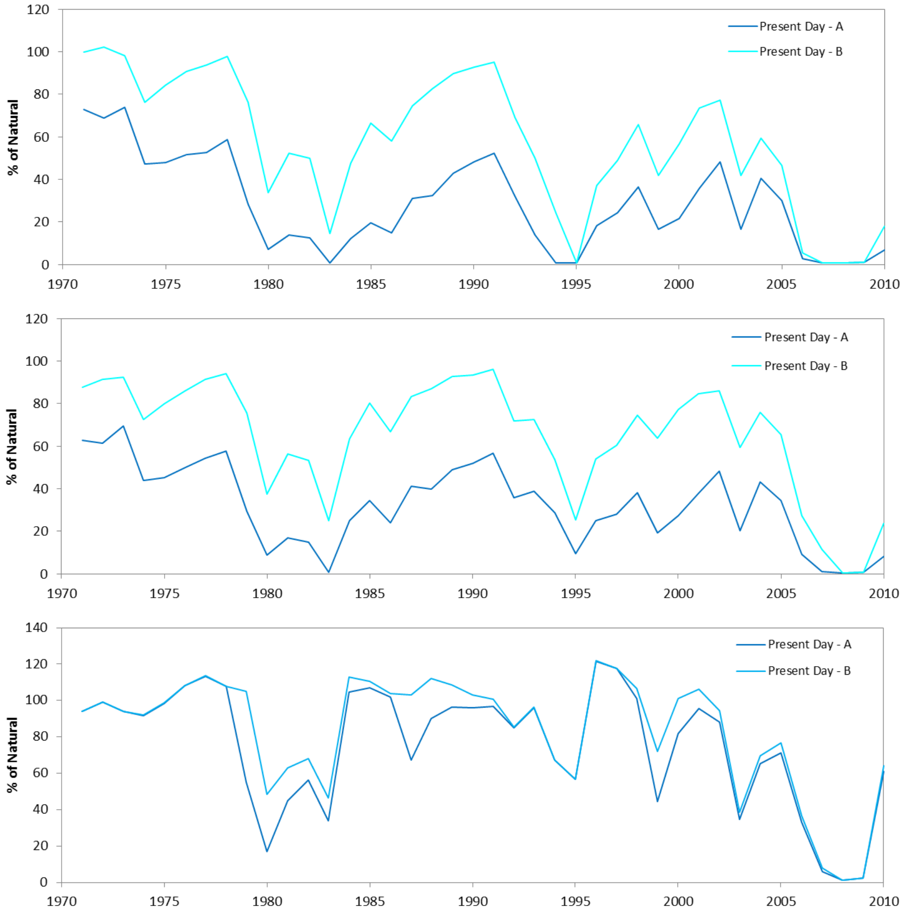


Figure 4.63. Variation in the abundance of catadromous piscivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

4.3.4.8 Fish health scores: Present Day

Fish health scores for the Lake St Lucia estuary system under present-day conditions for the Beach channel (Mouth A) and after Phase 1 excavation (Mouth B), calculated in accordance with methods prescribed for estuaries in DWA (2012), are presented in Table 4.31. The overall health score assigned for Mouth A (with beach channel) was low (49 = D Class) but was markedly better (62 = C class) for Mouth B (after Phase 1 excavation). The low score for Mouth A and the marked improvement under Mouth B reflect a high sensitivity amongst the fish to changes in hydrodynamic functioning (mouth state and tidal prism) and changes in water quality (salinity and turbidity) in the Lake St Lucia system.

Table 4.31. Fish health scores for the Lake St Lucia system under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

Component	Present Day - A	Present Day - B
Lakes	51	63
Narrows	41	59
uMfolozi	62	61
All	**49** **D**	**62** **C**

Confidence in the health scores assigned for fish communities in the Lake St Lucia estuary under present day conditions was medium (70%) owing to the paucity of data available on abundance and community composition of these organisms in the system as a whole, especially for the earlier periods (i.e. pre-1980).

4.3.5 Birds

4.3.5.1 Available information

The earliest published records of birds on Lake St Lucia date back to the 1960s, by which time about 117 waterbird species had been recorded within the St Lucia Lake Game Reserve (Kriel 1966). Some 111 species of waterbirds have been recorded in the regular counts on the Lake St Lucia estuary that have taken place up to four times per year since 1975. These count data have been analysed and summarised in Turpie *et al*. (2013), and were further analysed for this study using additional physical data sourced and modelled for this study.

4.3.5.2 Brief overview of birds on the Lake St Lucia system[2]

At least 117 species of waterbirds have been recorded on the Lake St Lucia estuary, with about 60 to 65 species typically counted in any single count of the estuary. The numbers and composition of birds in the Lake St Lucia estuarine system fluctuate both seasonally and inter-annually. Since 1975, counts of birds have been highly dissimilar and seasonal patterns have not been easy to discern. The variations in numbers are due to the arrival of seasonal long- and short-distance migrants, and changes in habitat, such as water levels, salinity and vegetation, and the associated changes in food availability. Variations in bird numbers on the estuary are also linked to conditions in other wetlands, such as nearby pans. Monthly average counts vary between 6 000 and 17 000 birds (overall average 8 800), with the largest number of birds recorded since 1975 being just over 38 000. Overall, the avifauna is dominated numerically by flamingos and waders although these groups dominate at different times of year and differ markedly in their visibility.

Both greater flamingos *Phoenicopterus roseus* and lesser flamingos *Phoeniconaias minor* occur on the estuarine system, and greater flamingos have bred at Lake St Lucia when conditions were favourable. Greater flamingos feed on benthic invertebrates and are tolerant of a wide range of salinities. Lesser flamingos feed on blue green algae, benthic diatoms, small insects and crustaceans such as brine shrimp.

The waders at Lake St Lucia comprise a mixture of resident and migrant species. The Palaearctic-breeding migrant waders which spend the austral summer at the estuary are dominated by curlew sandpiper *Calidris ferruginea*, little stint *Calidris minuta*, ruff *Philomachus pugnax*, common greenshank *Tringa nebularia* and common sandpiper *Actitis hypoleucos.* Count data also suggest that the estuary may be a staging area for birds migrating further south. Resident waders are dominated by white-fronted plover *Charadrius marginatus*, Kittlitz's plover *Charadrius pecuarius*, pied avocet *Recurvirostra avosetta* and black-winged stilt *Himantopus himantopus*. This latter group is more abundant during the winter months, when many of them breed at the estuary.

Waterfowl are dominated by ducks (13 species), with grebes and rallids such as coot being relatively scarce. Although waterfowl are generally highly nomadic, they are abundant at the Lake St Lucia estuarine system year-round, with some species such as Egyptian goose

[2] Summarised from Turpie *et al*. (2013)'s analysis of count data for 1975-2010

Alopochen aegyptiaca and yellow-billed duck *Anas undulata* being present in relatively stable numbers. However, numbers of most species including Cape teal *Anas capensis*, Hottentot teal *Anas hottentota*, red-billed teal *Anas erythrorhyncha*, white-faced duck *Dendrocygna viduata*, fulvous duck *Dendrocygna bicolor*, southern pochard *Netta erythrophthalma* (although rare), African pygmy goose *Nettapus auritus* and red-knobbed coot *Fulica cristata*, do increase in spring and early summer, reflecting the improvement in conditions for ducks as the summer rains arrive, and possibly indicating some influx of breeding birds. Others, such as little grebe *Tachybaptus ruficollis*, common moorhen *Gallinula chloropus*, Cape shoveler *Anas smithii* and spur-winged goose *Plectropterus gambensis*, are more abundant in winter and early spring. The composition and numbers of waterfowl are influenced by water depth, salinity and the abundance of macrophytes in the estuary.

The remaining birds at the estuarine system are mainly species which subsist partly or entirely on fish. The substantial proportion of piscivorous species is characteristic of systems that close periodically and that harbour important fish nursery areas. Because of the abundant fish and the presence of islands providing safety from predators, the estuary supports significant breeding populations of several piscivorous species including pelicans, wading birds (comprising the herons, egrets, ibises, spoonbills and storks), darters and cormorants. These birds tend to be more common in winter when water levels typically recede after the end of the rains, and fish resources become more concentrated.

The Lake St Lucia system contains one of South Africa's two breeding populations of great white pelican, *Pelecanus onocrotalus* (near-threatened), as well as an important non-breeding population of the pink-backed pelican *Pelecanus rufescens* (vulnerable; Hockey *et al.*, 2005). About 5-6 000 great white pelicans use Lake St Lucia as a breeding area during autumn-winter, but breeding numbers in any year vary with lake conditions (Bowker & Downs, 2008a). Lake St Lucia used to be the only regularly-used breeding site for pink-backed pelicans (Berruti 1980b), but they now breed at Nsumo Pan (in summer), about 30 km north of the lake.

Both reed cormorants *Phalacrocorax africanus*, and white-breasted cormorants *Phalacrocorax lucidus*, forage in the estuary, with the former foraging closer to shore. Wading birds (herons, egrets, ibises, spoonbills and storks), are an important group of largely resident species, with most species breeding here. The most abundant of the wading birds is the African spoonbill *Platalea alba*, although the system also supports significant numbers of goliath herons *Ardea goliath*, great egrets *Egretta alba* and yellow-billed storks *Mycteria ibis*. While wading bird numbers tend to be highest in winter, storks are an exception because several species are summer migrants.

Five aquatic species of kingfishers occur at Lake St Lucia, including the rare mangrove kingfisher *Halcyon senegaloides*, a local migrant of which up to ten have been recorded during the winter months. Giant kingfishers are also more common in winter, whereas pied kingfishers *Ceryle rudis*, are relatively common year-round. Estuarine birds of prey are dominated by the African fish-eagle *Haliaeetus vocifer*, whose numbers average 55, with up to 129 having been recorded.

The estuarine system supports hundreds of gulls and terns. The grey-headed gull, *Chroicocephalus cirrocephalus* arrives on the estuary in large numbers to breed colonially during winter (Brooke *et al.* 1999), with recent count data suggesting this is still the case. The estuarine system also supports South Africa's largest breeding population of Caspian terns *Hydroprogne caspia* (Cooper *et al.* 1992). In 1948-51 they were "by far the commonest tern" on the estuarine system (Day *et al.* 1954). While their numbers have declined, the importance of Lake St Lucia as a breeding site has increased, as the number of breeding sites in southern Africa has gradually diminished from 28 to fewer than ten (Hockey *et al.* 2005). Swift *Thalasseus bergii,* lesser crested *Thalasseus bengalensis,* sandwich *Thalasseus sandvicensis*, common *Sterna hirundo*, little *Sternula albifrons*, whiskered *Chlidonias hybridus* and white-winged terns *Chlidonias leucopterus*, also occur, particularly in summer, with common terns probably using the estuary both as a roost and a staging area *en route* to and from feeding grounds to the south.

A summary of the seasonal trends is shown in Figure 4.64. These data in combination with modelled data for the system will provide some of the insights into the driver-response relationships to supplement data gleaned from other South African estuary studies and the literature. Nevertheless, there are few studies that attempt to quantify these relationships.

The detailed count data from Lake St Lucia were analysed in terms of the recorded and modelled variations in water level, taking season into account. A number of patterns were found where the number of birds was seemingly affected by the water level. Similar patterns were found with salinity, which was strongly related to water level. Not all groups of birds showed consistent responses, however within the Lakes system, both flamingos and waders showed a significant negative trend, with lower number of birds counted during periods of higher water levels (Flamingos: $R^2 = 0.062$, $F_{1,72} = 4.74$, $p = 0.033$; Waders: $R^2 = 0.052$, $F_{1,72} = 4.01$, $p = 0.049$; Figure 4.65). In the Narrows system, the only significant patterns were found with Kingfishers and Birds of Prey, which showed higher numbers in periods with higher water levels (Kingfishers: $R^2 = 0.18$, $F_{1,51} = 11.03$, $p = 0.002$; Birds of Prey: $R^2 = 0.16$, $F_{1,51} = 9.35$, $p = 0.003$). The weak correlations with water level are due to the fact that these variables do not sufficiently capture all of the variation in habitat and prey abundance, as well as inter- and intraspecific interactions and disturbances by humans.

While detailed data are available for the Lake St Lucia estuary, comparatively little is known of the birds of the uMfolozi system. While a small number of counts were completed in 1976 and 1980, regular counting of the mouth area began only from about 2003. These data suggest that the mouth area is sporadically used by waterfowl, cormorants and pelicans, but the most regular users are wading birds, waders and fish eagles, as well as roosting terns.

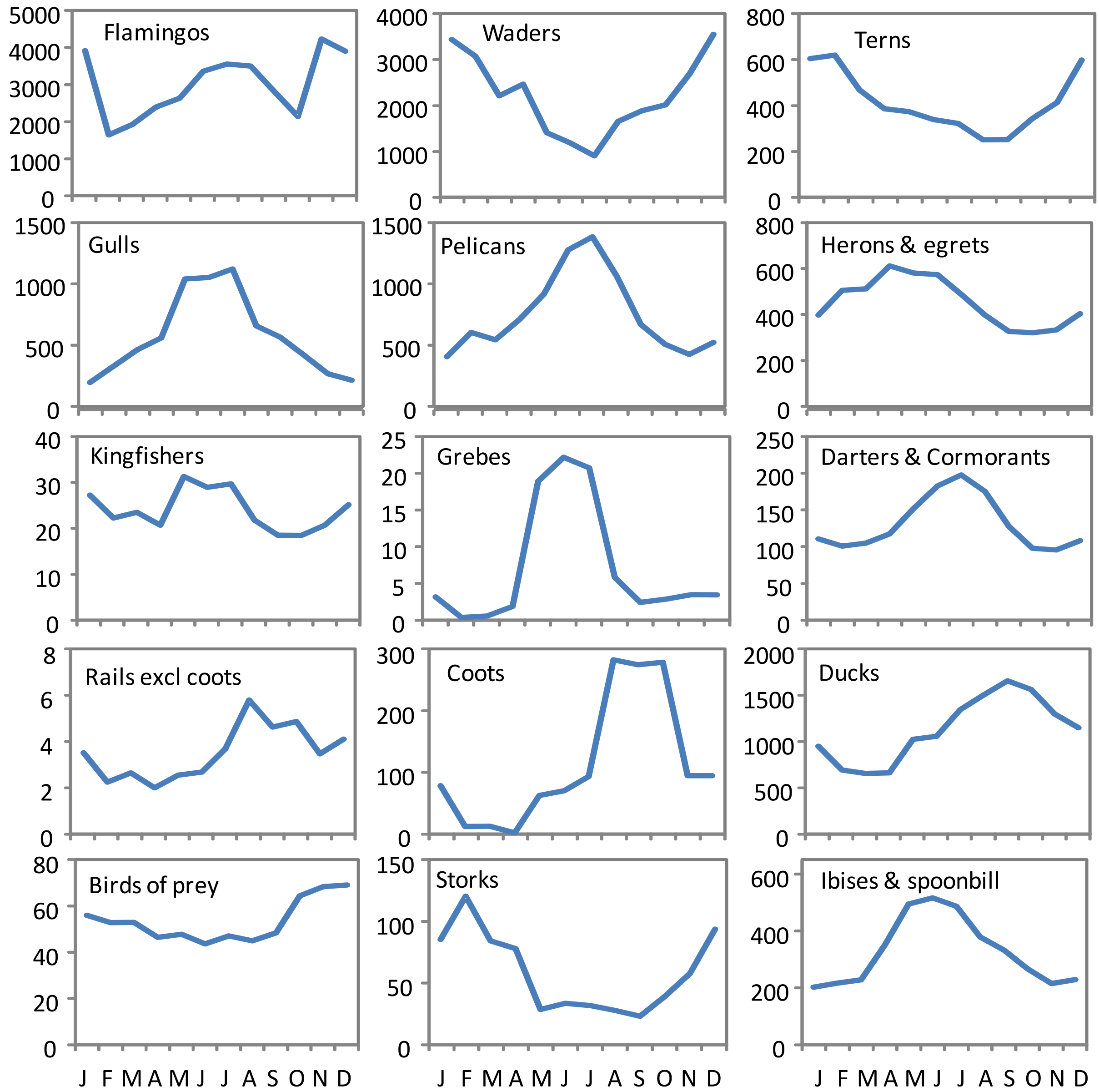


Figure 4.64. Long-term average seasonality in the numbers of different types of birds on Lake St Lucia, using a three-month running mean (Source: Turpie *et al.* 2013).

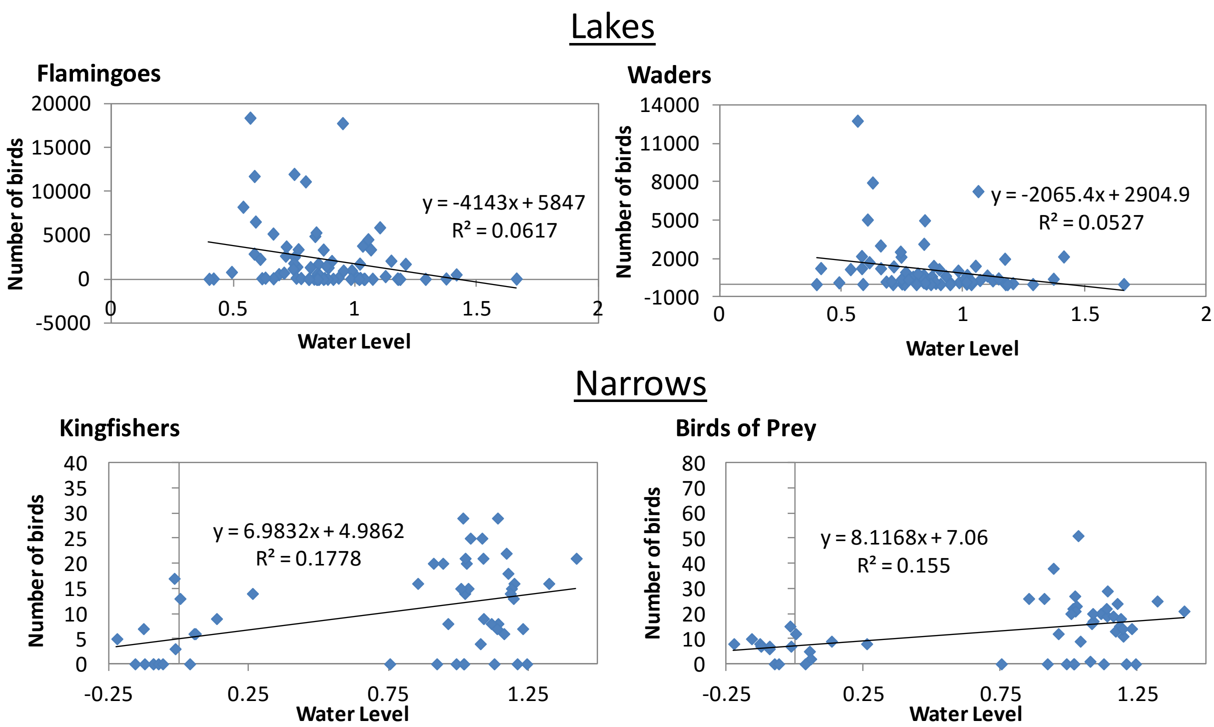


Figure 4.65. Correlations of different bird groups with water level in the lakes and narrows. Source: Clark *et al.* (2014).

4.3.5.3 Component subgroups and their key drivers

A summary of the bird groups described above is provided in Table 4.32. Some of the main influencing factors to be considered in estimating the abundance/biomass/extent of groupings under reference conditions and the alternative scenarios are listed in Table 4.33.

Table 4.32. Major bird groups found in the Lake St Lucia estuarine system, and their defining features. Red data species are highlighted in bold.

Bird groups	Defining features, typical/dominant species
Greater flamingos	**Greater flamingos** *Phoenicopterus roseus* feed on benthic invertebrates and are tolerant of a wide range of salinities. This species is of particular conservation importance.
Lesser flamingos	**Lesser flamingos** *Phoeniconaias minor* feed on phytoplankton and thrive in very high salinities when their food can be abundant. This species is of particular conservation importance.
Pelicans	**Great white pelican** *Pelecanus onocrotalus*, and **pink-backed pelican** *Pelecanus rufescens* occur, though the latter has moved its breeding colony away from the lake. Both species are piscivorous. Both are of particular conservation importance.
Waders	The group includes both migrant species (dominated by curlew sandpiper *Calidris ferruginea*, little stint *Calidris minuta*, ruff *Philomachus pugnax*, common greenshank *Tringa nebularia* and common sandpiper *Actitis hypoleucos*) and resident species (dominated by white-fronted plover *Charadrius marginatus*, Kittlitz's plover *Charadrius pecuarius*, pied avocet *Recurvirostra avosetta* and black-winged stilt *Himantopus himantopus*). They are the smallest birds 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.
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. Most are euryhaline, but certain tern species on the estuary tend to be associated with low salinity environments. Gulls and terns can be very abundant and use the estuary primarily for roosting. **Caspian Tern** will be isolated as a key species of conservation importance.
Waterfowl	13 species of ducks, plus some rallids. Egyptian Goose *Alopochen aegyptiaca*, Yellow-billed Duck *Anas undulata,* Cape Teal *A. capensis*, Hottentot Teal *A. hottentota*, Red-billed Teal *A. erythrorhyncha*, White-faced Duck *Dendrocygna viduata*, Fulvous Duck *D. bicolor*, Southern Pochard *Netta erythrophthalma*, African Pygmy Goose *Nettapus auritus*, Red-knobbed Coot *Fulica cristata,* Little Grebe *Tachybaptus ruficollis*, Common Moorhen *Gallinula chloropus*, Cape Shoveler *A. smithii*, Spur-winged Goose *Plectropterus gambensis*. These are mainly herbivorous and omnivorous species. A few, such as grebes, are piscivorous. The **Pygmy Goose** is a key species of conservation importance.
Cormorants	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 *Phalacrocorax africanus*, Cape Cormorant *Phalacrocorax capensis*, White-breasted Cormorant *Phalacrocorax lucidus* and African Darter *Anhinga rufa*.
Wading birds	This group comprises the egrets, herons, ibises, spoonbill and storks. Loosely termed piscivores, their diet varies with fish usually dominating, but often also includes other vertebrates, such as frogs, and invertebrates. The ibises were included in this group, though their diet mainly comprises invertebrates and is fairly plastic. They tend to be tolerant of a wide range of salinities. Wading piscivores prefer shallow water up to a certain species dependant wading depth.
Kingfishers and birds of prey	The African Fish Eagle *Haliaeetus vocifer* is the dominant bird of prey in this group. They are not confined to a diet of fish, also taking other vertebrates and invertebrates. Five species of kingfishers occur on the estuary in relatively low numbers, all of which are piscivorous. Kingfishers and birds of prey breed and perch on trees on the banks of the estuary. The rare **Mangrove Kingfisher** *Halcyon senegaloides* is a key species of conservation importance.

Table 4.33. Effect of abiotic characteristics and processes, as well as other biotic components on bird groupings

Group	**Key drivers**			**Other influencing factors**
Greater flamingos	Water level *Area of water depth < 35cm would provide a reasonable indicator of available feeding habitat*	Salinity *Prefers moderately saline conditions*	Benthic macrofauna *Food abundance will limit the abundance of flamingos*	Regional population
Lesser flamingos	Water level *Area of water depth < 30cm would provide a reasonable indicator of available feeding habitat*	Salinity *Prefers moderate to very high salinities*	Microalgae & benthic macrofauna *Abundance of blue green algae, benthic diatoms, small insects and crustaceans such as brine shrimp.*	Regional population
Pelicans	Fish abundance *Availability of food*	Water level in winter *Intermediate water levels for feeding and creating suitable island habitat*		Regional population Availability of suitable habitat in region
Waders	Water level in winter (masl) *Water depth <15cm would have positive effect as attractive to certain waders (e.g. many resident spp.)*	Newly exposed area *Intertidal and recently exposed shorelines would have a positive influence on wader numbers – residents in winter and migrants in summer*	Benthic macrofauna *In extreme conditions, food abundance could limit the abundance of waders*	Global population
Gulls & terns	Open mouth *Open mouth conditions leading to creation of islands and safe roosting areas in the lower estuary, will attract large roosts. Open mouth conditions will also attract feeding birds, due to recruitment and movements of fish and invertebrates through the mouth*	Water level *Intermediate & receding water levels likely to provide more suitable habitat and feeding conditions than very low or very high levels.*	Abundance of fish and swimming crustaceans *Abundance of food, which may also be particularly high during breaching, strong tidal exchange, and temporarily when water levels are receding*	
Waterfowl	Water level *Intermediate water levels provide abundance and diversity of habitats for waterfowl.*	Submerged and emergent aquatic vegetation *Both as a habitat for shier species and as food source*	Salinity *Most waterfowl have upper limits to salinity tolerance, with waterfowl generally preferring fresher conditions*	Rainfall and availability of suitable habitat in region
Cormorants & darters	Fish abundance *Abundance of*	Water level *Intermediate &*		Mortality due to gillnetting

	cormorants and darters is probably strongly linked to fish abundance	*receding water levels likely to provide more suitable habitat and feeding conditions than very low or very high levels.*		
Wading birds	Water level *Area of water depth < 20cm would provide a reasonable indicator of available feeding habitat*	Fringing and emergent vegetation *To some extent, the presence of this vegetation adds to the diversity and abundance of this group as some species like to roost and/or in reed beds and trees*	Fish and macroinvertebrate abundance *Food abundance will limit the abundance of wading birds*	
Kingfishers & birds of prey	Water level *Intermediate-high & receding water levels likely to provide more suitable habitat and feeding conditions than low levels.*	Fringing vegetation *This group can be limited by the available of suitable perches; Mangrove kingfishers need mangrove habitat.*	Fish abundance *Fish abundance will limit the abundance of kingfishers and birds of prey*	

4.3.5.4 Avifauna abundance – Present Day and Reference condition

Summary statistics on the abundance of avifauna under present-day conditions (Beach channel and after Phase 1 excavation options) are presented in Table 4.30 and time series data for the period 1971-2010 are presented in Figure 4.53-Figure 4.63. Differences in relative abundance (% of natural) between the two different mouth options are linked mostly to differences in the salinity, water level (habitat) and prey abundance (invertebrates and fish) for the various avifauna groups.

Table 4.34. Simulated avifauna abundance (% of natural) in the Lakes (at Lister's Point), Narrows (at Honeymoon Bend) and the uMfolozi for the period 1971 to 2010, under reference and present-day conditions.

Hydrological scenario	Groupo	% of Reference		
		Lakes	Narrows	uMfolozi
Present (Mouth A - with beach channel)	Flamingos	84.5	61.1	87.9
	Gulls & Caspian Tern	100.6	111.1	109.0
	Pelicans	102.0	97.7	110.6
	Waders	98.0	32.7	56.1
	Other terns	102.7	54.2	81.8
	Waterfowl	104.8	176.2	97.1
	Cormorants	103.6	17.3	45.1
	Wading birds	29.5	17.3	45.1
	Perching piscivores	64.5	53.3	69.0
	Common & Little Terns	73.5	58.3	85.5
Present (Mouth B – after Phase 1 excavation)	Flamingos	68.6	81.3	100.7
	Gulls & Caspian Tern	99.8	105.1	106.6
	Pelicans	103.3	113.6	109.8
	Waders	107.5	80.2	62.1
	Other terns	101.4	90.9	83.6
	Waterfowl	86.3	128.0	85.0
	Cormorants	106.0	65.8	59.2
	Wading birds	62.5	65.9	59.2
	Perching piscivores	80.8	91.1	76.2
	Common & Little Terns	85.5	93.9	86.4

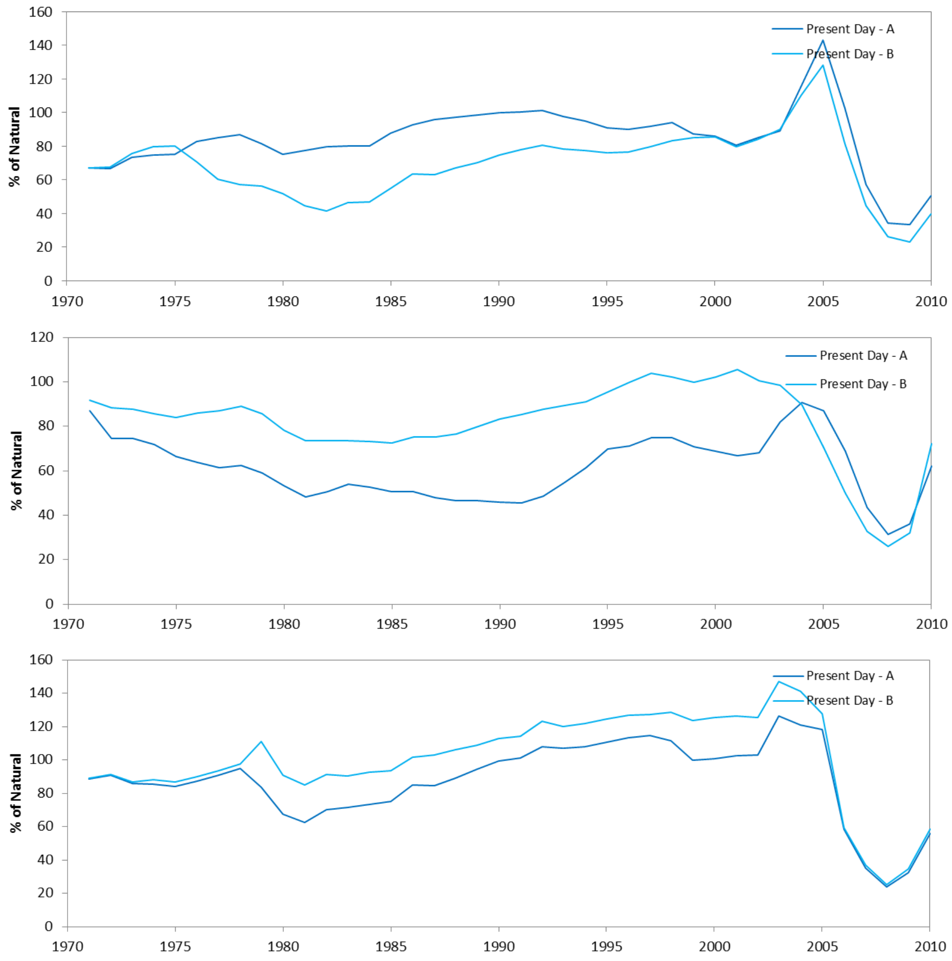


Figure 4.66. **Variation in the abundance of Flamingos (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

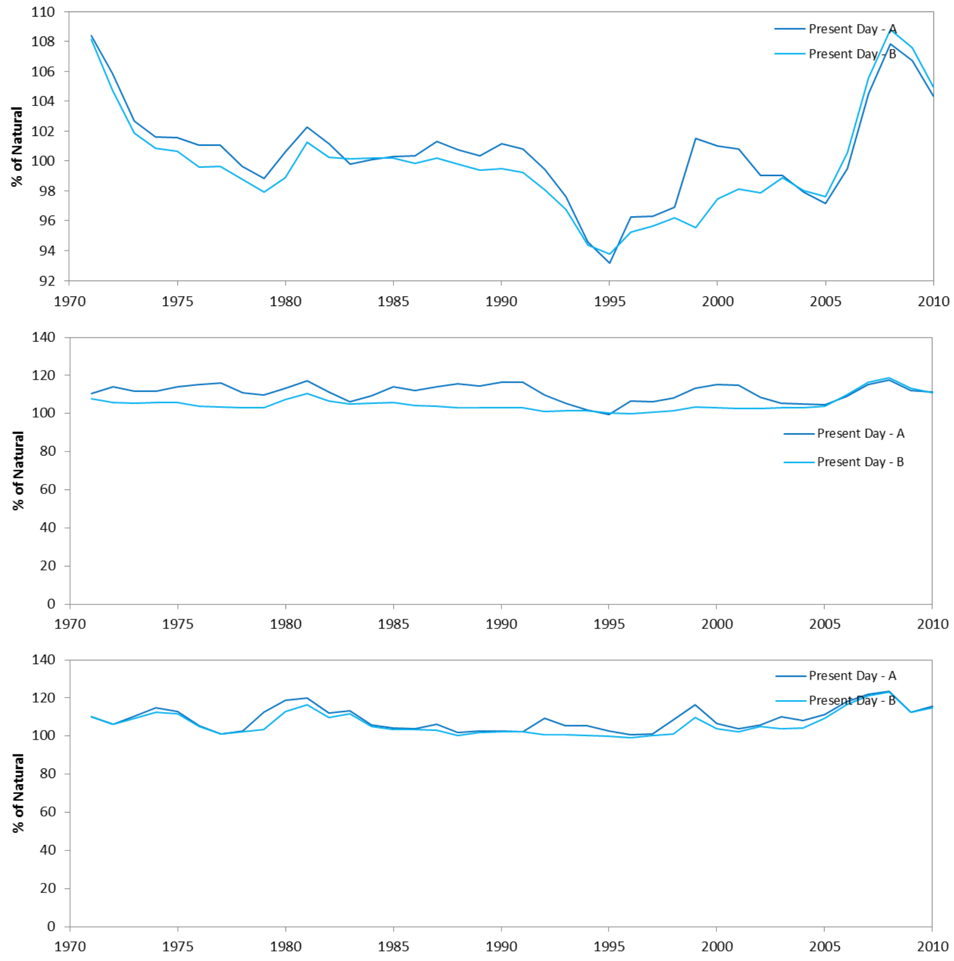


Figure 4.67. **Variation in the abundance of gulls and Caspian terns (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

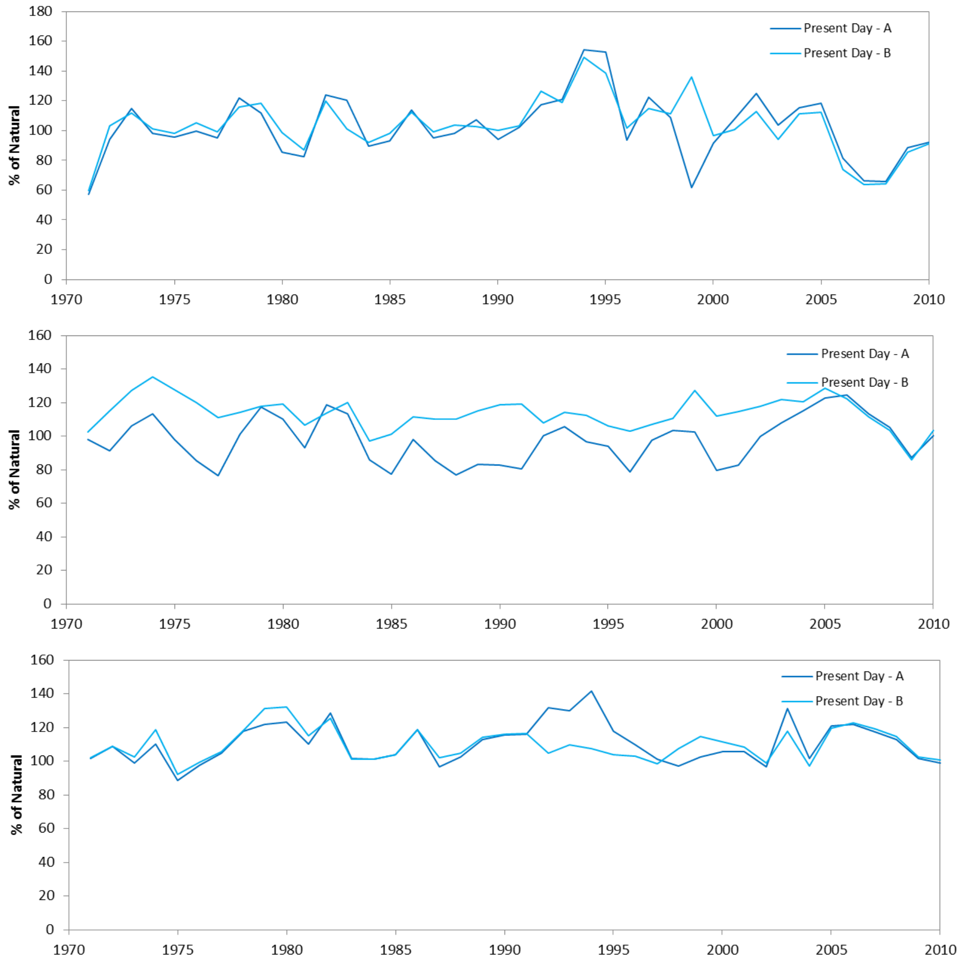


Figure 4.68. **Variation in the abundance of Pelicans (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

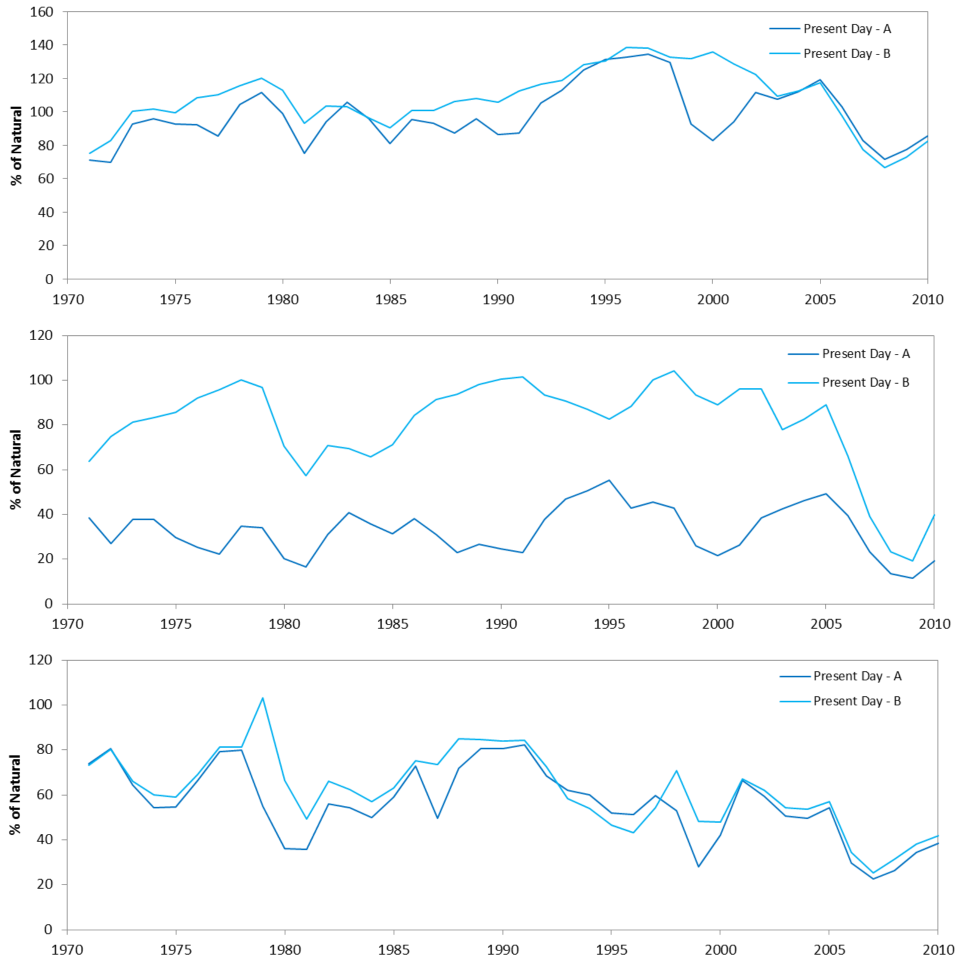


Figure 4.69. **Variation in the abundance of waders (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

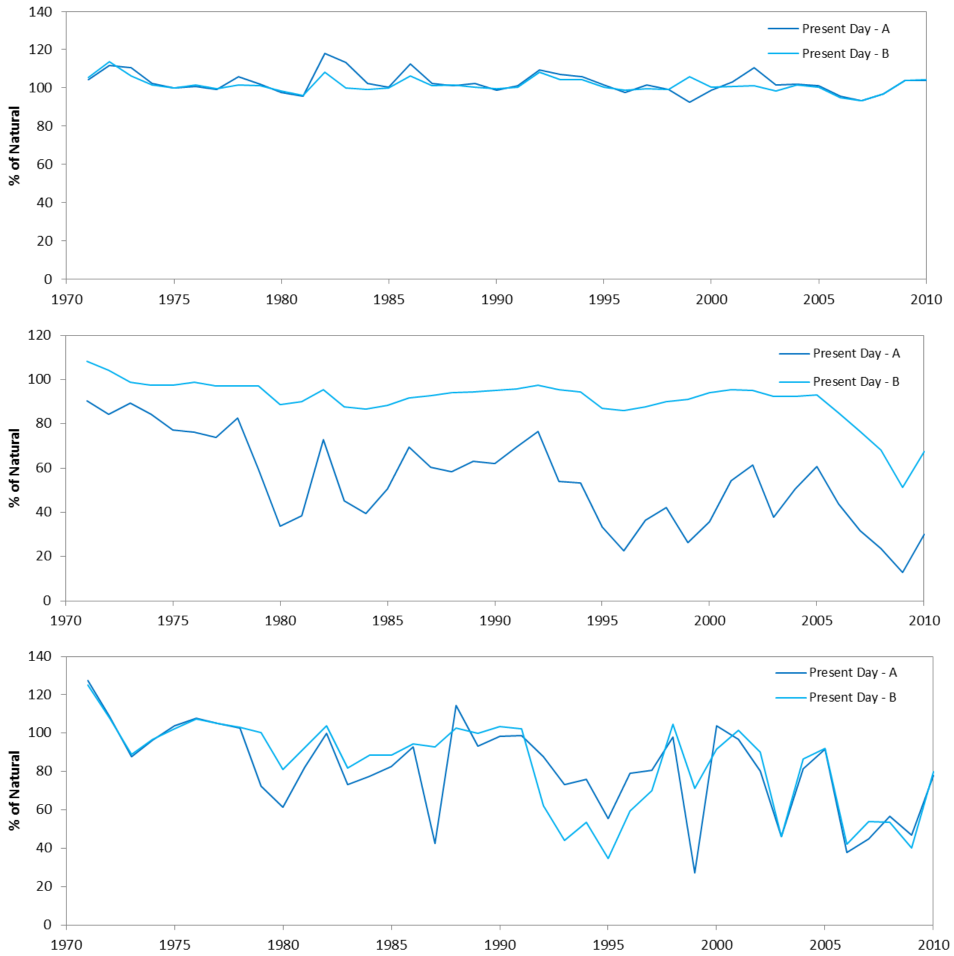


Figure 4.70. **Variation in the abundance of other terns (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

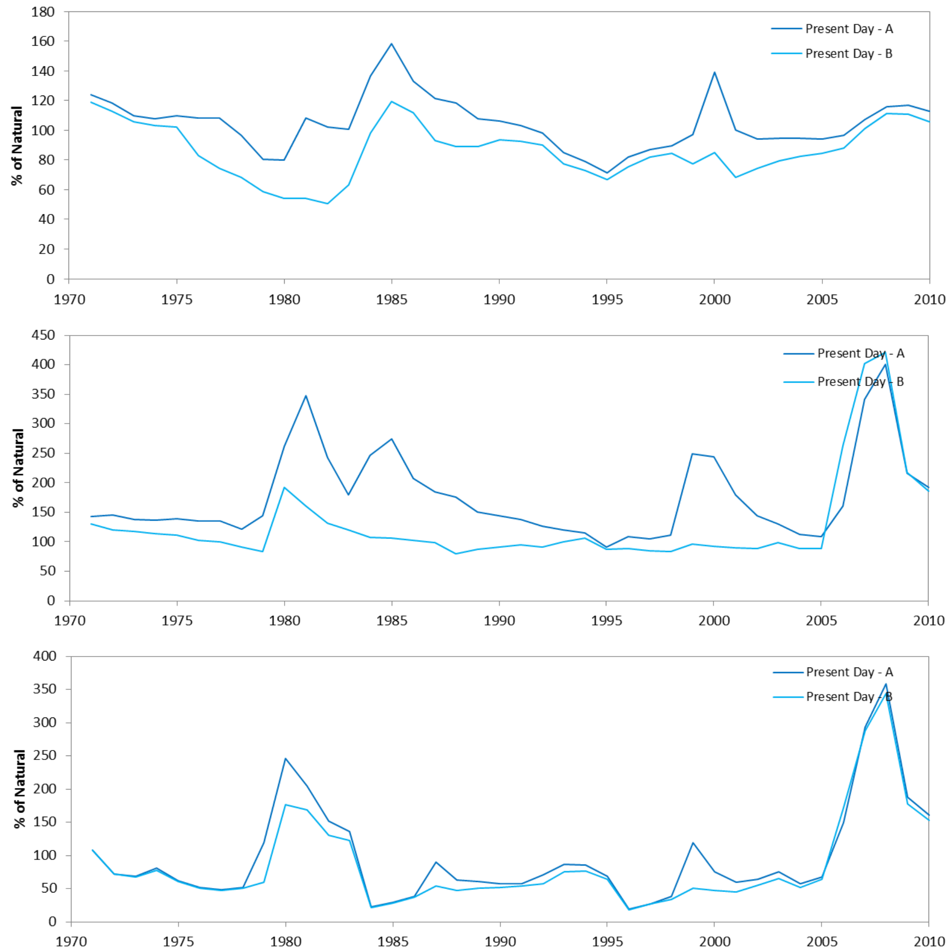


Figure 4.71. **Variation in the abundance of waterfowl (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

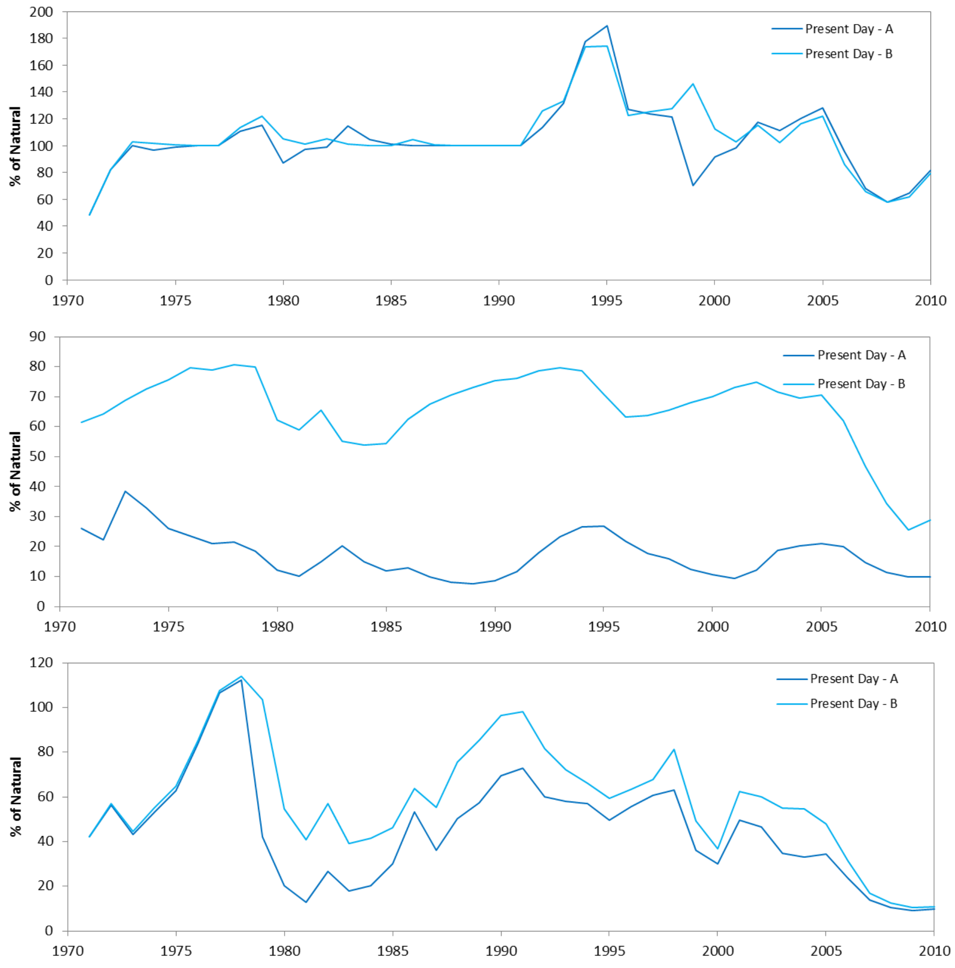


Figure 4.72. **Variation in the abundance of cormorants (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

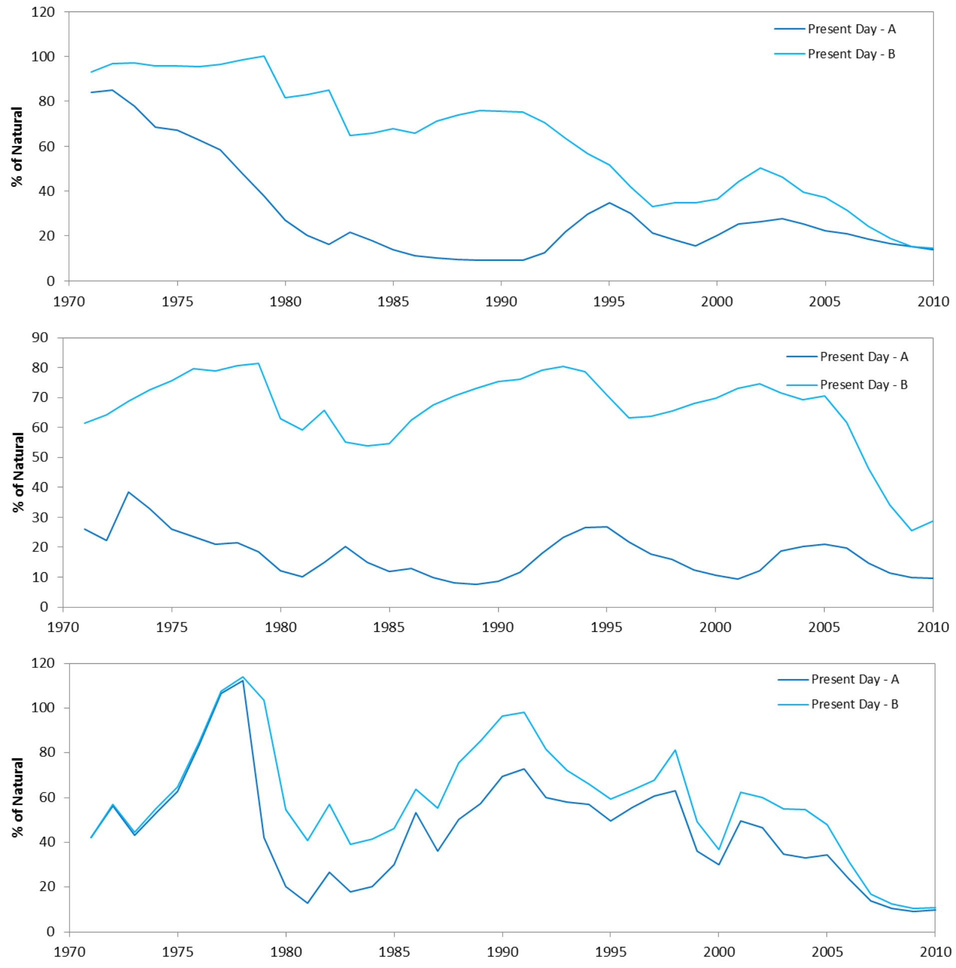


Figure 4.73. **Variation in the abundance of wading birds (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).**

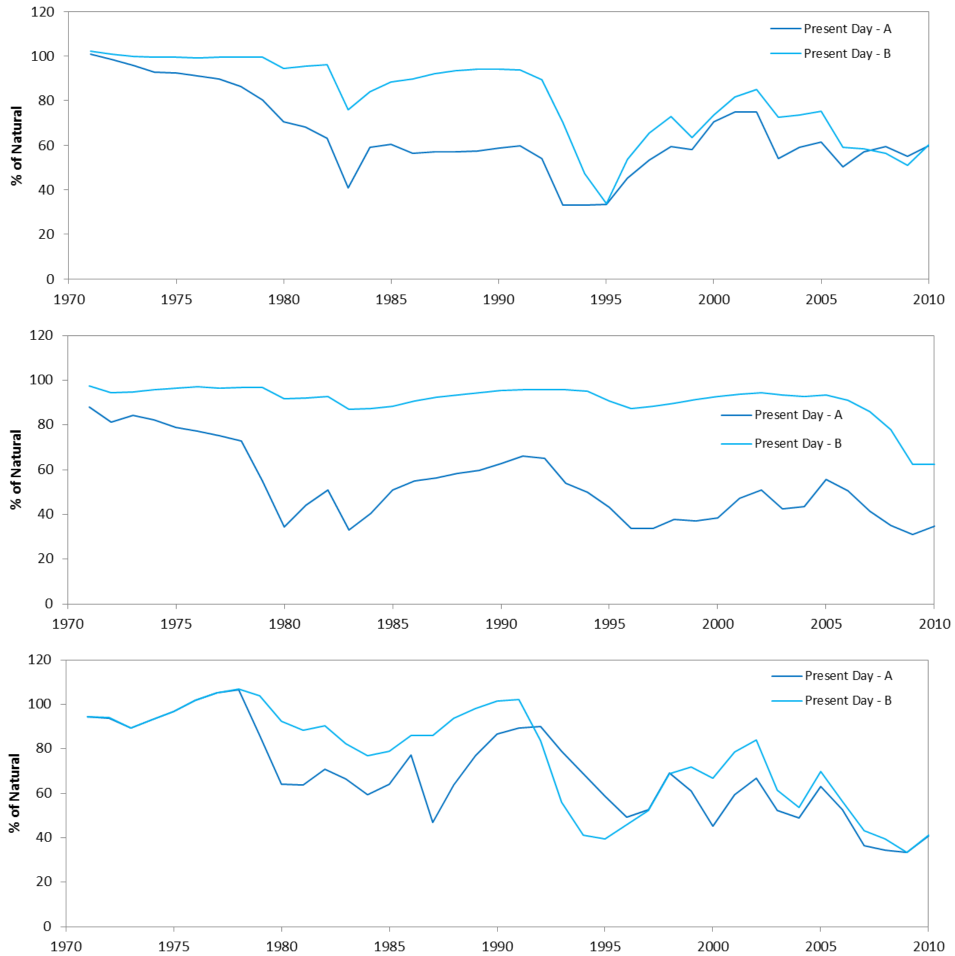


Figure 4.74. Variation in the abundance of perching piscivores (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

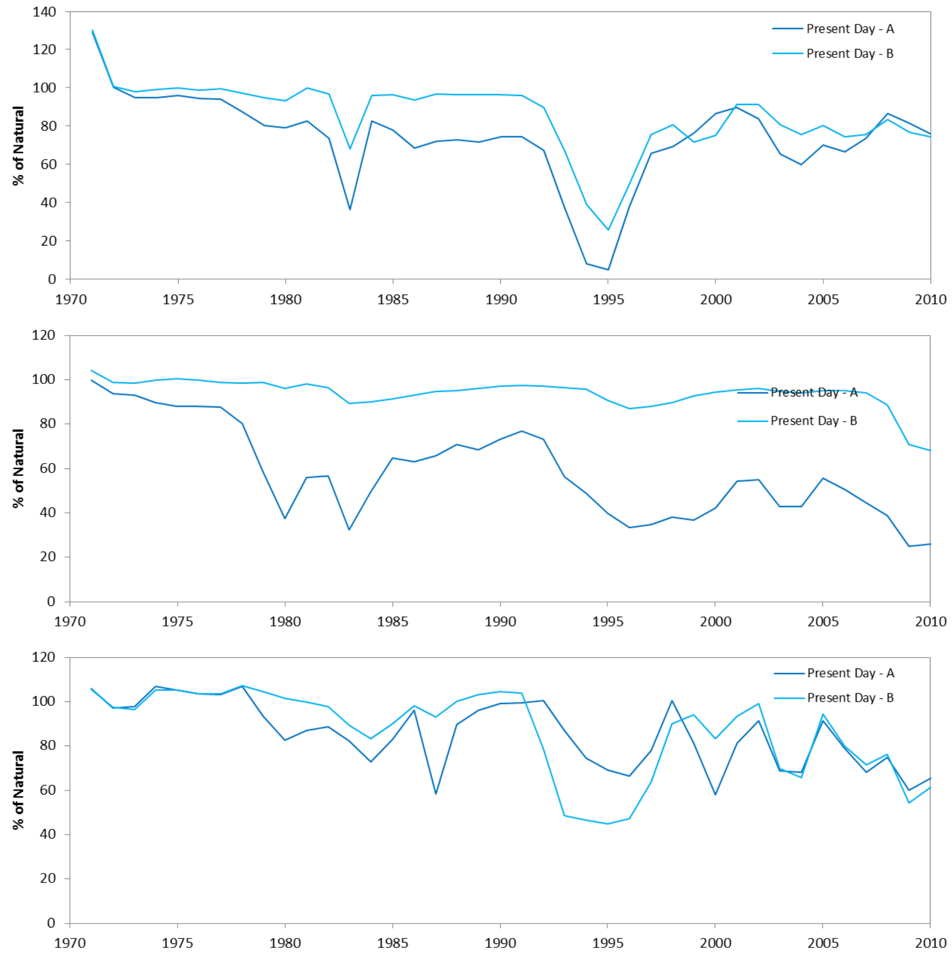


Figure 4.75. Variation in the abundance of Common and Little terns (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

4.3.5.5 Avifauna health scores: Present Day

Avifauna health scores for the Lake St Lucia estuary system under present-day conditions for the Beach channel (Mouth A) and after Phase 1 excavation (Mouth B), calculated in accordance with methods prescribed for estuaries in DWA (2012), are presented in Table 4.35. The overall health score assigned for Mouth A (with beach channel) was moderately low (55 = D Class) but was somewhat better (64 = C class) for Mouth B (after Phase 1 excavation). The low score for Mouth A and the improvement under Mouth B reflect a moderate sensitivity amongst the avifauna to changes in water quality (salinity), hydrodynamic functioning (mostly water level and habitat area) and prey abundance (invertebrates and fish) in the Lake St Lucia system.

Table 4.35. Avifauna health scores for the Lake St Lucia system under present-day conditions – Mouth A (with beach channel) and Mouth B (after Phase 1 excavation).

Component	Present Day - A	Present Day - B
Lakes **Narrows** **uMfolozi**	65 38 49	65 65 53
All	**55** **D**	**64** **C**

Confidence in the health scores assigned for avifauna communities in the Lake St Lucia estuary under Present day conditions was medium-high (80%). Good data are available on avifauna abundance and community composition for the entire system from 1975 to present day, but data on avifauna communities under Reference conditions (pre-1950) is limited.

4.4 Present Ecological Status

The Estuarine Health Index (EHI) scores allocated to the various abiotic and biotic health parameters for the Lake St Lucia estuary system and the overall Present Ecological Status (PES) for the system were calculated using methods prescribed in DWS (2012) and are presented in Table 4.36.

The EHI score for the Lake St Lucia estuary system in its present state with the beach channel in place (Mouth A) was estimated to be 48 (i.e. 48% similar to the Reference condition, which translates into a Present Ecological Status (PES) of D. (Note that this is very similar to the score assigned to the system as part of a preliminary RDM study completed in 2004 – DWAF 2004). This was an improvement on the score prior to the reconnection of the uMfolozi via the beach channel (see Clark *et al.* 2014). The EHI score is expected to improve significantly to 63% or Class C, once Phase 1 of the process of removing the dredge spoil that was historically deposited between the St Lucia Narrows and the uMfolozi mouth has been completed (i.e. Mouth B – combined mouths). The process of removing this dredge spoil material has already been initiated and it is thus recommended that the EHI score for the Present Ecological Status of the Lake St Lucia system be taken as 63% or Class C.

Table 4.36. Estuarine Health Score (EHI) for the Lake St Lucia estuary system under present-day conditions with beach channel in place (Mouth A), and confidence levels (scores are derived to produce overall confidence).

Variable	Present Day - A		Present Day - B		Confidence
a. Hydrology	79	B	75	B	Low (40%)
b. Hydrodynamics	7	F	71	C	Med-low (60%)
c. Water quality	55	D	53	D	Med-low (60%)
Abiotic health ((a+b+c)/3)	**47**	**D**	**67**	**C**	
d. Microalgae	32	E	49	D	Low (40%)
e. Macrophytes	75	B	77	B	Med-high (80%)
f. Invertebrates	31	E	46	D	Med-low (40%)
g. Fish	49	D	62	C	Med (70%)
h. Birds	55	D	64	C	Med-high (80%)
Biotic health ((d+e+f+g+h)/5)	**49**	**D**	**59**	**D**	
Overall health (ave Abiotic + Biotic)	**48**	**D**	**63**	**C**	**Low (40%)**

Improvements in the health of the system from Mouth A to B can be attributed to improvements in hydrodynamic functioning (mouth state, tidal prism and water level) which in turn allows for improved water quality (salinity, DIN and DIP and turbidity), and also the abundance and community structure of the estuary biota (particularly the microalgae, invertebrates, fish and birds). Note that health scores allocated to these two Present Day scenarios are subtly different to those assigned to the corresponding mouth management options in the GEF-funded

"Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" commissioned by the iSimangaliso Wetland Park Authority (Clark *et al*. 2014) and are linked to refinements in the hydrological data used for this study and also differences in the approach to the phased removal of the dredge spoil.

The level of confidence in each of the component scores of the EHI is also presented in Table 4.36. Overall confidence in this assessment was rated as medium-low (60%), and is linked to low confidence in the hydrological data in particular, but also in the paucity of historical data on water quality and microalgae and invertebrate communities in the system. The implications of this are that the authorities will need be very 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, particularly hydrological data.

5 RECOMMENDED ECOLOGICAL CATEGORY

5.1 Conservation importance of the Lake St Lucia estuary

The Estuary Importance Score (EIS) for an estuary takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (Table 5.2 and Table 5.1). Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, algae, 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 was scored by the project team in the EWR workshop for this study. The Lake St Lucia estuary system is the largest estuary in the country, encompassing more than 50% of the total estuarine habitat area, and was ranked the 5th most important estuary in South Africa in terms of conservation importance by Turpie *et al.* (2002). The functional importance of the system was thus deemed to be very high (100%, Table 5.2). The EIS for the Lake St Lucia Estuary, based on its present state, was therefore estimated to be 93, i.e. the estuary is rated as “Highly important” (Table 5.3).

Table 5.1. Importance scores (EIS) for the Lake St Lucia estuary

Criterion	Weight	Score
Estuary Size	15	100
Zonal Rarity Type	10	70
Habitat Diversity	25	100
Biodiversity Importance	25	99
Functional Importance	25	100
Weighted Estuary Importance Score		**93**

Table 5.2. Estimation of the functional importance score of the Lake St Lucia estuary

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

Table 5.3. Estuarine importance scores (EIS) and significance

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

5.2 Recommended Ecological Category

The Recommended Ecological Category (REC) represents the level of protection assigned to an estuary. The first step is to determine the 'minimum' EC, based on its PES. The relationship between EHI Score, PES and minimum REC is set out in Table 5.4.

Table 5.4. Relationship between the EHI, PES and minimum ERC

EHI SCORE	PES	DESCRIPTION	MINIMUM "EC"
91 – 100	A	Unmodified, natural	A
76 – 90	B	Largely natural with few modifications	B
61 – 75	C	Moderately modified	C
41 – 60	D	Largely modified	D
21 – 40	E	Highly degraded	-
0 – 20	F	Extremely degraded	-

The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of **importance** and level of **protection or desired** protection of a particular estuary (Table 5.2). Almost the whole of the Lake St Lucia estuary system up to the 5 m contour is included within the iSimangaliso Wetland Park, which was registered as a World Heritage Site in 1999and is included in the subset of estuaries identified as requiring protection in order to conserve South Africa estuarine biodiversity estate (Turpie *et al.* 2004, Turpie & Clark 2007, Turpie *et al.* 2012). Thus, according to the rules laid down in DWA (2012), the REC for the Lake St Lucia estuary system is thus an "A" Class or "Best attainable State" (BAS).

Table 5.2. Estuary protection status and importance, and the basis for assigning a recommended ecological reserve category

Protection status and 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 (based on complementarity)		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category
Important	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D category

* BAS = Best Attainable State

The PES for the Lake St Lucia estuary system is a C. The estuary is rated as "Highly important", and is included with the iSimangaliso Wetland Park, a proclaimed World Heritage Site. Thus the **Recommended Ecological Category** for the estuary is an A or its "Best Attainable State".

6 OPERATIONAL FLOW SCENARIOS

6.1 Description of the Scenarios

A number of future flow scenarios were modelled by Aurecon for the Lake St Lucia system as part of the *Usuthu to Mhlatuze EWR study* (DWS 2016). This included nine flow scenarios for the uMfolozi (Table 6.1), three for the Mkuse (Table 6.2), and four for the Hluhluwe River (Table 6.3). No operational scenarios were considered for the other smaller influent rivers. It was obviously not possible to consider the impacts of all of these scenarios separately as this would have required running 360 different scenarios through the hydrological and ecological models for this study. The operational flow scenarios for the Mkuse, and Hluhluwe were, however, all very similar to Present Day (Figure 6.2, Figure 6.3) and did not have measurably different impacts on the health of the estuary. It was thus agreed that these would not be considered in the estuary health assessment. Furthermore, many of the operational flow scenarios for the uMfolozi system were also found to be very similar (e.g. LMF1-1, 1-2, 1-3 and LM F1-4 and 1-5) and thus only five operational scenarios were considered for this catchment – LMF 1-4, LMF 1-7, LMF 1-8, LMF 1-9 and LMF EWR (min). Flows for these scenarios were then used in conjunction with the modelled Present Day (= baseline) flows for the other influent rivers. Flow scenarios for the estuary were then renamed as Scenarios 1-5 for the purposes of this study (Table 6.4).

It is also important to note that all of the operational scenarios represented reductions in flow from Present Day. No EWR scenarios (hypothetical scenarios not considered by DWS but constructed to explore greater extremes or options, such as increased runoff) were evaluated as part of this study. This is considered to be an important shortcoming as this does not allow for the identification of a Recommended Ecological Scenario (REC) as required in terms of the "Methods for the Determination of the Ecological Reserve for Estuaries" (DWS 2012).

Table 6.1. Main land-use, water demands and operational features of LMF1 scenarios for uMfolozi downstream of EWR sites BM2 and WM1#. Source: DWS (2014). OCS = Off Channel Storage.

Item	Baseline (LMF1-1)	LMF1-2	LMF1-3	LMF1-4	LMF1-5	LMF1-6	LMF1-7
With EWRs	No	Yes	No	No	Yes	No	No
Domestic demand (10^6 m^3)	7.4	7.4	7.4	17.7 (2040)	17.7 (2040)	17.7 (2040)	17.7 (2040)
Industrial demand(10^6 m^3)	11.0	11.0	11.0	12.6 (2040)	12.6 (2040)	12.6 (2040)	25.0 (>2040)
Dam Capacity (10^6 m^3)	6.0 (Richards Bay Minerals)	6.0 (RBM)	6.0 (RBM)	6.0 (RBM) 7.5 (OCS)	6.0 (RBM) 7.5 (OCS)	6.0 (RBM)	10.0 (RBM) 7.5 (OCS)
Afforestation (km^2)	65.0	65.0	49.8	65.0	65.0	65.0	65.0
Domestic return flows (%)	25	25	25	25	25	25	25
Irrigation (km^2)	39.0	39.0	39.0	39.0	39.0	39.0	39.0
Irrigation effic. and distribution losses (%)	75	75	75	75	75	75	75
MAR (Mm^3/a)	952.2	952.2	952.9	942.8	942.8	959.8	932.0

#: It should be noted that the Baseline scenarios BM2-1 and WM1-1 were in place during the above LMF1 scenario modelling exercise.

Scenario LMF1-8: LMF1-6 plus an in-channel dam of Operational Capacity = 90 million m^3 and yield 66 million m^3/a in the Lower uMfolozi; 50% of the yield is used inside the uMfolozi catchment, leading to 25% return flows to the uMfolozi. MAR = 840.1 Mm^3/a.
Scenario LMF1-9: LMF1-6 plus an off-channel dam of Operational Capacity = 90 million m^3 and yield 56 million m^3/a in the Lower Mfolozi; 50% of the yield is used inside the uMfolozi catchment, leading to 25% return flows to the uMfolozi. MAR = 850.6 Mm^3/a.
Scenario LMF1–EWR: River EWR flows defined at BM2 and WM1, including larger floods (>1:2 yr RI) as well as current-day flows from the Lower uMfolozi, provided to the Estuary; current-day abstractions from the Lower uMfolozi curtailed to preserve the EWR flows. MAR = 270.9 Mm^3/a.

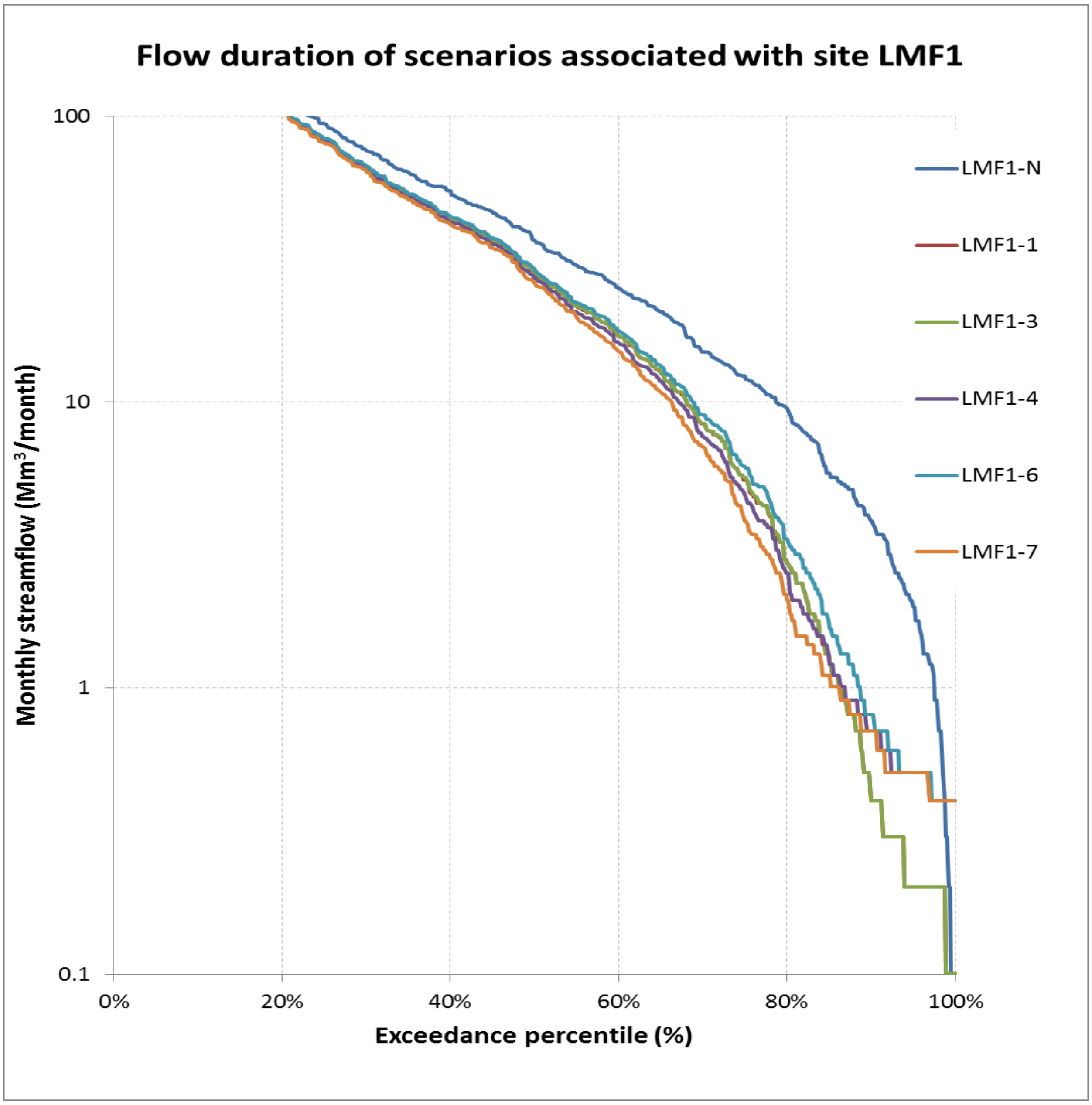


Figure 6.1. Monthly flow duration curves at the uMfolozi estuary for different scenarios. Source: DWS (2014).

Table 6.2. Main land-use, water demands and operational features of MK1 scenarios for the Mkuse River. Source: DWS (2014).

Item	Baseline MK1-1	MK1-2	MK1-3	MK1-4	MK1-5
With EWRs	No	Yes	No	No	Yes
Domestic demand (10^6 m^3)	3.02	3.02	5.74 (2040)	5.74	5.74
Industrial demand (10^6 m^3)	2.33	2.33	5.16 (2040)	4.02 (2040 with 22% WDM savings)	4.02
Afforestation (km^2)	202.1	202.1	202.1	202.1	202.1
Domestic return flows (%)	35	35	35	35	35
Irrigation (km^2)	56.8	48.76	56.8	56.8	56.8
Irrigation effic. (incl. distrib. losses) (%)	75	85	75	85	85

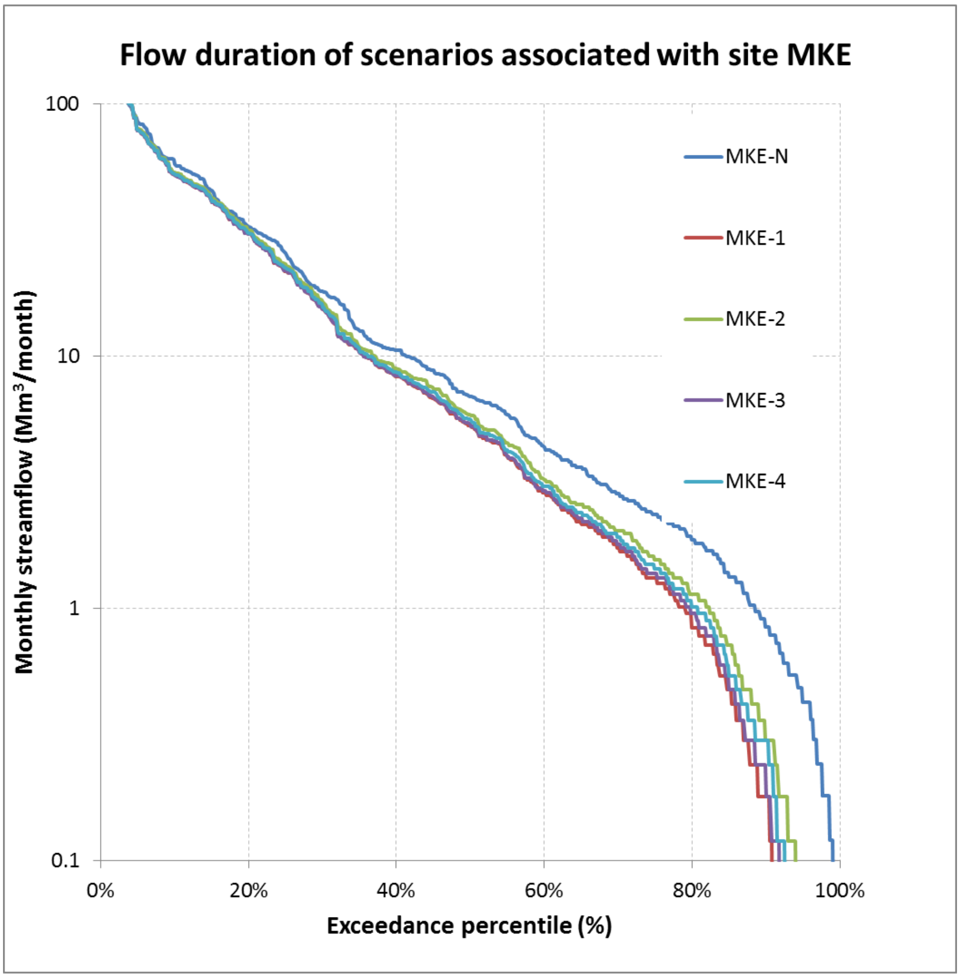


Figure 6.2. Monthly flow duration curves of Mkuze inflows into Lake St Lucia for different scenarios. Source: DWS (2014).

Table 6.3. Main land-use, water demands and operational features of Hluhluwe scenarios. Source: DWS (2014).

Item	Baseline HH1-1	HH1-2	HH1-3	HH1-4	HH1-5
With EWRs	No	No	Yes	No	No
Domestic demand (10^6 m^3)	3.1	3.1	3.1	6.02 (2040) (Transfer in = 6.10^6 m^3/a)	6.02 (2040) (Zero transfer in)
Afforestation (km^2)	13.9	0	0	13.9	0
Domestic return flows (%)	0	0	0	0	0
Irrigation (km^2)	13.8	13.8	13.8	13.8	13.8
Irrigation effic. and distrib. losses (%)	75	75	75	85	75

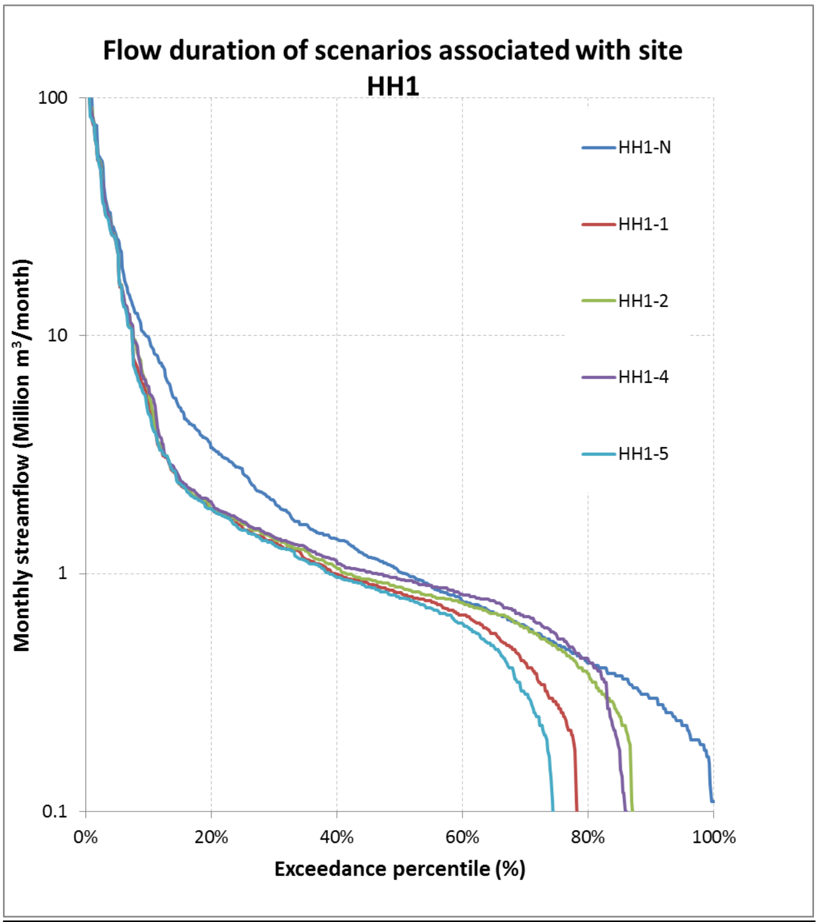


Figure 6.3. Monthly flow duration curves of Hluhluwe inflows into Lake St Lucia for different scenarios

Table 6.4. Operational flows scenarios for the Lake St Lucia estuary system used in this study.

Scenario	uMfolozi	Nyalazi	Hluhluwe	Mzinene	Mkuze
Reference	LMF 1_0 (1054.4)	NYAL-N (123.8)	HH1_N (61.5)	MSIN-N (26.4)	MKE 1_N (271.8)
Present Day	LMF1_1 (952.2)	NYA-C (103)	HH_1-1 (48)	MSIN-C (20)	MKE-1 (248.7)
Scenario 1	LMF1_4 (942.8)				
Scenario 2	LMF1_7 (932.0)				
Scenario 3	LMF1_8 (840.1)				
Scenario 4	LMF1_9 (850.6))				
Scenario 5	LMF1_EWR (270.9)				

6.2 Impacts of the operational flows scenarios on abiotic components

6.2.1 Hydrology

Variation in total annual inflows to the Lakes and down the uMfolozi under reference and present-day conditions and under the operational flow scenarios are presented in Figure 6.4. Inflows directly to the St Lucia Lakes are the same for all operational scenarios and are only subtly different for the operational scenarios on the uMfolozi. Reduction in the magnitude and frequency of flood in the St Lucia rivers and on the uMfolozi are estimated to be very small for all scenarios even for Scenario 5 (LMF 1_EWR_{min}) as all floods >1:2 are included in the EWR releases.

Two parameters were included in the calculation of the hydrology scores for the operational scenarios – MAR and Flood frequency (Table 6.5). The minimum of these two parameters was taken as the hydrology score. Scores were calculated separately for the three components of the system (Lakes, Narrows and uMfolozi) and a weighted average was used to calculate the final score for each scenario. Separate scores were calculated for the Beach channel (Present Day – A, Scenarios A1-5) and Combined mouth management options (Present Day – B, Scenarios B1-5).

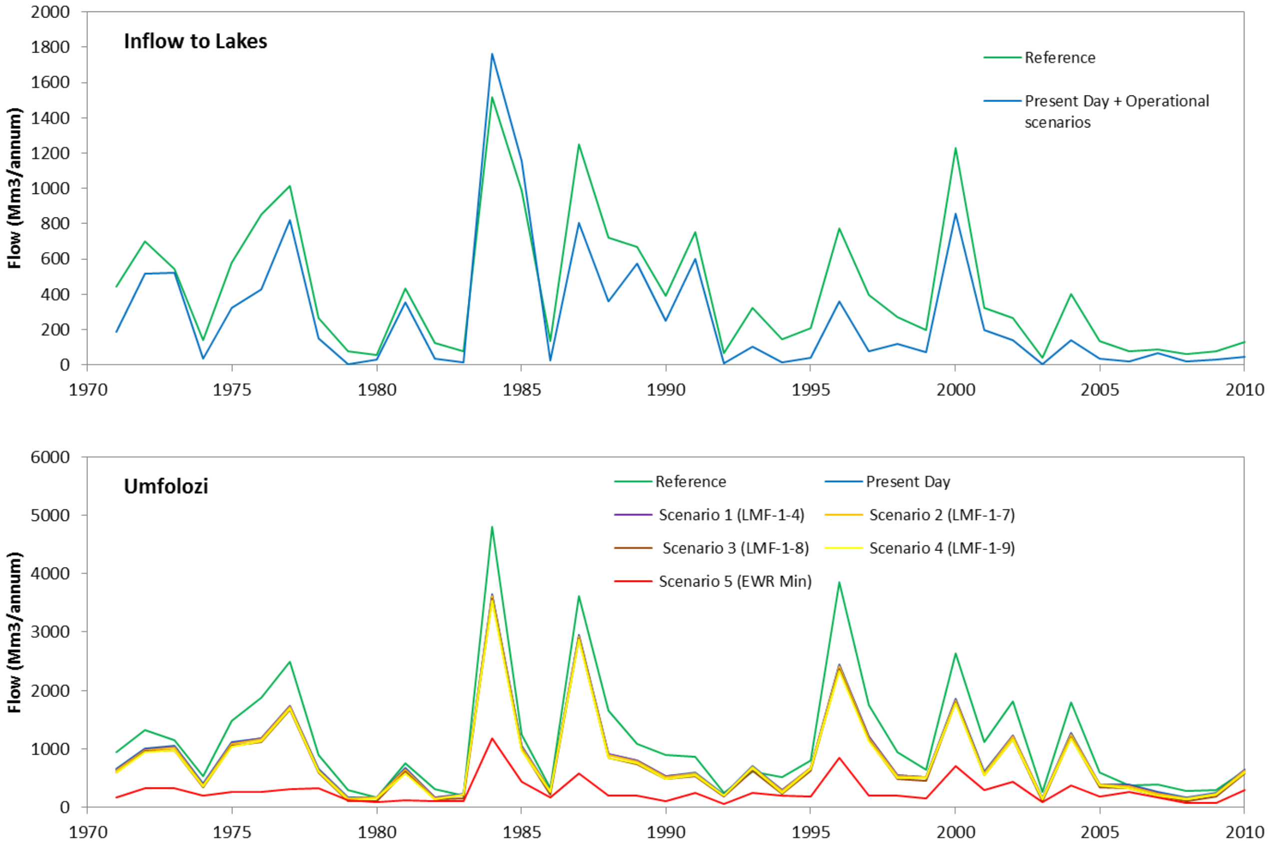


Figure 6.4. Inflows directly to the Lakes (top) and down the uMfolozi (bottom) under reference and present-day conditions and under the operational flow scenarios. Note that inflows directly to the St Lucia Lakes are the same for all operational scenarios.

Overall hydrology scores for the various operational flow scenarios were higher for the Beach channel (70.0-78.8%) than for the after Phase 1 excavation configuration (67.5-74.9%) (Table 6.5 and Figure 6.5). This may be counter intuitive but is linked to the fact the estuary mouth is closed for a greater portion of the time under the Beach channel option than for the after Phase 1 excavation option, which allows for a greater amount of freshwater from the uMfolozi to flow up into the Narrows and Lakes. The impact of the operational scenarios on the hydrology scores is similar, however, for the two mouth management options, with little difference evident between Scenario 1-4 (<3% difference, “B” class for all) but a big drop in score for Scenario 5 (~10% reduction, drops to a “C” class). This result is not surprising given that the difference in MAR between Scenarios 1-4 is no more than 6% whereas the reduction in MAR relative to Present for Scenario 5 is over 67%.

Table 6.5. Hydrological health scores for the operational scenarios 1-5 for the two mouth configurations. Present-day scores are also included.

Component	Parameter	Mouth A – with beach channel						Mouth B - after Phase 1 excavation					
		Present Day - A	Sc. A1 (LMF-1-4)	Sc. A2 (LMF-1-7)	Sc. A3 (LMF-1-8)	Sc. A4 (LMF-1-9)	Sc. A5 (LMF EWR min)	Present Day - B	Sc. B1 (LMF1B-4)	Sc. B2 (LMF-1B-7)	Sc. B3 (LMF-1B-8)	Sc. B4 (LMF-1B-9)	Sc. B5 (LMF EWR min)
Lakes	1.1.a. MAR (%Nat; St Lucia + uMfolozi)	79.6	79.5	78.9	77.6	78.0	75.2	75.4	75.2	75.0	75.5	75.2	72.4
	1.1.b. Flood frequency (weighted ave Class 1, 2, 3, 4)	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6
	1.1. Hydrology (min a-b)	**79.6**	**79.5**	**78.9**	**77.6**	**78.0**	**75.2**	**75.4**	**75.2**	**75.0**	**75.5**	**75.2**	**72.4**
Narrows	1.1.a. MAR (%Nat; St Lucia + uMfolozi, % Nat))	79.6	79.5	78.9	77.6	78.0	75.2	75.4	75.2	75.0	75.5	75.2	72.4
	1.2.b. Flood frequency (weighted ave Class 1, 2, 3, 4)	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6
	1.2. Hydrology (min a-b)	**79.6**	**79.5**	**78.9**	**77.6**	**78.0**	**75.2**	**75.4**	**75.2**	**75.0**	**75.5**	**75.2**	**72.4**
uMfolozi	1.3a. MAR (%Nat, uMfolozi)	72.7	71.9	70.9	66.8	68.2	23.3	72.7	71.9	70.9	66.8	68.2	23.3
	1.3.b. Flood frequency (weighted ave Class 1, 2, 3, 4)	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7
	1.3. Hydrology (min a-b)	**72.7**	**71.9**	**70.9**	**66.8**	**68.2**	**23.3**	**72.7**	**71.9**	**70.9**	**66.8**	**68.2**	**23.3**
All	**1. Hydrology (Lx0.6+Nx0.3+Mx0.1)**	**78.9**	**78.8**	**78.1**	**76.5**	**77.0**	**70.0**	**75.1**	**74.9**	**74.6**	**74.6**	**74.5**	**67.5**
		B	**B**	**B**	**B**	**B**	**C**	**B**	**B**	**B**	**B**	**B**	**C**

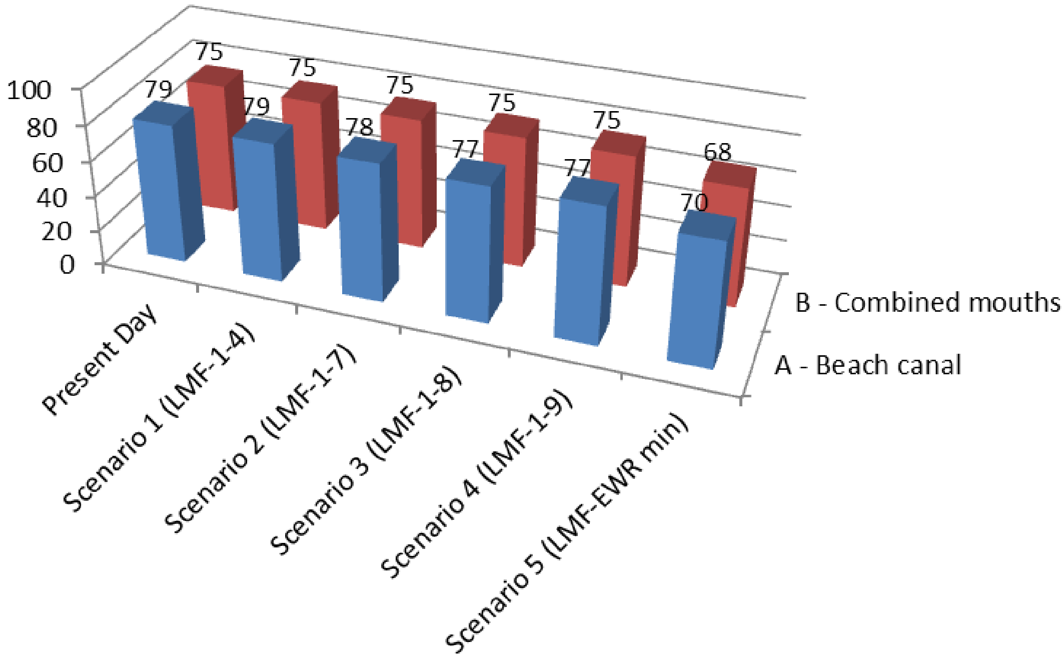


Figure 6.5. Hydrology health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation).

6.2.2 Hydrodynamic functioning

6.2.2.1 Mouth state

Variation in mouth state (% time open) for all of the operational flow scenarios under the "Beach channel" and "Combined mouth" options are shown in Figure 6.6. Summary data (overall % open) is presented in Table 6.6. The proportion of time that the mouth remains open is higher for all operational flow scenarios under the "after Phase 1 excavation" option (66.5-62.0% open) than for the "Beach channel" option (60.8-45.3). There is also little difference between mouth state for Scenarios 1-4 (<10% difference) for both mouth options but this drops sharply for Scenario 5 (>20% reduction).

Table 6.6. Summary data for change in mouth state (% open, % of Reference) for the various operational flow scenarios.

Scenario	% Open	% of Reference
Reference	80.6	
Present Day (Beach channel)	60.8	75.5
Mouth A1 (LMF 1-4)	60.6	75.2
Mouth A2 (LMF 1-7)	60.3	74.8
Mouth A3 (LMF1-8)	58.7	72.8
Mouth A4 (LMF 1-9)	59.4	73.7
Mouth A5 (LMF EWR min)	45.3	56.2
Present Day (after Phase 1 excavation)	66.5	82.5
Mouth B1 (LMF 1-4)	66.3	82.3
Mouth B2 (LMF 1-7)	65.9	81.8
Mouth B3 (LMF1-8)	62.0	77.0
Mouth B4 (LMF 1-9)	64.2	79.7
Mouth B5 (LMF EWR min)	52.2	64.8

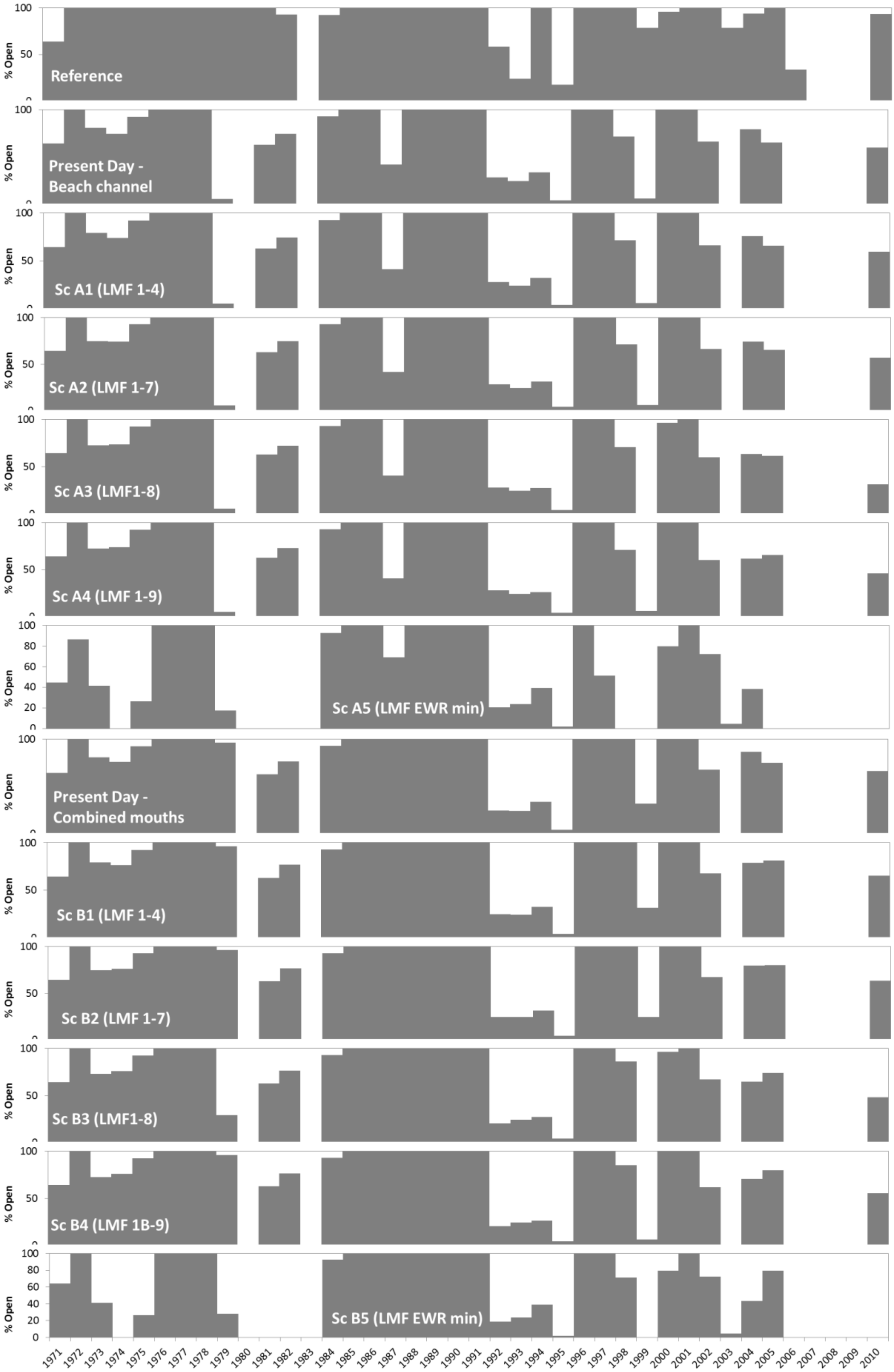


Figure 6.6. Mouth status (% open) for all operational flow scenarios.

6.2.2.2 Tidal prism

Variation in tidal prism for all of the operational flows scenarios under the “Beach channel” and “Combined mouth” options are shown in Figure 6.7 and Figure 6.8, respectively. Summary data (overall % open) are presented in Table 6.6. While there is a very clear difference in the size of the tidal prism between Mouth A (with the beach channel in place) and Mouth B (combined mouths), the impact of the different flow scenarios on the size of the tidal prism is extremely small. There is no measurable difference in the magnitude of the tidal flow up the Narrows between flow Scenarios 1-4 with the beach channel in place (Mouth A) and only a modest increase under flow Scenario 5 (9% increase). Under the combined mouth configuation (Mouth B), tidal inflows up the Narrows decrease by around 4% under flow scenarios 1, 2 and 4, by 9% for flow Scenario 3 and by 15% for Scenario 5. Note that the reversal in the response for the two different mouth options is linked to a decrease in the open phase with declining flows in the case of Mouth B which does not happen with Mouth A (beach channel). The magnitude of the changes in the volume of the tidal prism for uMfolozi channel are similar to those for the Narrows but are all positive (i.e. increase) relative to Present Day.

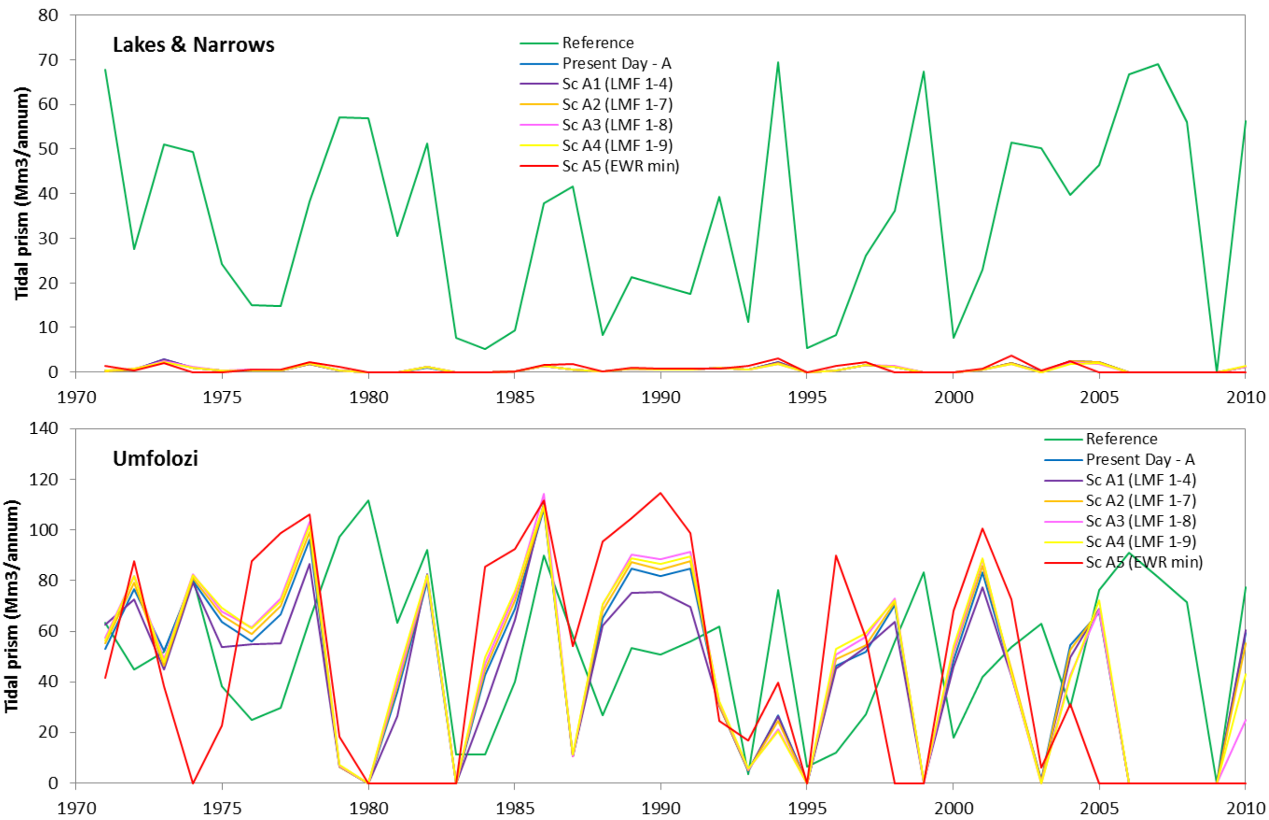


Figure 6.7. Variation in tidal inflow volume up the Narrows (top) and the uMfolozi channel (bottom) with the Beach channel (Mouth A) under reference and present-day conditions and under the operational flow scenarios.

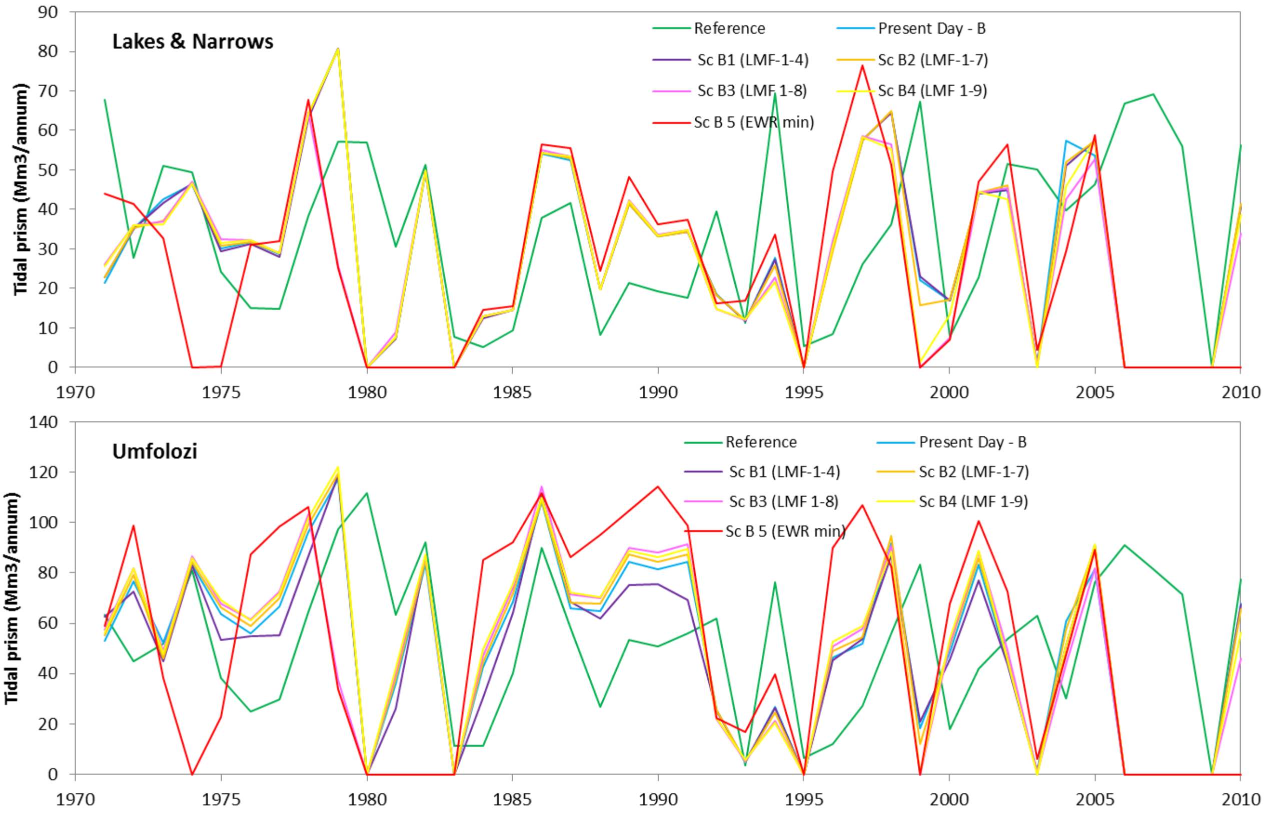


Figure 6.8. **Variation in tidal inflow volume up the Narrows (top) and the uMfolozi channel (bottom) with after Phase 1 excavation (Scenario B) under reference and present-day conditions and under the operational flow scenarios.**

Table 6.7. **Summary data for change in the size of the tidal prism for the Reference condition, Present Day and the various operational flow scenarios under the "Beach channel" (A) and "after Phase 1 excavation" (B) conditions.**

	St Lucia Narrows		uMfolozi	
	Volume (Mm3/a)	% of Ref	Volume (Mm3/a)	% of Ref
Reference	34.5	-	52.3	-
Present Day - A	0.7	2.0%	45.1	86.2%
Sc A1 (LMF 1-4)	0.7	2.0%	42.3	80.9%
Sc A2 (LMF 1-7)	0.7	2.0%	46.0	88.0%
Sc A3 (LMF 1-8)	0.7	2.0%	46.3	88.5%
Sc A4 (LMF 1-9)	0.7	2.0%	46.8	89.5%
Sc A5 (EWR min)	0.8	2.2%	44.2	84.4%
Present Day - B	29.8	86.2%	51.0	97.5%
Sc B1 (LMF-1-4)	29.7	85.9%	48.5	92.8%
Sc B2 (LMF-1-7)	29.5	85.4%	52.1	99.6%
Sc B3 (LMF 1-8)	27.0	78.1%	50.0	95.7%
Sc B4 (LMF 1-9)	28.5	82.6%	52.6	100.7%
Sc B 5 (EWR min)	25.2	73.1%	51.9	99.2%

6.2.2.3 Water level

Variation in mean water level for all of the operational flow scenarios under the "Beach channel" and "Combined mouth" configurations are shown in Figure 6.9 and Figure 6.10, respectively. Summary data are presented in Table 6.6. Average water level in the Lakes was modestly elevated above Reference for all the operational flow scenarios except for Scenario 3 with the Beach channel in place (Mouth A) but was slightly lower than Reference (but very similar to Present Day) for all the operational flow scenarios except Scenario 5 under the combined mouths configuration (Mouth B). In the case of the Narrows and the uMfolozi, water levels were all dramatically elevated above Reference for all operational flow scenarios (more so with the beach channel in place), but again not very different from Present Day, aside possibly for Scenario 5 where the differences were more marked.

Table 6.8. Summary data for change in water level for the Reference condition, Present Day and the various operational flow scenarios under the "Beach channel" (A) and "after Phase 1 excavation" (B) conditions.

	Lakes		Narrows		uMfolozi	
	Water level (m)	% Natural	Water level (m)	% Natural	Water level (m)	% Natural
Reference	0.515	-	0.226	-	0.210	-
Present Day - A	0.594	115.4%	0.678	299.7%	0.433	206.7%
Sc A1 (LMF 1-4)	0.583	113.3%	0.668	295.6%	0.429	204.5%
Sc A2 (LMF 1-7)	0.580	112.6%	0.668	295.7%	0.433	206.8%
Sc A3 (LMF 1-8)	0.511	99.3%	0.600	265.3%	0.363	173.3%
Sc A4 (LMF 1-9)	0.543	105.4%	0.635	280.7%	0.399	190.6%
Sc A5 (EWR min)	0.580	112.6%	0.694	307.1%	0.541	258.1%
Present Day - B	0.507	98.5%	0.425	187.9%	0.352	167.8%
Sc B1 (LMF-1-4)	0.509	98.9%	0.425	188.1%	0.358	170.8%
Sc B2 (LMF-1-7)	0.511	99.2%	0.425	188.1%	0.353	168.4%
Sc B3 (LMF 1-8)	0.476	92.5%	0.392	173.3%	0.319	152.1%
Sc B4 (LMF 1-9)	0.496	96.3%	0.411	181.8%	0.337	161.0%
Sc B 5 (EWR min)	0.553	107.5%	0.526	232.6%	0.448	214.0%

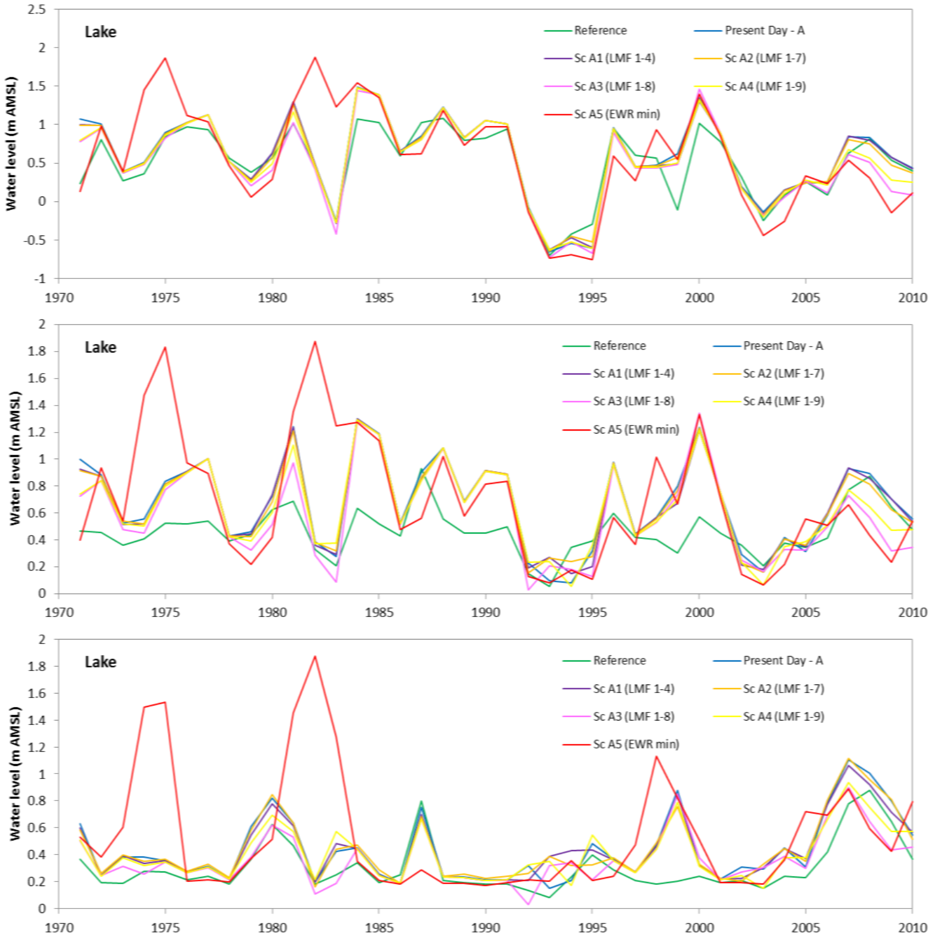


Figure 6.9. Variation in water level in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with the Beach channel under reference and present-day conditions and under the operational flow scenarios.

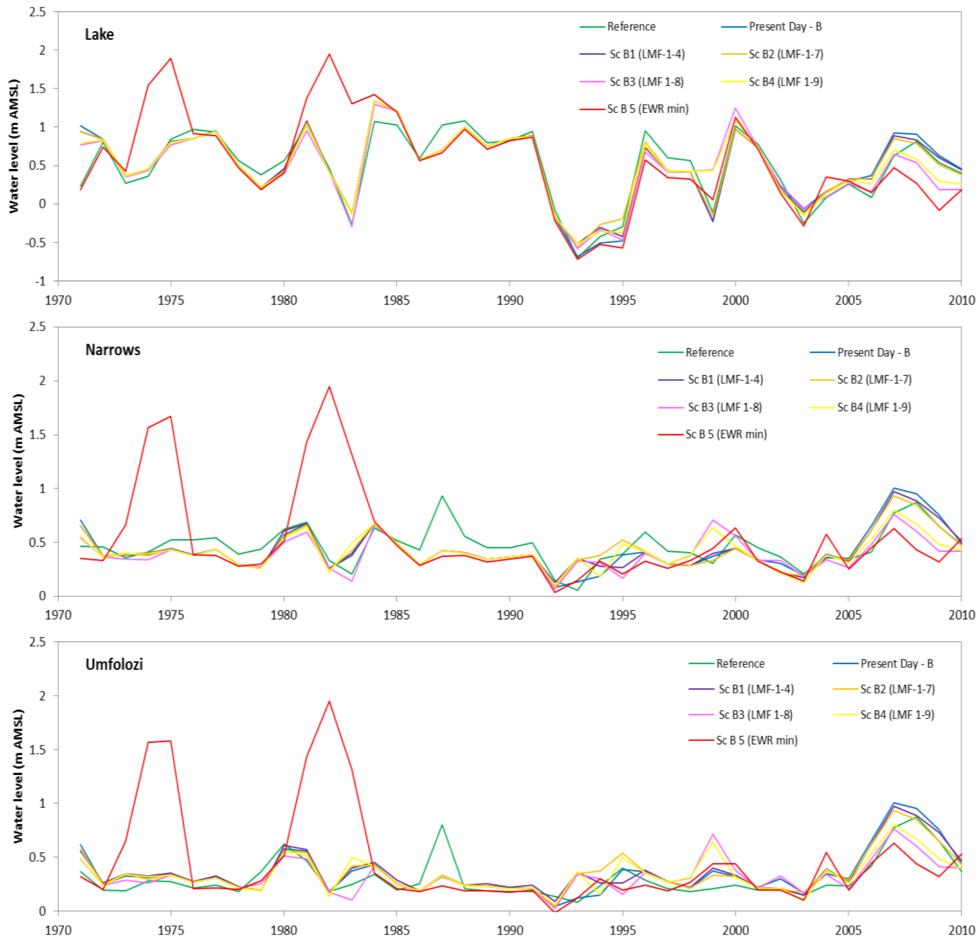


Figure 6.10. Variation in water level in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with

after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

Table 6.9. Hydrodynamic health scores for Operational scenarios 1-5 for the "Beach channel" and "Combined mouth" configurations. Scores for Present Day are also included.

Component	Parameter	Beach channel						after Phase 1 excavation					
		Present Day - A	Sc. A1 (LMF-1-4)	Sc. A2 (LMF-1-7)	Sc. A3 (LMF-1-8)	Sc. A4 (LMF-1-9)	Sc. A5 (LMF EWR min)	Present Day - B	Sc. B1 (LMF1B-4)	Sc. B2 (LMF-1B-7)	Sc. B3 (LMF-1B-8)	Sc. B4 (LMF-1B-9)	Sc. B5 (LMF EWR min)
Lakes	2.1.a. Mouth condition (% time open, %Nat)	75.5	75.2	74.8	72.8	73.7	56.2	82.5	82.3	81.8	77.0	79.7	64.8
	2.1.b. Tidal prism (ave, %Nat)	2.0	2.0	2.0	2.0	2.0	2.2	86.2	85.9	85.4	78.1	82.6	73.1
	2.1.c. Water level (ave, %Nat)	86.7	88.3	88.8	99.3	94.9	88.8	98.5	98.9	99.2	92.5	96.3	93.1
	2.1. Hydrodynamics (min a-c)	2.0	2.0	2.0	2.0	2.0	2.2	82.5	82.3	81.8	77.0	79.7	64.8
Narrows	2.2.a. Mouth condition (% time open, %Nat)	75.5	75.2	74.8	72.8	73.7	56.2	82.5	82.3	81.8	77.0	79.7	64.8
	2.2.b. Tidal prism (ave, %Nat)	2.0	2.0	2.0	2.0	2.0	2.2	86.2	85.9	85.4	78.1	82.6	73.1
	2.2.c. Water level (ave, %Nat)	33.4	33.8	33.8	37.7	35.6	32.6	53.2	53.2	53.2	57.7	55.0	43.0
	2.2. Hydrodynamics (min a-c)	2.0	2.0	2.0	2.0	2.0	2.2	53.2	53.2	53.2	57.7	55.0	43.0
uMfolozi	2.3.a. Mouth condition	75.5	75.2	74.8	72.8	73.7	56.2	82.5	82.3	81.8	77.0	79.7	64.8
	2.3.b. Tidal prism (ave, %Nat)	86.2	80.9	88.0	88.5	89.5	84.4	97.5	92.8	99.6	95.7	100.7	99.2
	2.3.c. Water level (ave, %Nat)	48.4	48.4	48.9	57.7	52.5	38.7	59.6	58.6	59.4	65.7	62.1	46.7
	2.3. Hydrodynamics (min a-c)	48.4	48.4	48.9	57.7	52.5	38.7	59.6	58.6	59.4	65.7	62.1	46.7
All	2. Hydrodynamics (Lx0.6+Nx0.3+Mx0.1)	6.7	6.7	6.7	7.6	7.0	5.9	71.4	71.2	71.0	70.1	70.5	56.4
		F	F	F	F	F	F	C	C	C	C	C	D

6.2.2.4 Hydrodynamic health

Hydrodynamic health scores for Present Day and all the operational scenarios are presented in Table 6.9 and Figure 6.11. There is a large difference in the health scores for the Mouth A (beach channel) and B (combined mouths) but little difference between the scores for the various flow scenarios aside from a marked reduction in hydrodynamic health under flow Scenario 5 (linked to changes in health scores for all three component parameters – mouth state, tidal prism and water level). This is not surprising given that the difference in MAR between Scenarios 1-4 is no more than 6%, whereas the reduction in MAR relative to Present for Scenario 5 is over 67% for.

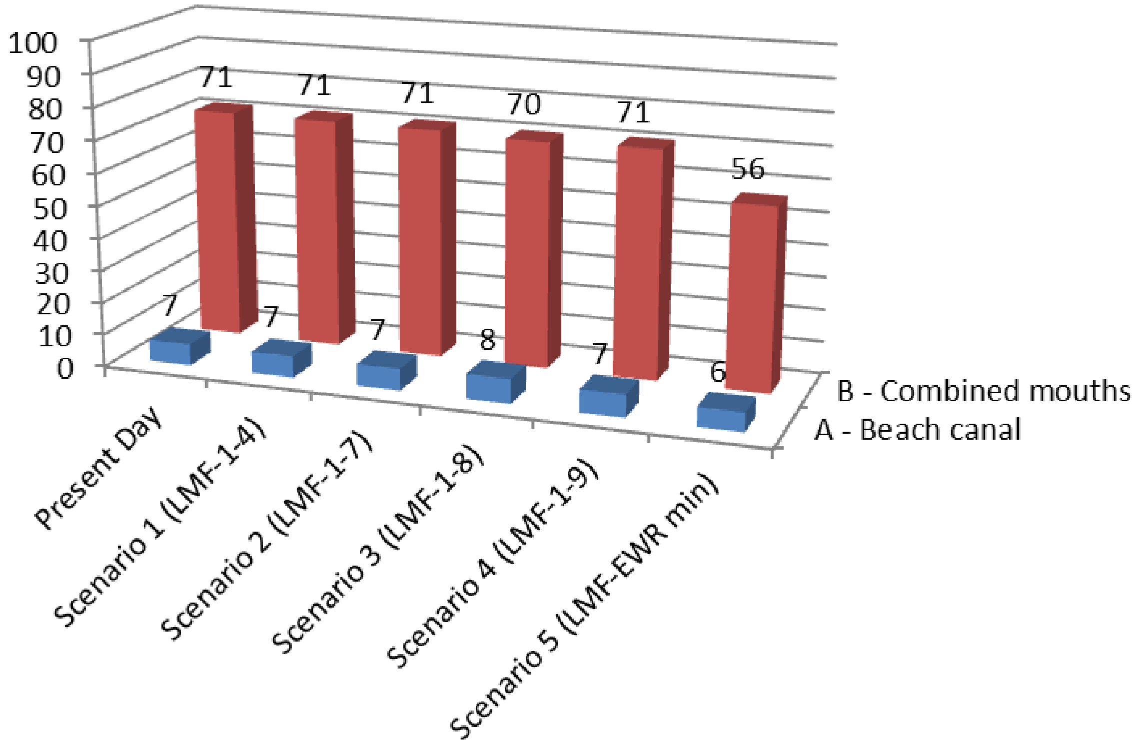


Figure 6.11. Hydrodynamic health scores for Operational scenarios 1-5 for the “Beach channel” and “Combined mouth” configurations

6.2.3 Water quality

6.2.3.1 Salinity

Variations in mean salinity for all of the operational flow scenarios under the “Beach channel” and “Combined mouth” configurations are shown in Figure 6.12 and Figure 6.13, respectively. Summary data are presented in Table 6.10. Salinity levels in the Lakes are elevated relative to both Reference and Present Day for all the operational flow scenarios, but more so for the after Phase 1 excavation as opposed to the Beach channel scenario. The elevation is particularly marked in the case of flow Scenario 5 in both cases. The situation in the uMfolozi is similar (salinity elevated relative to Reference and Present Day for all operational flow scenarios) but the reverse is true in the Narrows (salinity is lower than Reference but not Present Day). These changes are linked to changes in flow, mouth state and tidal prism, all of which influence salinity in the respective components of the system.

Table 6.10. Summary data for change in salinity for the Reference condition, Present Day and the various operational flow scenarios under the "Beach channel" (A) and "after Phase 1 excavation" (B) conditions.

	Lakes		Narrows		uMfolozi	
	Salinity	% Natural	Salinity	% Natural	Salinity	% Natural
Reference	7.4	-	14.3	-	6.8	-
Present Day - A	9.9	132.4%	8.4	58.4%	11.2	164.3%
Sc A1 (LMF 1-4)	10.9	146.2%	8.7	60.7%	11.8	173.3%
Sc A2 (LMF 1-7)	10.9	147.0%	8.8	61.3%	11.1	163.1%
Sc A3 (LMF 1-8)	12.2	164.0%	10.1	70.3%	13.2	194.5%
Sc A4 (LMF 1-9)	11.9	160.0%	9.2	64.0%	12.4	182.4%
Sc A5 (EWR min)	15.7	211.3%	9.7	67.8%	12.0	177.2%
Present Day - B	17.4	233.2%	14.1	98.7%	12.7	186.2%
Sc B1 (LMF-1-4)	18.7	250.9%	14.5	101.5%	12.6	185.4%
Sc B2 (LMF-1-7)	18.9	254.1%	14.6	102.3%	13.3	196.2%
Sc B3 (LMF 1-8)	20.3	273.0%	14.7	102.5%	14.0	205.7%
Sc B4 (LMF 1-9)	17.7	238.4%	14.3	99.6%	13.5	198.3%
Sc B 5 (EWR min)	22.4	300.5%	14.3	100.2%	13.6	200.2%

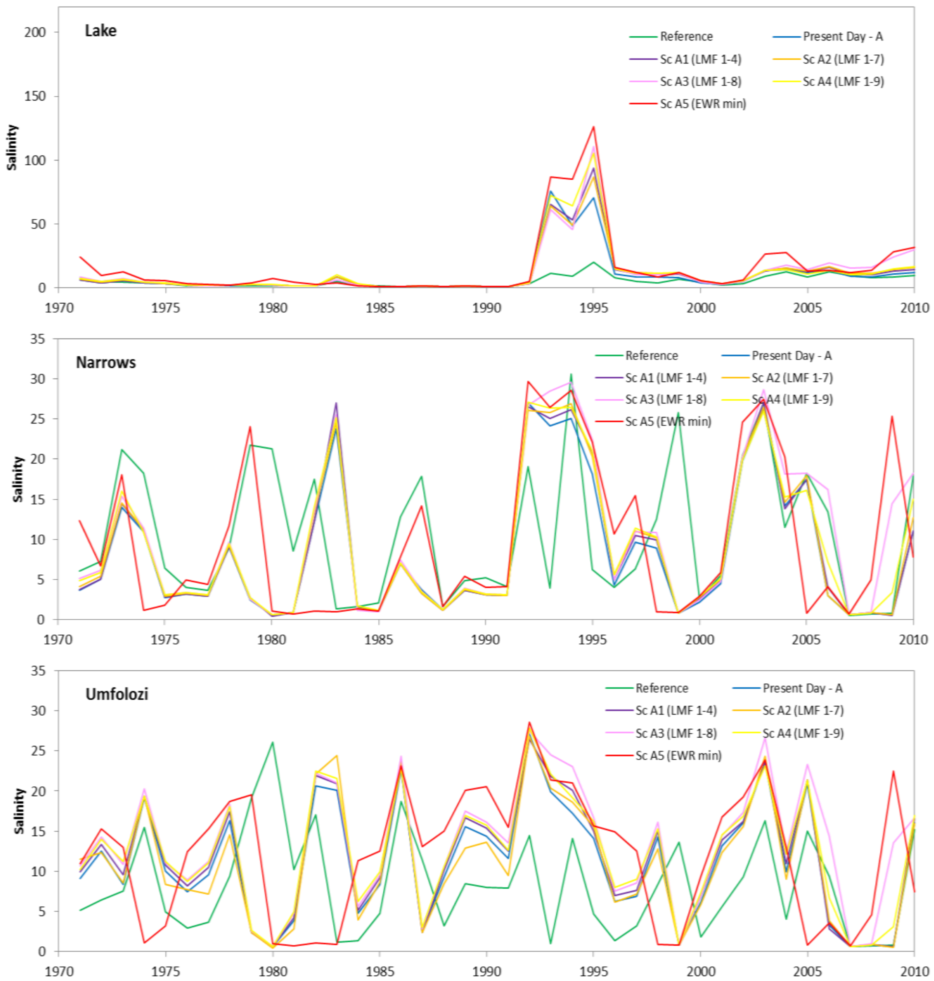


Figure 6.12. Variation in salinity in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with the Beach channel under reference and present-day conditions and under the operational flow scenarios.

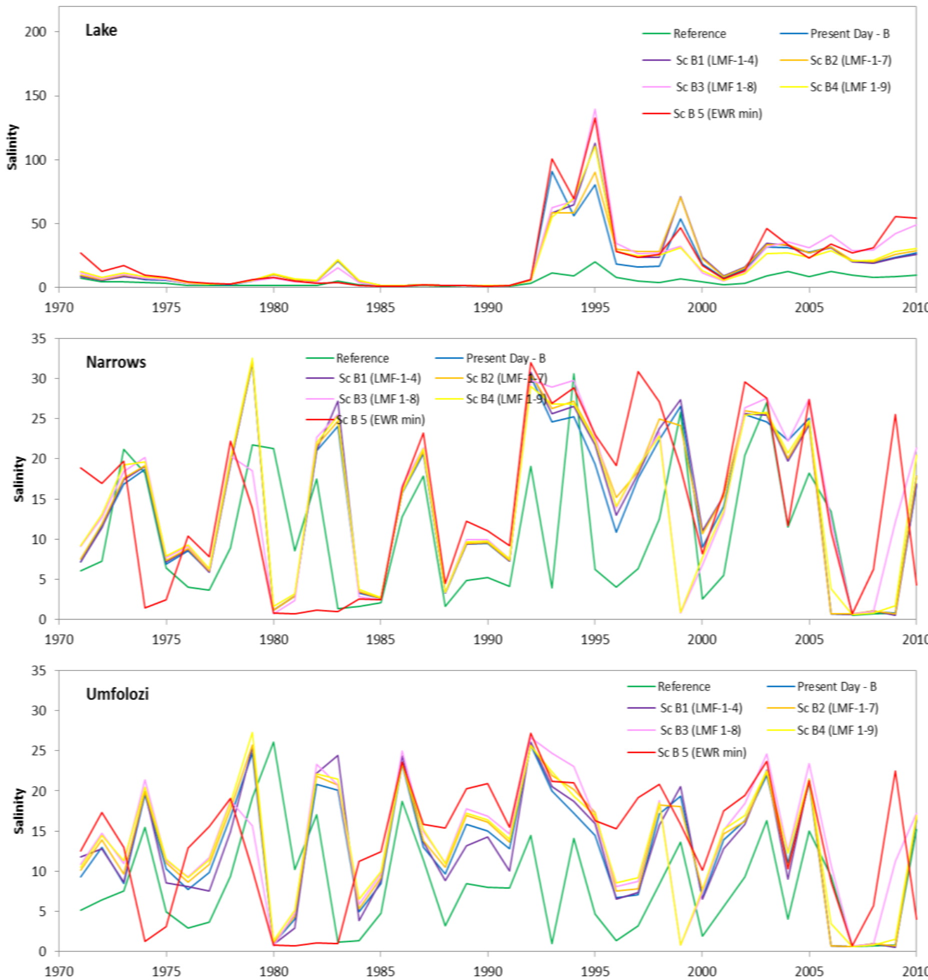


Figure 6.13. Variation in salinity in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with after

Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

6.2.3.2 Turbidity

Variation in turbidity for all of the operational flow scenarios under the “Beach channel” and “Combined mouth” configurations are shown in Figure 6.14 and Figure 6.15, respectively. Summary data are presented in Table 6.11. Turbidity levels in the various components of the Lake St Lucia system are elevated relative to Reference for all operational flow scenarios except in the Narrows under Scenario 3, and are mostly lower than Present except in the Lakes (flow scenarios 2-5). This is a function of the complex interplay between relative influences of suspended sediment levels in the influent water (important in the uMfolozi and to a lesser extent in the Narrows), variations in water level (very important in the Lakes), and the magnitude of the tidal prism (important in the Narrows and uMfolozi).

Table 6.11. Summary data for change in turbidity for the Reference condition, Present Day and the various operational flow scenarios under the “Beach channel” (A) and “after Phase 1 excavation” (B) conditions.

	Lakes		Narrows		uMfolozi	
	Turbidity (NTU)	% Natural	Turbidity (NTU)	% Natural	Turbidity (NTU)	% Natural
Reference	298.6	-	15.8	-	20.8	-
Present Day - A	412.2	138.0%	35.7	225.5%	53.4	256.2%
Sc A1 (LMF 1-4)	401.1	134.3%	35.5	224.2%	52.3	251.2%
Sc A2 (LMF 1-7)	395.9	132.6%	35.6	224.6%	52.9	254.0%
Sc A3 (LMF 1-8)	482.9	161.7%	14.8	93.6%	21.2	101.6%
Sc A4 (LMF 1-9)	434.4	145.5%	35.3	223.0%	52.8	253.6%
Sc A5 (EWR min)	531.7	178.0%	25.8	162.9%	43.2	207.4%
Present Day - B	420.6	140.8%	38.7	244.6%	53.4	256.4%
Sc B1 (LMF-1-4)	364.9	122.2%	38.7	244.1%	52.2	250.7%
Sc B2 (LMF-1-7)	471.0	157.7%	38.6	243.8%	52.9	253.8%
Sc B3 (LMF 1-8)	384.3	128.7%	15.9	100.6%	21.0	100.8%
Sc B4 (LMF 1-9)	362.3	121.3%	38.2	241.4%	51.8	248.8%
Sc B 5 (EWR min)	447.7	149.9%	29.6	186.9%	43.8	210.4%

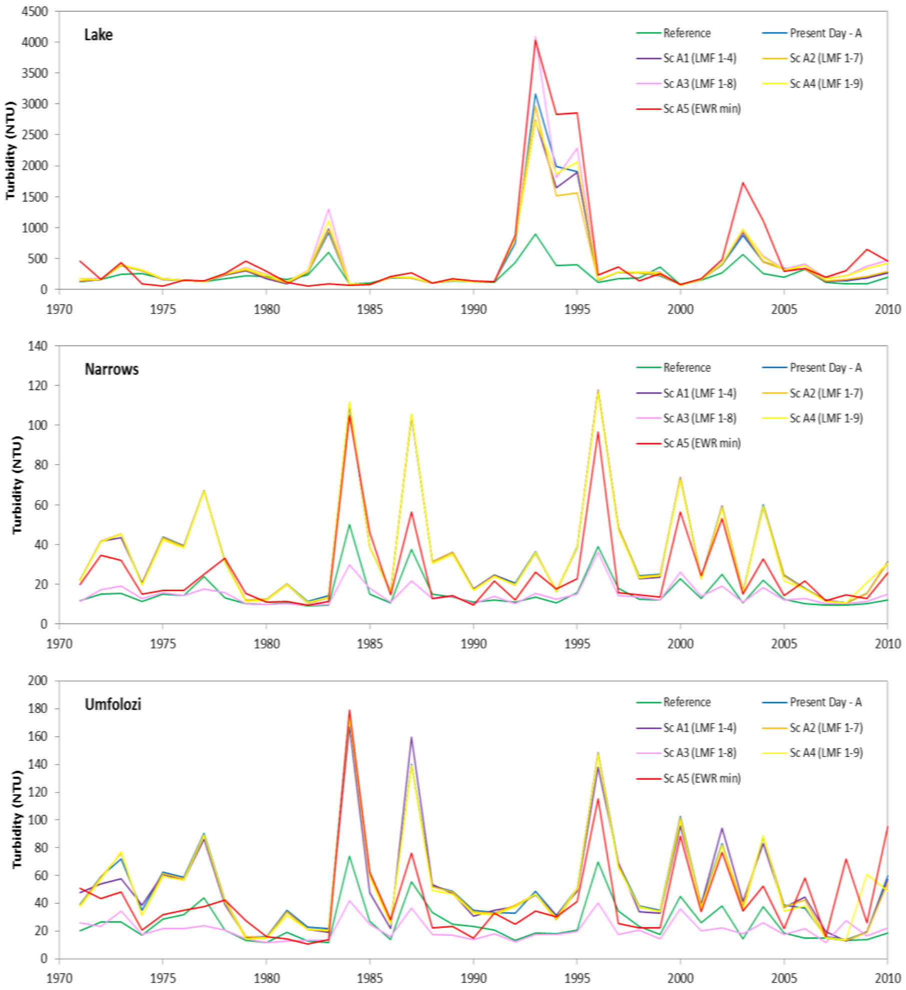


Figure 6.14. Variation in turbidity in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with the Beach channel under reference and present-day conditions and under the operational flow scenarios.

Figure 6.15. Variation in turbidity in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with after

Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

Table 6.12. Water quality health scores for Operational scenarios 1-5 for the "Beach channel" and "Combined mouth" configurations. Scores for Present Day are also included.

Component	Parameter	Beach channel						after Phase 1 excavation					
		Present Day - A	Sc. A1 (LMF-1-4)	Sc. A2 (LMF-1-7)	Sc. A3 (LMF-1-8)	Sc. A4 (LMF-1-9)	Sc. A5 (LMF EWR min)	Present Day - B	Sc. B1 (LMF1B-4)	Sc. B2 (LMF-1B-7)	Sc. B3 (LMF-1B-8)	Sc. B4 (LMF-1B-9)	Sc. B5 (LMF EWR min)
Lakes	4.1.a. Salinity	75.5	68.4	68.0	61.0	62.5	47.3	42.9	39.9	39.4	36.6	41.9	33.3
	4.1.b. DIN + DIP (Ave-min, Sim. Coeff.)	42.9	46.0	45.7	45.2	43.8	37.2	53.1	65.8	65.9	63.2	65.7	48.2
	4.1.c. Turbidity	72.4	74.5	75.4	61.8	68.7	56.2	71.0	81.8	63.4	77.7	82.4	66.7
	4.1. Water quality (Score = (0.6*S+0.4*(min to b-c))	62.5	59.4	59.1	54.7	55.0	43.3	47.0	49.9	49.3	47.3	51.5	39.2
Narrows	4.2.a. Salinity	58.4	60.7	61.3	70.3	64.0	67.8	98.7	98.5	97.8	97.5	99.6	99.8
	4.2.b. DIN + DIP	36.9	36.9	36.9	36.7	36.9	37.0	56.7	56.7	56.5	54.2	55.6	53.1
	4.2.c. Turbidity	44.3	44.6	44.5	93.6	44.8	61.4	40.9	41.0	41.0	99.4	41.4	53.5
	4.2. Water quality (Score = (0.6*S+0.4*(min to b-c))	49.8	51.2	51.5	56.9	53.1	55.5	75.6	75.5	75.1	80.2	76.4	81.1
uMfolozi	4.3.a. Salinity	11.2	11.1	11.8	13.2	12.4	12.0	12.7	12.6	13.3	14.0	13.5	13.6
	4.3.b. DIN + DIP	58.1	57.7	58.3	58.6	58.6	59.5	59.1	58.8	59.5	59.1	59.7	61.0
	4.3.c. Turbidity	39.0	39.8	39.4	98.4	39.4	48.2	39.0	39.9	39.4	99.2	40.2	47.5
	4.3. Water quality (Score = (0.6*S+0.4*(min to b-c))	22.3	22.6	22.8	31.4	23.2	26.5	23.2	23.5	23.8	32.0	24.2	27.2
All	4. Water quality (Lx0.6+Nx0.3+Mx0.1)	54.7	53.3	53.2	53.0	51.3	45.3	53.2	55.0	54.5	55.6	56.2	50.6
		D	D	D	D	D	D	D	D	D	D	D	D

6.2.3.3 Water quality health

Water quality health scores for Present Day and all the operational scenarios are presented in Table 6.12 and Figure 6.16. Under the Beach channel configuration (Mouth A) water quality health is lower for the operational scenarios than for Present Day (Scenario 5 being the lowest, followed by Scenarios 4, then 1-3). However, under the after Phase 1 excavation configuration, the water quality health scores for the operational scenarios (50.6-56.2) were mostly higher than Present Day (53.2) aside from Scenario 5 (50.6). Scenario 3 and 4 yielded the highest scores (55.6 and 56.2, respectively) while Scenarios 1 ad 2 yield scores intermediate between these scores and Present Day (54.5-55.0).

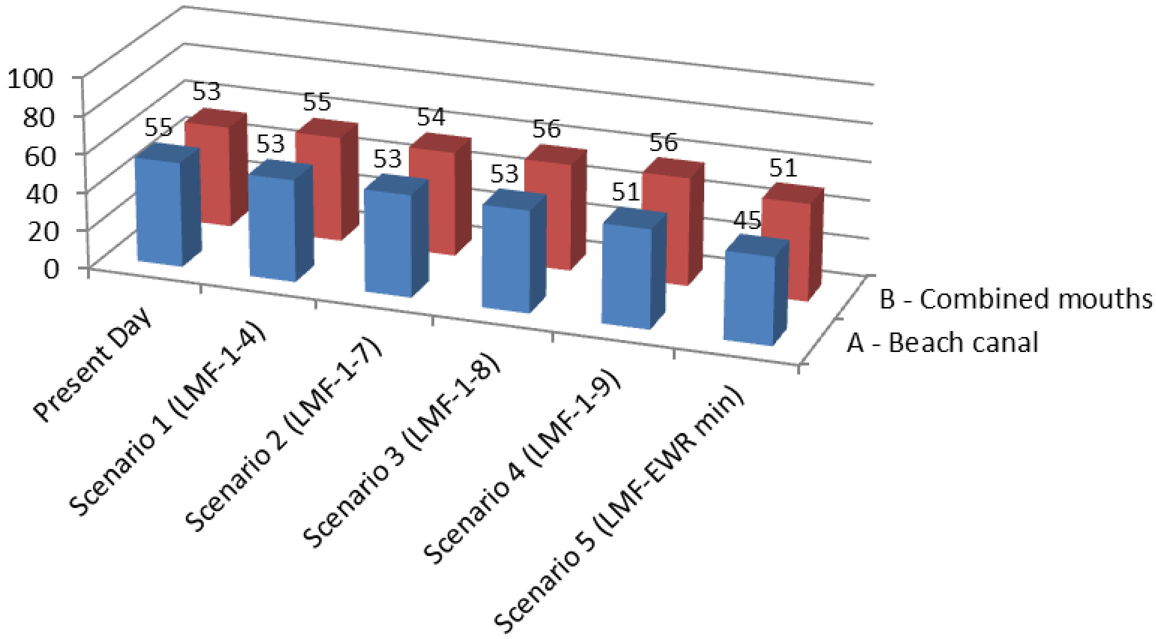


Figure 6.16. Water quality health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation)

6.2.4 Overall abiotic health - Operational scenarios

Overall abiotic health scores for the operational scenarios are presented in Table 6.13 and Figure 6.17. Overall abiotic health scores for all the operational scenarios (40.4-46.2, all class D) were marginally lower than Present Day (46.8) under the “Beach channel” configuration. In the case of the “after Phase 1 excavation” configuration, however, abiotic health scores were marginally higher than Present Day (66.6) for all flow scenarios (66.7-67.9) except Scenario 5 (58.2). This is linked to the rather complex interplay between the effects of reduced inflows from the rivers feeding directly into the St Lucia Lakes (Mkuze, Hluhluwe, Mzinene, and Nyalazi) under present-day conditions, which in turn have caused changes in water level and water quality (particularly salinity) in the Lakes, and the fact that a small reduction in flow in the uMfolozi (as is evident for Scenarios 1-4) results in an reduction in amount of time that the mouth remains open and hence an increase in the volume of water reaching the Lakes from the uMfolozi

The correlation between abiotic health of the system as a whole and MAR in the uMfolozi was positive across the full range of scenarios (Figure 6.18).

Table 6.13. Abiotic health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation).

	1. Hydrology		2. Hydrodynamics		3. Water quality		Abiotic health	
Present Day - A	78.9	B	6.7	F	54.7	D	46.8	D
Sc. A1 (LMF 1-4)	78.8	B	6.7	F	53.3	D	46.2	D
Sc. A2 (LMF 1-7)	78.1	B	6.7	F	53.2	D	46.0	D
Sc. A3 (LMF 1-8)	76.5	B	7.6	F	53.0	D	45.7	D
Sc. A4 (LMF 1-9)	77.0	B	7.0	F	51.3	D	45.1	D
Sc. A5 (LMF EWR min)	70.0	C	5.9	F	45.3	D	40.4	D
Present Day - B	75.1	B	71.4	C	53.2	D	66.6	C
Sc. B1 (LMF 1-4)	74.9	C	71.2	C	55.0	D	67.0	C
Sc. B2 (LMF 1-7)	74.6	C	71.0	C	54.5	D	66.7	C
Sc. B3 (LMF 1-8)	74.6	C	70.1	C	55.6	D	66.8	C
Sc. B4 (LMF 1-9)	74.5	C	70.5	C	56.2	D	67.1	C
Sc. B5 (LMF EWR min)	67.5	C	56.4	D	50.6	D	58.2	D

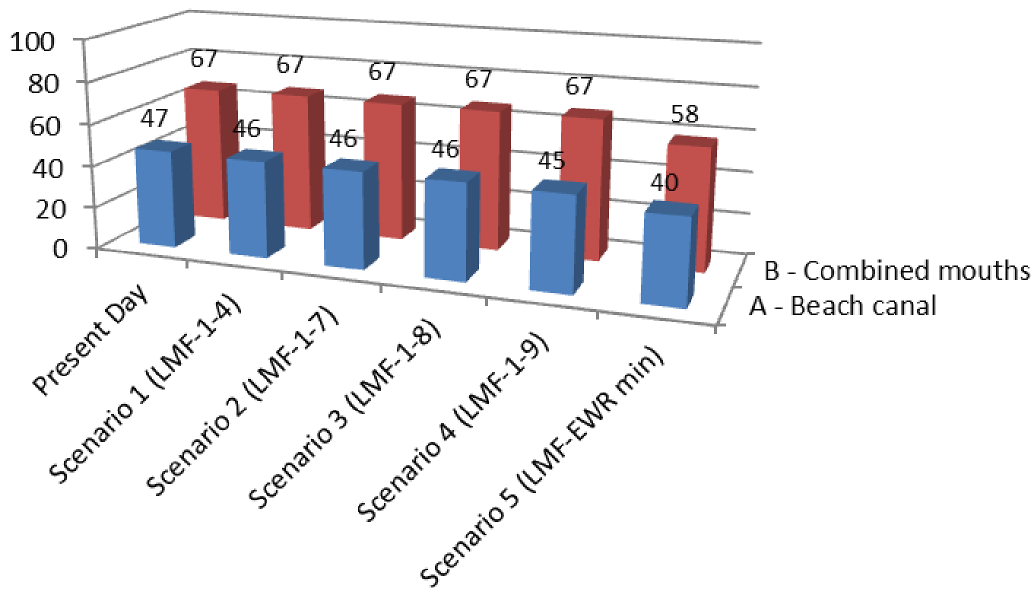


Figure 6.17. Abiotic health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation).

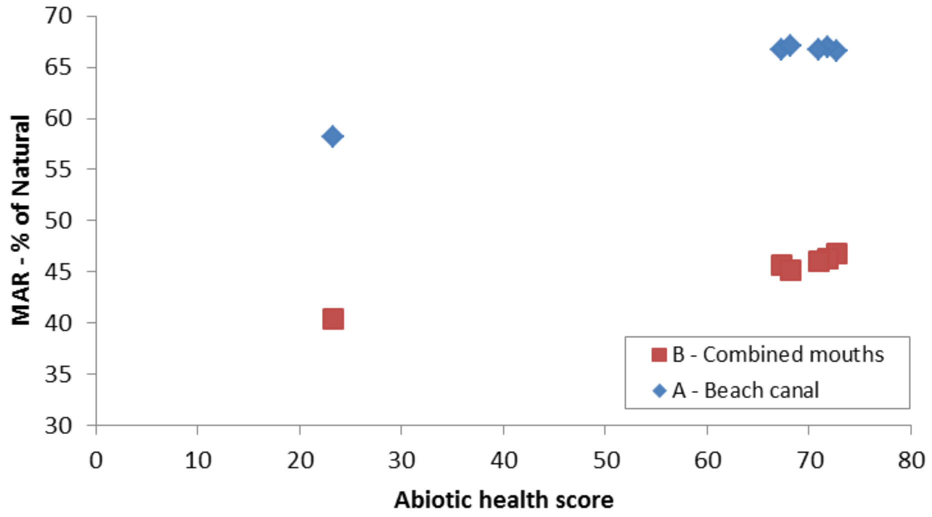


Figure 6.18. **Relationship between abiotic health of the Lake St Lucia system as a whole and MAR in the uMfolozi.**

6.3 Impacts of the operational flows scenarios on biotic components

6.3.1 Microalgae

6.3.1.1 Variation in abundance under the operational flow scenarios

Variation in the abundance of the three microalgae groups (benthic microalgae, phytoplankton and epiphytes) for all of the operational flow scenarios under the “Beach channel” and “Combined mouth” configurations are shown in Figure 6.19-Figure 6.24. Summary data are presented in Table 6.14. Benthic microalgae, phytoplankton and epiphyte abundance was elevated above Present Day levels for most of the operational flow scenarios under the Beach channel and after Phase 1 excavation configurations, but not markedly so. Corresponding values for the Beach channel and after Phase 1 excavation configuration were always considerably elevated for the former option, however.

6.3.1.2 Health scores for the operational scenarios

Microalgae health scores for the operational scenarios are presented in Table 6.15 and Figure 6.25. Health scores for the operational scenarios were all in an E class (34.2-35.6) for the Beach channel configuration (Mouth A) (as was the case for Present Day) but were all in a D class (48.3-56.7) for the after Phase 1 excavation configuration (again the same as Present Day). Operational flow scenario 2 was marginally better than Present Day with the Beach channel configuration, while the same was true for flow scenario 1, 2 and 4 under the after Phase 1 excavation configuration. A strong positive correlation is evident between microalgae health for the system as a whole and MAR in the uMfolozi (Figure 6.26).

Table 6.14. Summary data for abundance of microalgae (% of Reference) under present-day conditions and operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation).

	Benthic microalgae			Phytoplankton			Epiphytes		
	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi
Present Day - A	1696.7	403.2	2524.0	1707.9	933.5	1532.6	613.0	1033.1	613.0
Sc A1 (LMF 1-4)	1669.9	404.6	2527.6	1690.5	937.8	1564.6	609.6	1036.6	609.6
Sc A2 (LMF 1-7)	1677.9	404.1	2527.4	1700.1	935.7	1480.9	616.3	1034.4	616.3
Sc A3 (LMF 1-8)	1759.2	428.9	2681.9	1775.6	995.7	1517.0	115.4	105.9	115.4
Sc A4 (LMF 1-9)	1756.7	404.9	2450.3	1771.6	950.0	1491.9	660.6	1044.6	660.6
Sc A5 (EWR min)	2271.2	408.0	1914.3	2164.8	914.4	1195.1	748.6	1015.1	748.6
Present Day - B	1079.7	188.3	2254.0	1075.8	349.6	1462.6	359.5	355.6	359.5
Sc B1 (LMF-1-4)	1002.6	189.4	2252.9	1006.0	354.2	1499.8	325.6	360.1	325.6
Sc B2 (LMF-1-7)	983.2	193.8	2213.4	985.8	368.5	4724.6	328.3	376.0	328.3
Sc B3 (LMF 1-8)	1086.6	226.9	2570.3	1084.0	474.2	1495.5	390.4	503.6	390.4
Sc B4 (LMF 1-9)	1009.2	200.6	2098.6	1013.0	401.4	1386.5	341.5	412.9	341.5
Sc B 5 (EWR min)	1617.5	222.4	1784.9	1497.0	411.2	1133.2	520.0	425.0	520.0

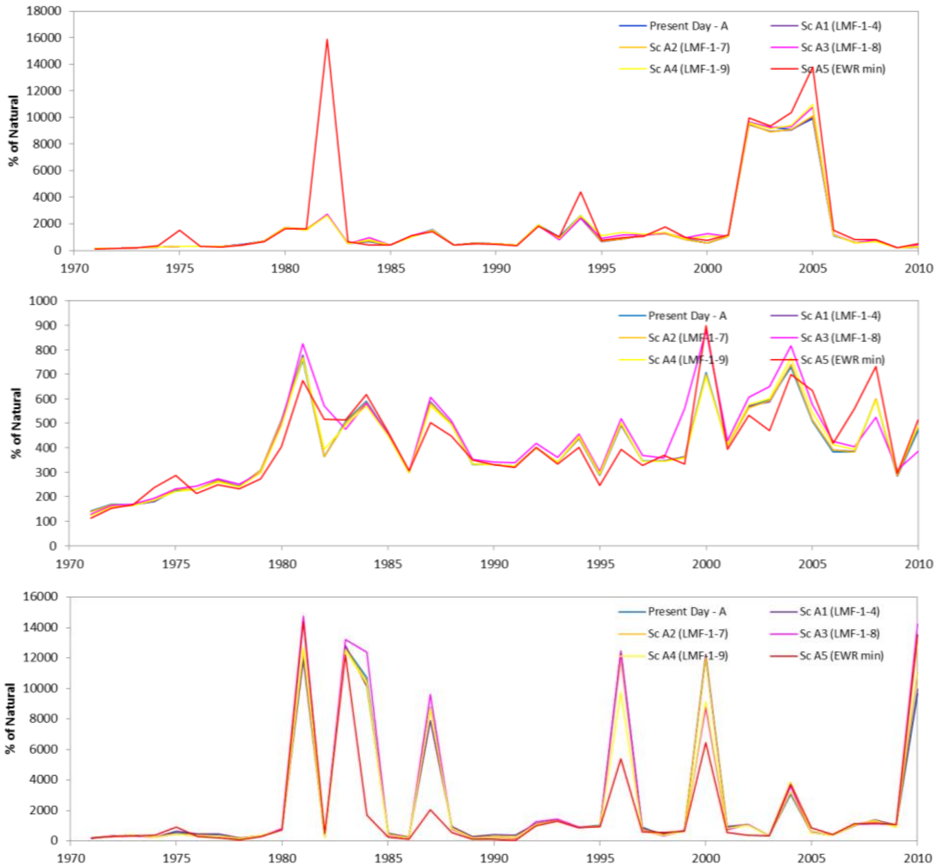


Figure 6.19. **Variation in benthic microalgae abundance in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with the Beach channel under reference and present-day conditions and under the operational flow scenarios.**

Figure 6.20. **Variation in benthic microalgae abundance in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

Figure 6.21. **Variation in phytoplankton abundance in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with Mouth A (the beach channel) under reference and present-day conditions and under the operational flow scenarios.**

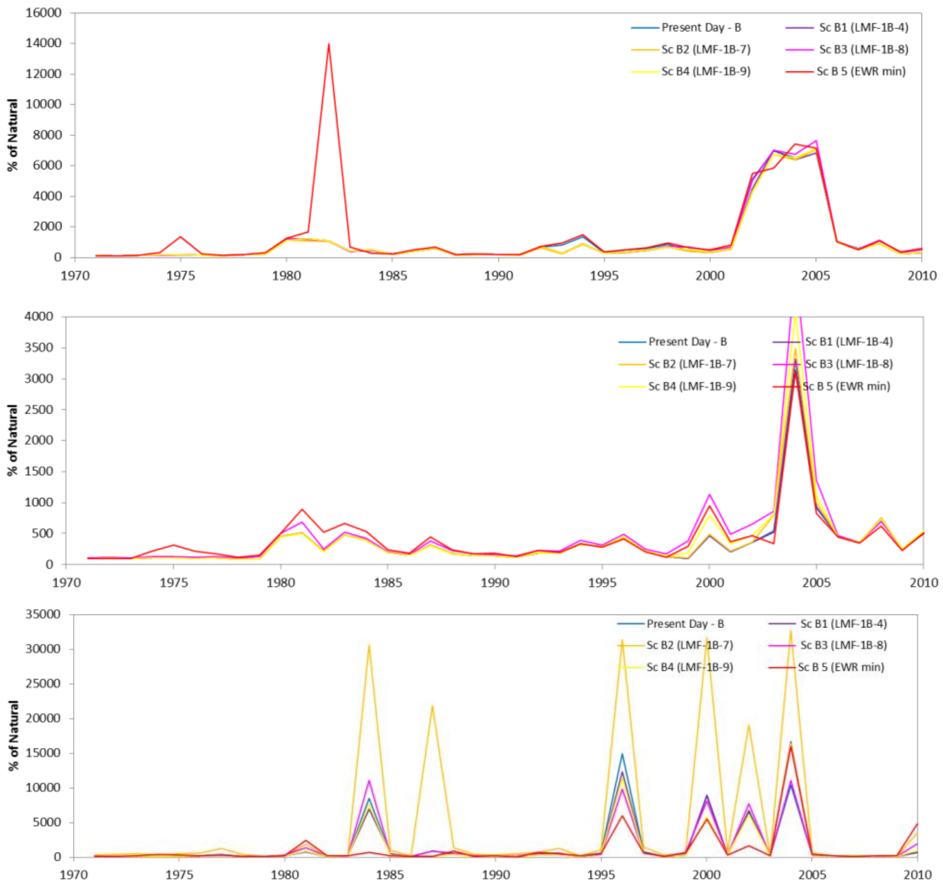


Figure 6.22. **Variation in phytoplankton abundance in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with Mouth B (after Phase 1 excavation) under reference and present-day conditions and under the operational flow scenarios.**

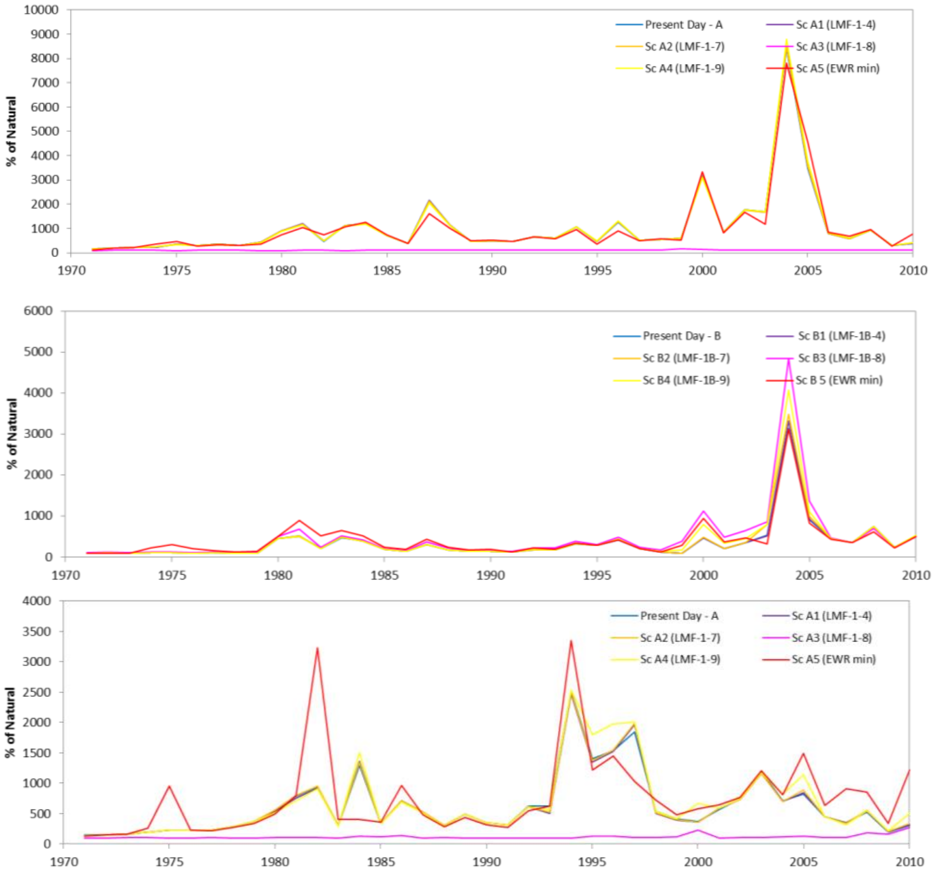


Figure 6.23. **Variation in abundance of epiphytes in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with the Beach channel under reference and present-day conditions and under the operational flow scenarios.**

Figure 6.24. **Variation in abundance of epiphytes in the Lakes (top), Narrows (middle) and the uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

Table 6.15. Microalgae health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation.

Scenario	Microalgae health score	
Present Day - A	35.5	E
Mouth A1 (LMF 1-4)	35.4	E
Mouth A2 (LMF 1-7)	35.6	E
Mouth A3 (LMF 1-8)	34.2	E
Mouth A4 (LMF 1-9)	35.3	E
Mouth A5 (LMF EWR min)	34.2	E
Present Day - B	54.4	D
Mouth B1 (LMF 1-4)	55.9	D
Mouth B2 (LMF 1-7)	56.7	D
Mouth B3 (LMF 1-8)	51.9	D
Mouth B4 (LMF 1-9)	55.0	D
Mouth B5 (LMF EWR min)	48.3	D

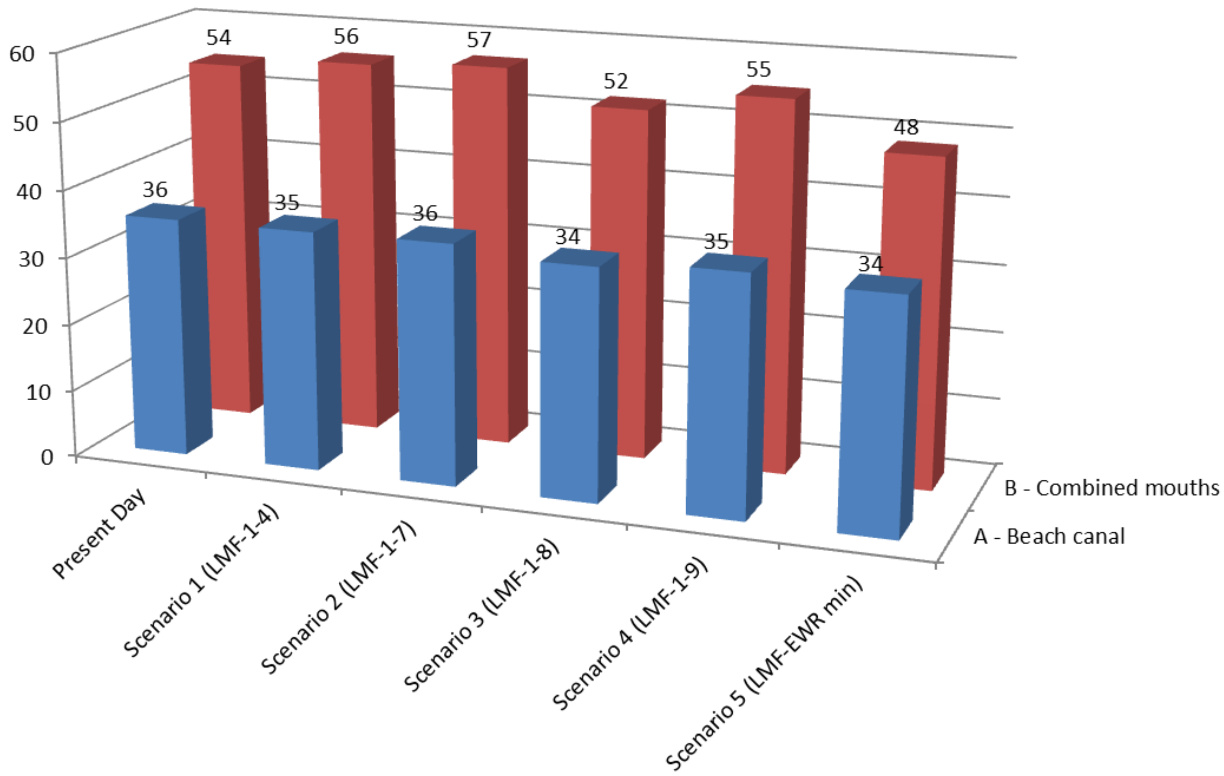


Figure 6.25. Microalgae health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation.

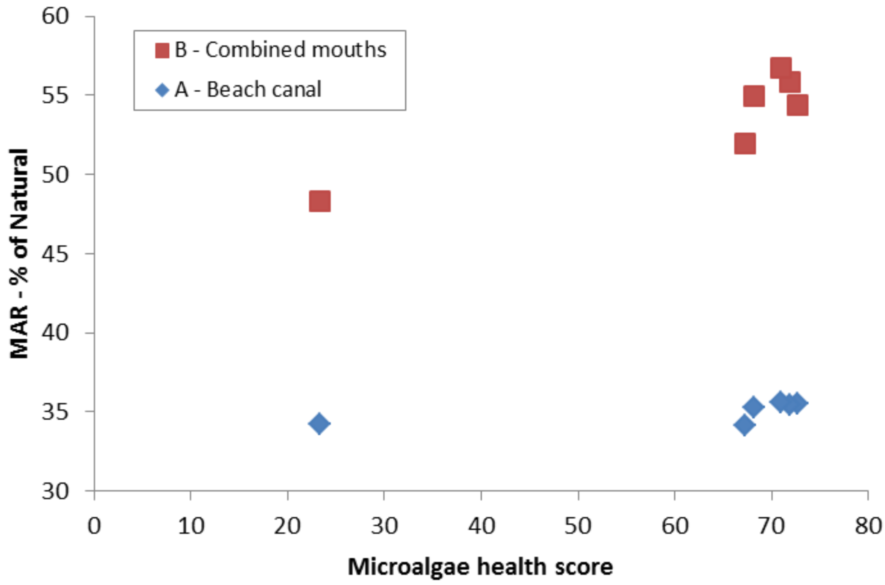


Figure 6.26. Relationship between microalgae health in the Lake St Lucia system as a whole and MAR in the uMfolozi.

6.3.2 Macrophytes

6.3.2.1 Variation in abundance under the operational flow scenarios

Variations in the abundance of the eight macrophyte groups (macroalgae, submerged macrophytes, reeds and sedges, mangroves, grass and shrubs, salt marsh, swamp forest) for all of the operational flow scenarios under the "Beach channel" and "Combined mouth" configurations are shown in Figure 6.27-Figure 6.42. Summary data are presented in Table 6.16. The responses to the changes in mouth configuration (Beach channel vs. after Phase 1 excavation) and the various operational flow scenarios differed for the various macrophyte groups in the different sections of the estuary (Lakes, Narrows, uMfolozi) but in general populations size were more similar to Reference for the Combined mouth (Mouth A) as opposed to the Beach channel (Mouth B) configuration.

6.3.2.2 Health scores for the operational scenarios

Macrophyte health scores for the operational scenarios are presented in Table 6.17 and Figure 6.43. Health scores for the operational scenarios were all in an B class for Scenario 1 and 2 (76.2-76.4) under the Beach channel mouth configuration (Mouth A) (as was the case for Present Day) but dropped down to a C class for Scenarios 3-5 (68.6-71.4), with Scenario 5 yielding the lowest score. For the after Phase 1 excavation configuration, Scenarios 1-4 were all in a B class (75.6-76.4, again the same as Present Day), but also dropped down to a C class for Scenario 5 (64.4). A strong positive correlation is evident between macrophyte health for the system as a whole and MAR in the uMfolozi (Figure 6.44).

Table 6.16. Summary data for abundance of macrophytes (% of Reference) under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation.

	Macroalgae			Submerged macrophytes			Floating macrophytes			Reeds and sedges		
	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi
Present Day - A	1577.1	1866.8	2423.5	1756.9	1981.0	-	79.4	202.3	74.4	1721.2	876.0	1015.4
Sc A1 (LMF 1-4)	1573.4	1864.7	2494.4	1727.2	1994.9	-	79.7	200.3	74.5	1701.1	872.4	1138.7
Sc A2 (LMF 1-7)	1576.7	1867.9	2365.8	1731.6	1978.6	-	80.0	199.0	72.6	1714.7	875.2	1008.5
Sc A3 (LMF 1-8)	1594.8	1851.0	2319.5	1737.2	2010.4	-	79.5	170.3	75.6	1701.8	823.4	881.3
Sc A4 (LMF 1-9)	1588.4	1854.1	2299.5	1758.6	1957.1	-	79.2	186.1	71.3	1750.0	862.9	955.8
Sc A5 (EWR min)	1577.7	1714.2	2216.7	1718.5	2606.5	-	90.2	243.3	125.4	1584.7	829.8	1059.9
Present Day - B	1011.2	568.6	2188.2	615.8	419.2	-	77.8	93.9	70.0	482.2	299.3	751.5
Sc B1 (LMF-1-4)	916.5	565.2	2253.7	462.3	415.4	-	78.5	97.1	69.9	352.0	293.2	808.2
Sc B2 (LMF-1-7)	914.1	611.2	2087.0	432.8	418.8	-	78.4	92.1	226.1	355.3	318.5	756.6
Sc B3 (LMF 1-8)	984.1	681.3	2252.6	536.2	473.6	-	76.8	82.2	71.9	365.2	345.2	772.2
Sc B4 (LMF 1-9)	929.1	638.0	2040.1	501.3	407.4	-	79.3	90.2	68.3	369.4	329.9	724.4
Sc B 5 (EWR min)	1148.3	886.1	2001.7	889.3	1124.2	-	79.6	142.9	115.6	593.6	433.3	876.4
	Mangroves			Grass And Shrubs			Salt Marsh			Swamp Forest		
Present Day - A	-	40.3	118.7	97.9	70.7	70.7	105.1	84.2	-	-	122.2	39.0
Sc A1 (LMF 1-4)	-	41.0	116.1	96.9	71.3	71.3	104.8	83.7	-	-	135.7	38.1
Sc A2 (LMF 1-7)	-	41.6	125.0	96.8	68.8	68.8	104.6	84.1	-	-	121.3	37.8
Sc A3 (LMF 1-8)	-	42.2	132.9	101.2	68.1	68.1	105.8	77.1	-	-	117.6	49.1
Sc A4 (LMF 1-9)	-	43.5	130.9	95.5	67.9	67.9	106.4	81.5	-	-	118.9	38.6
Sc A5 (EWR min)	-	38.0	134.0	96.6	70.6	70.6	102.2	86.4	-	-	120.6	42.9
Present Day - B	-	91.5	183.4	82.7	70.3	70.3	102.3	60.3	-	-	104.2	49.4
Sc B1 (LMF-1-4)	-	91.9	182.4	80.8	70.1	70.1	101.4	60.8	-	-	105.5	43.3
Sc B2 (LMF-1-7)	-	92.1	188.2	79.8	67.9	67.9	100.5	61.8	-	-	102.5	46.0
Sc B3 (LMF 1-8)	-	89.2	183.4	79.4	67.8	67.8	101.2	57.6	-	-	103.1	51.2
Sc B4 (LMF 1-9)	-	91.0	185.8	81.2	68.6	68.6	103.0	60.6	-	-	102.6	49.7
Sc B 5 (EWR min)	-	78.0	174.0	83.2	70.3	70.3	97.0	71.4	-	-	96.6	58.6

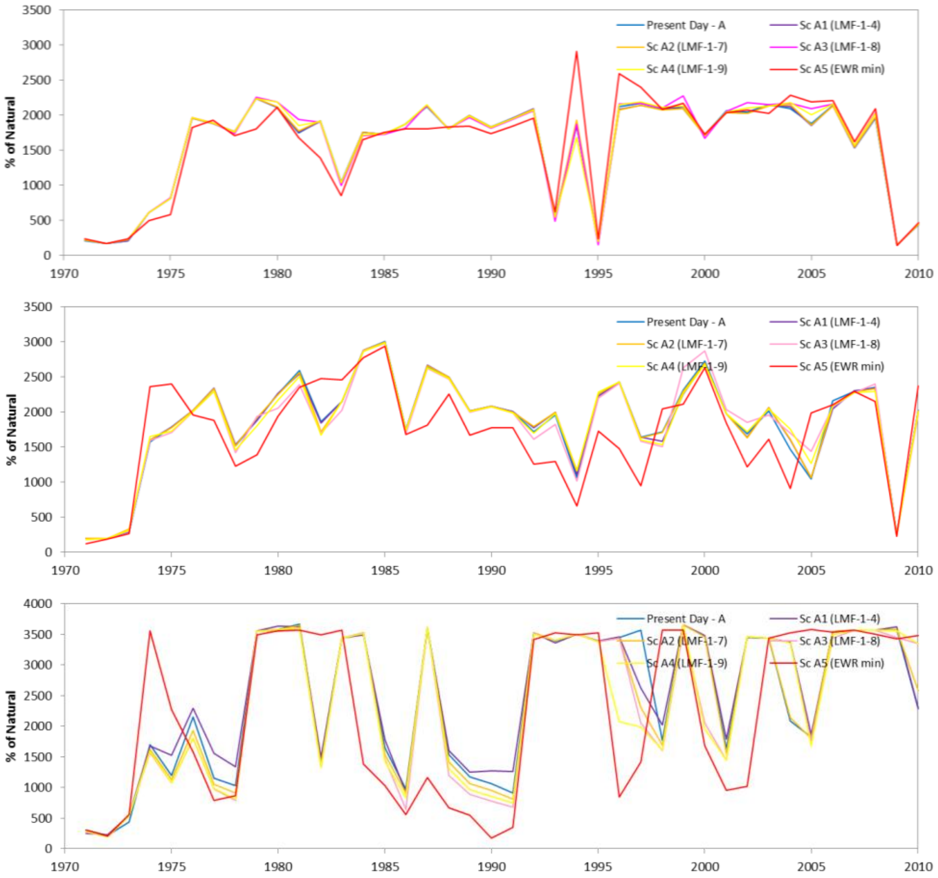


Figure 6.27. Variation in the abundance of macroalgae (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

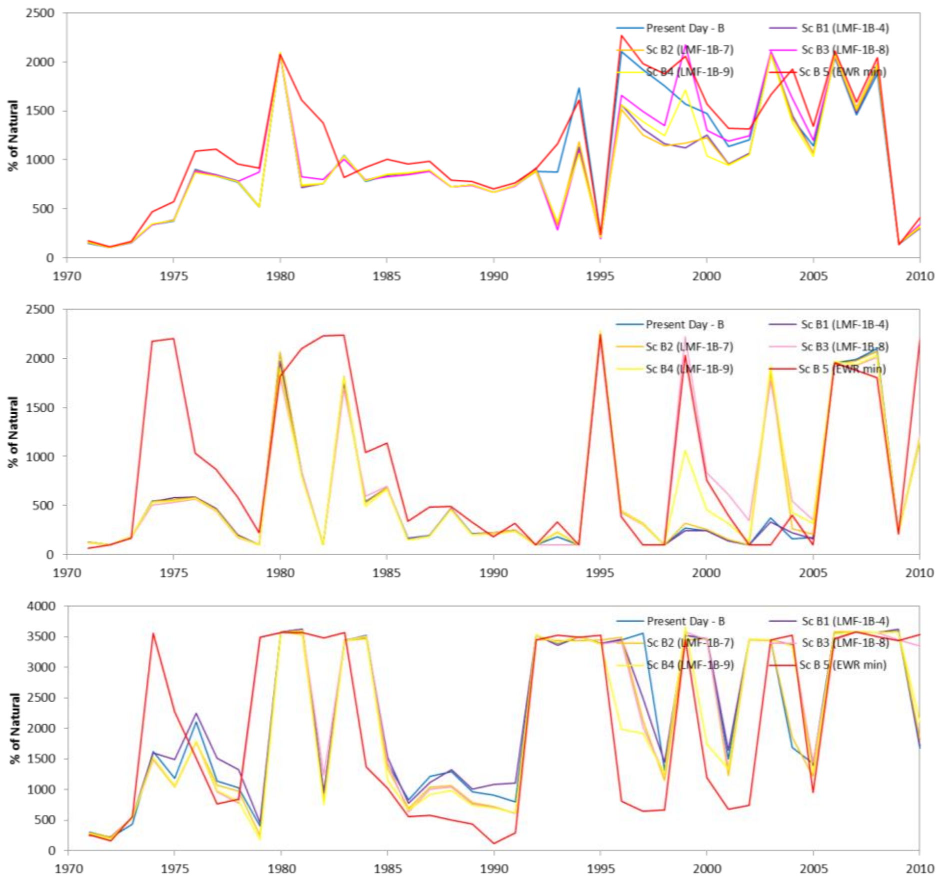


Figure 6.28. Variation in the abundance of macroalgae (% of natural) in the Lakes (top), Narrows (middle) and

uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

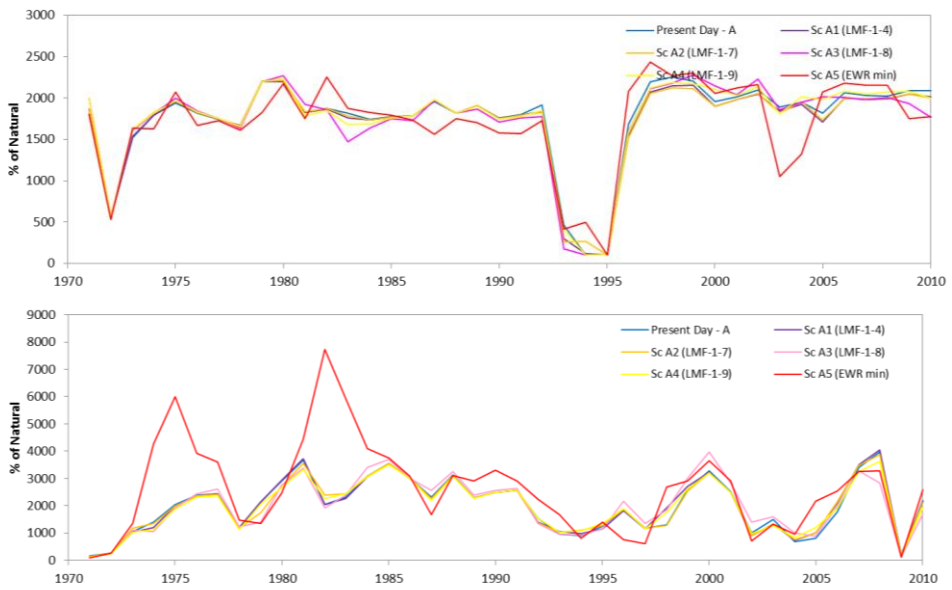


Figure 6.29. **Variation in the abundance of submerged macrophytes (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

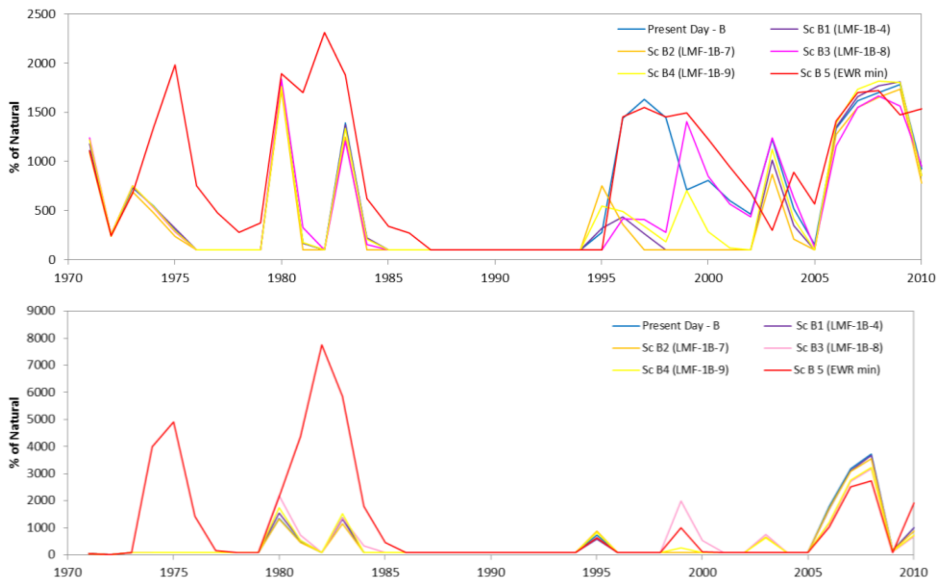


Figure 6.30. **Variation in the abundance of submerged macrophytes (% of natural) in the Lakes (top) and Narrows (bottom) after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

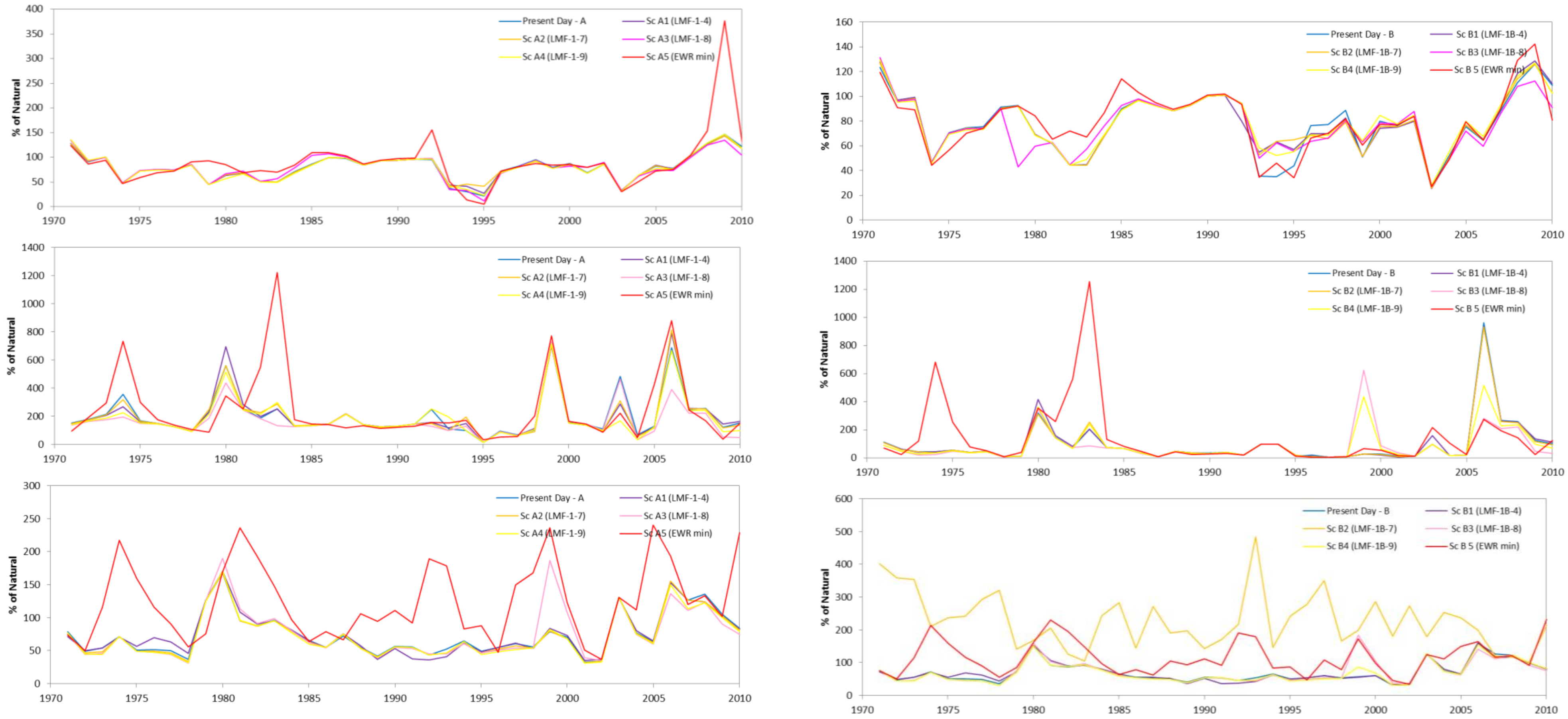


Figure 6.31. Variation in the abundance of floating macrophytes (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

Figure 6.32. Variation in the abundance of floating macrophytes (% of natural) in the Lakes (top) and Narrows (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

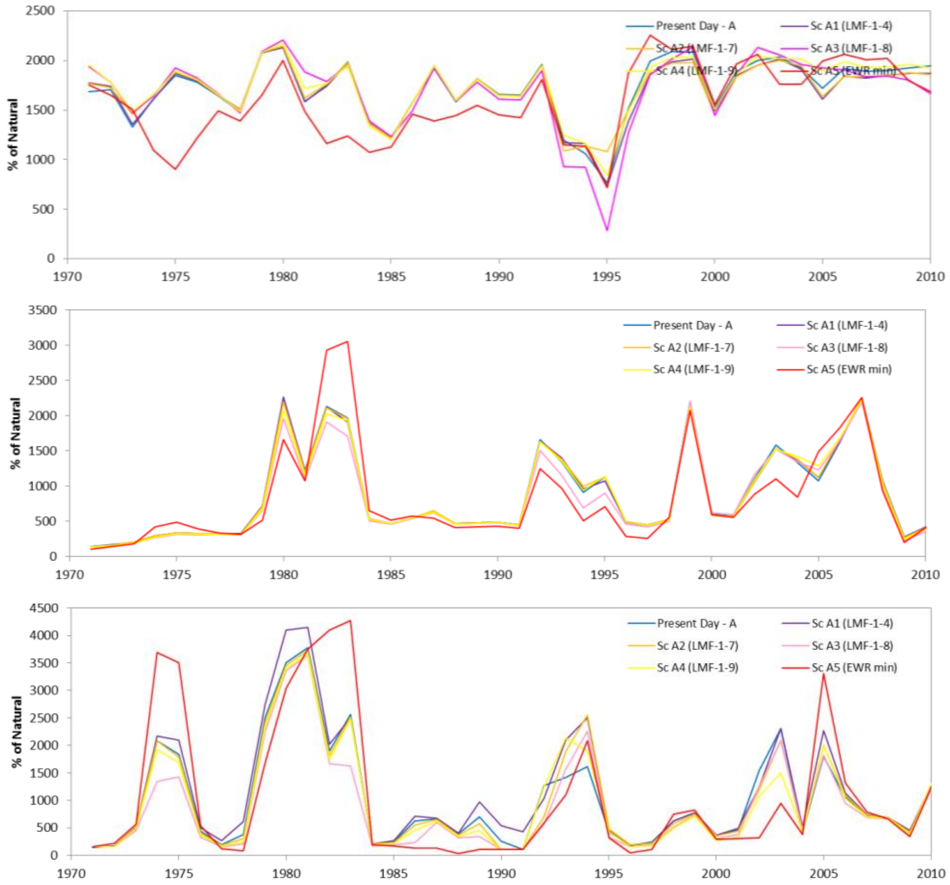


Figure 6.33. Variation in the abundance of reeds & sedges (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

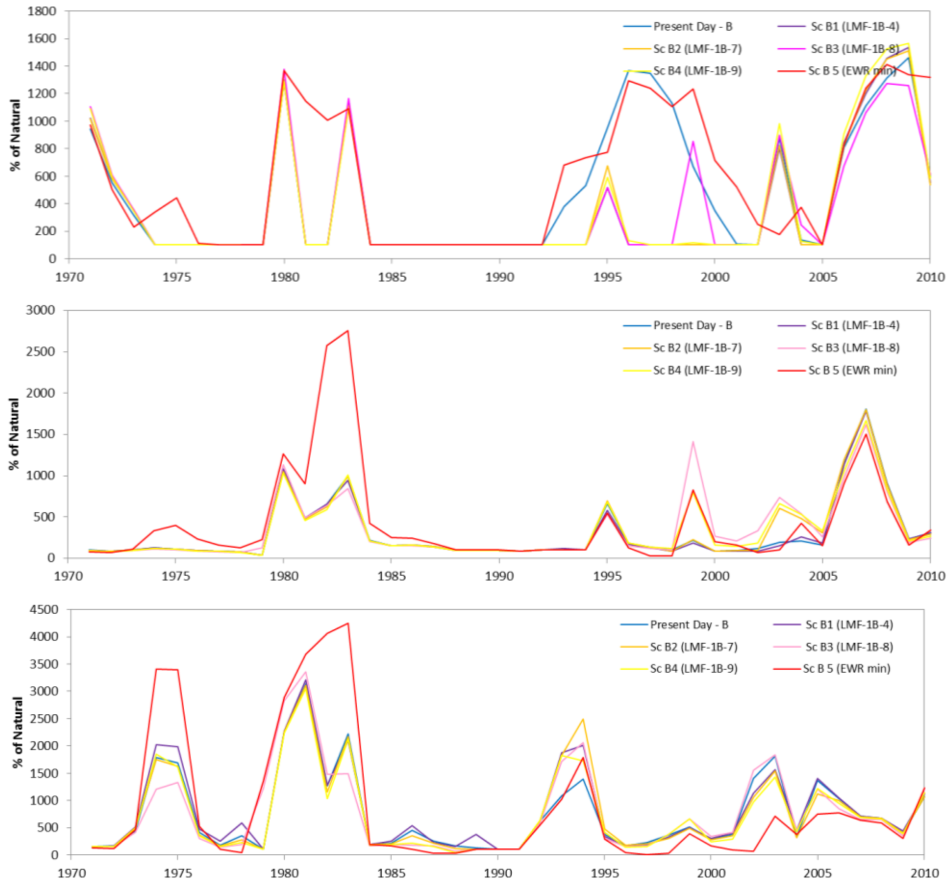


Figure 6.34. **Variation in the abundance of reeds & sedges (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

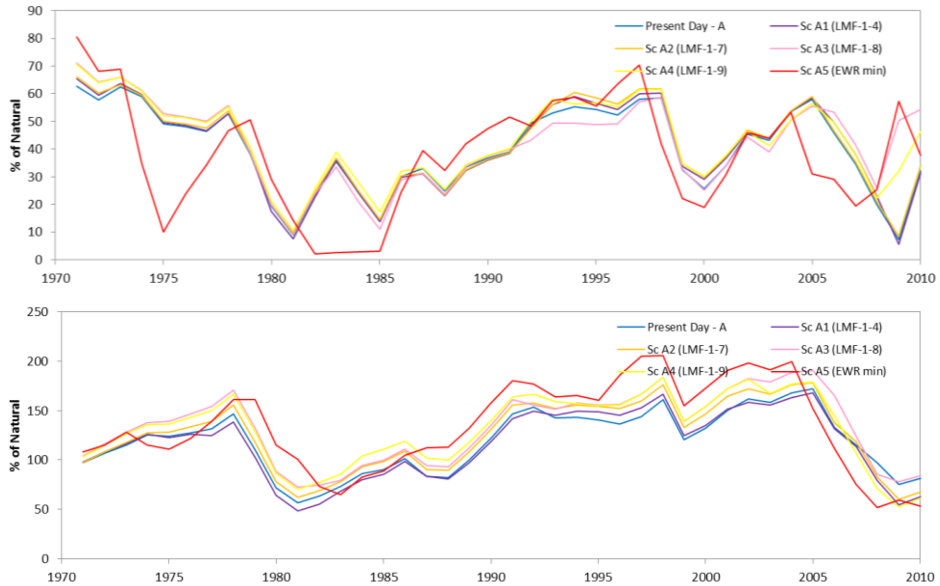


Figure 6.35. **Variation in the abundance of mangroves (% of natural) in the Narrows (top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

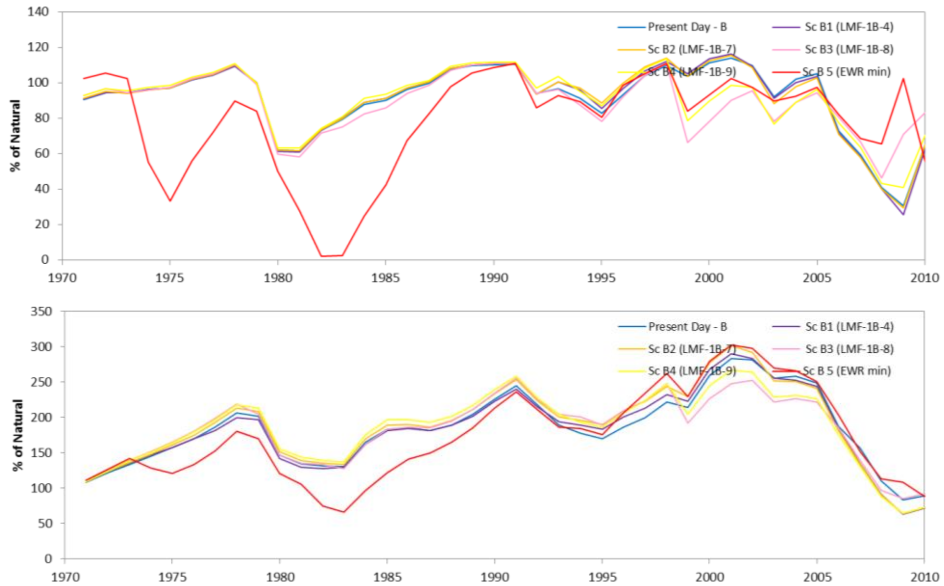


Figure 6.36. **Variation in the abundance of mangroves (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under**

reference and present-day conditions and under the operational flow scenarios.

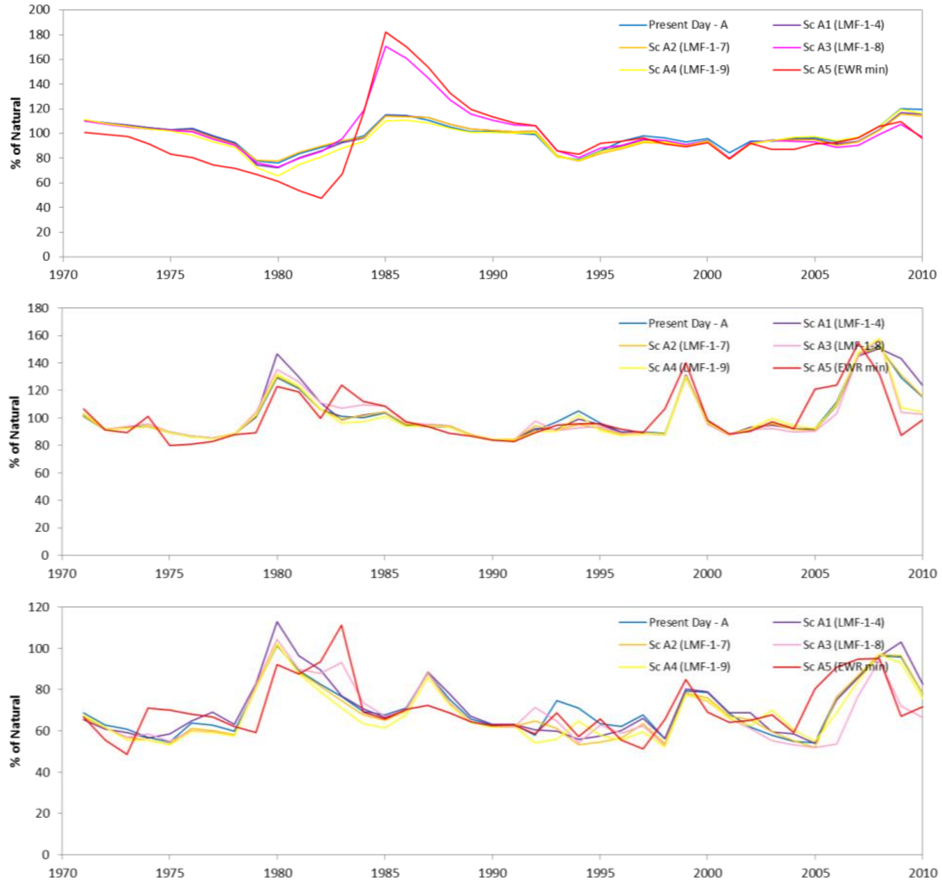


Figure 6.37. Variation in the abundance of grass & shrubs (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

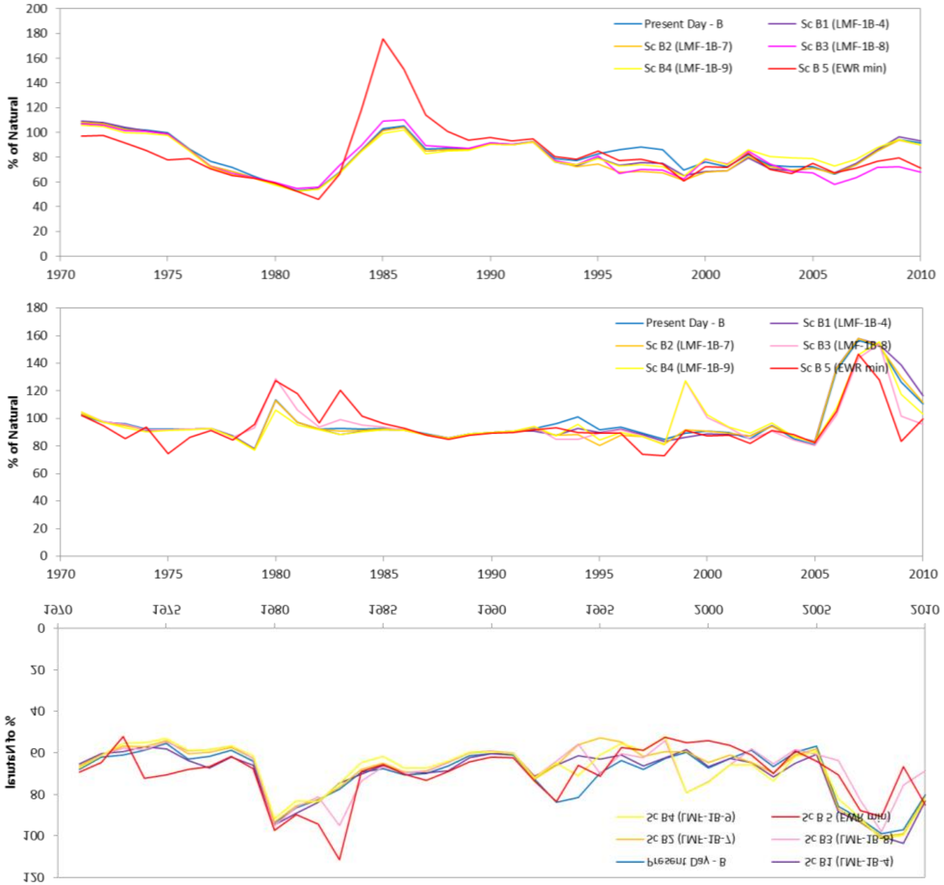


Figure 6.38. **Variation in the abundance of grass & shrubs (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

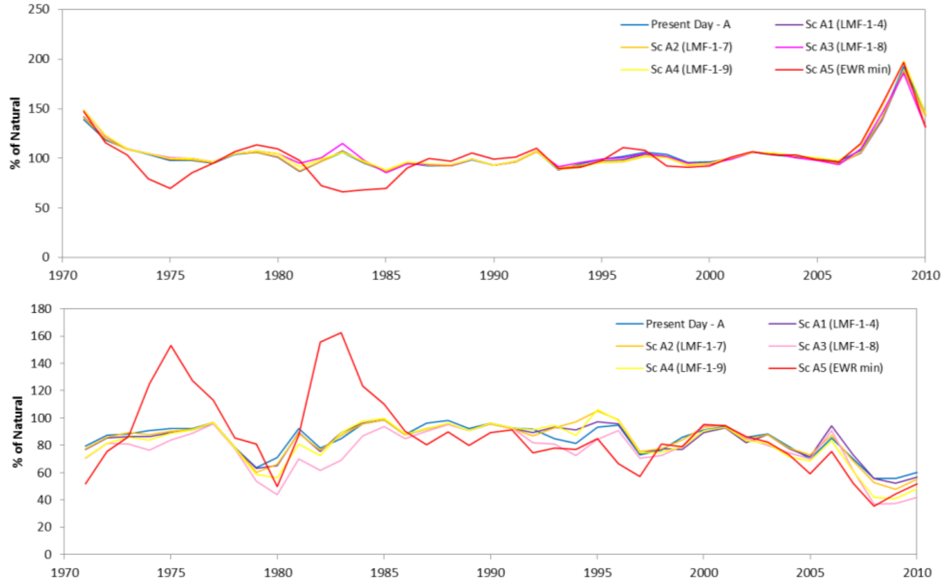


Figure 6.39. **Variation in the abundance of salt marsh (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

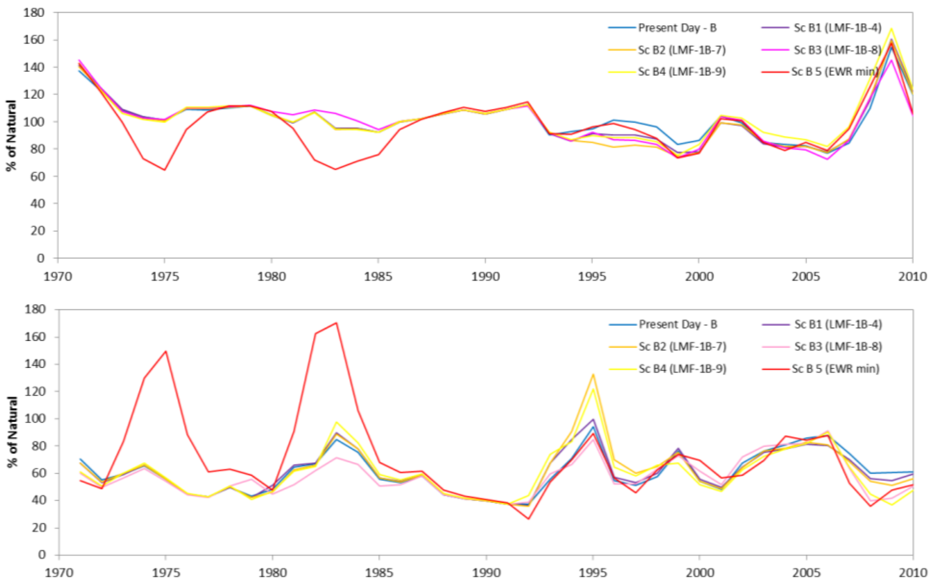


Figure 6.40. **Variation in the abundance of salt marsh (% of natural) in the Lakes (top) and Narrows (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

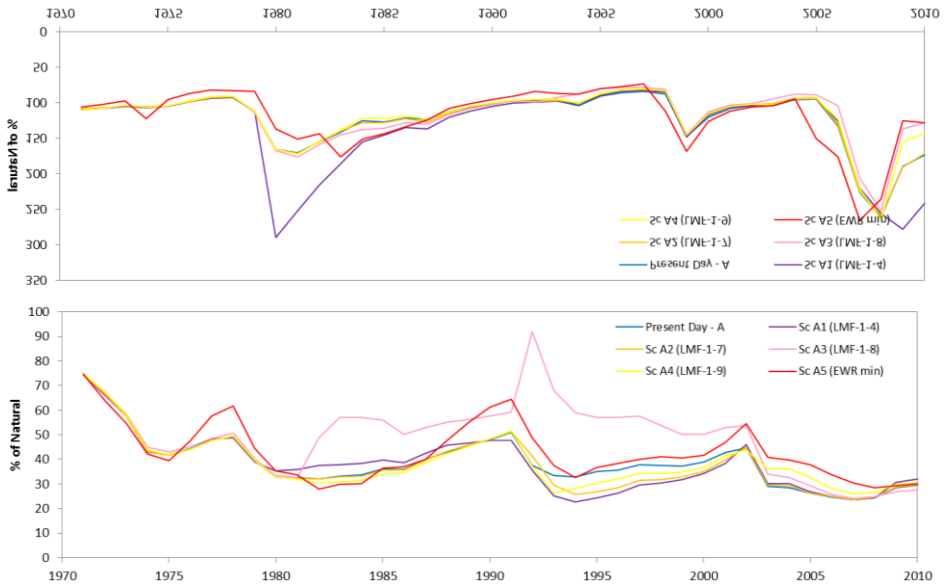


Figure 6.41. **Variation in the abundance of swamp forest (% of natural) in the Narrows (top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

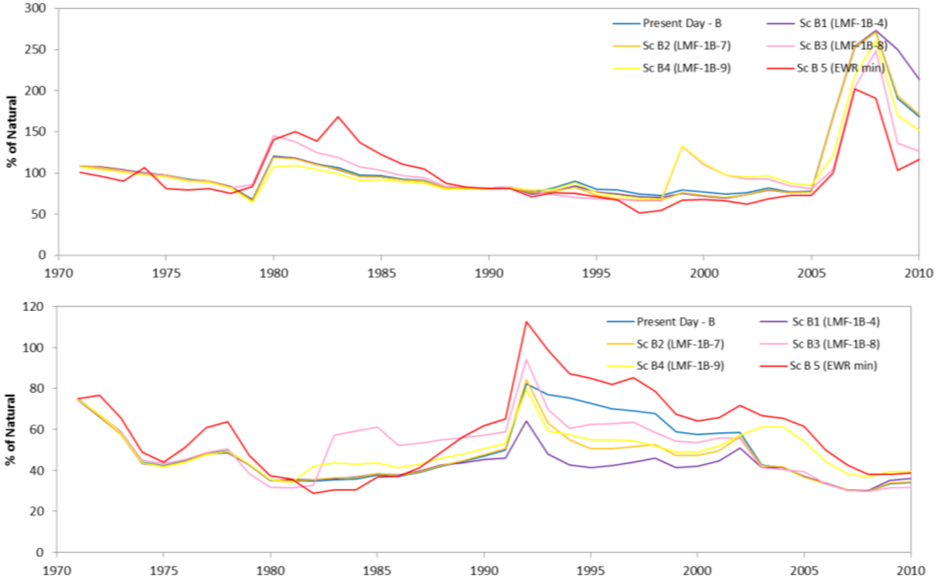


Figure 6.42. **Variation in the abundance of swamp forest (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

Table 6.17. Macrophyte health scores for Present Day and the Operational scenarios 1-5 for the "Beach channel" (A) and "Combined mouth" (B) configurations.

Scenario	Macrophyte health score	
Present Day - A	75.1	B
Sc. A1 (LMF 1-4)	75.0	B
Sc. A2 (LMF 1-7)	76.0	B
Sc. A3 (LMF 1-8)	71.7	C
Sc. A4 (LMF 1-9)	74.4	C
Sc. A5 (LMF EWR min)	68.6	C
Present Day - B	76.8	B
Sc. B1 (LMF 1-4)	76.4	B
Sc. B2 (LMF 1-7)	76.2	B
Sc. B3 (LMF 1-8)	75.6	B
Sc. B4 (LMF 1-9)	76.0	B
Sc. B5 (LMF EWR min)	64.4	C

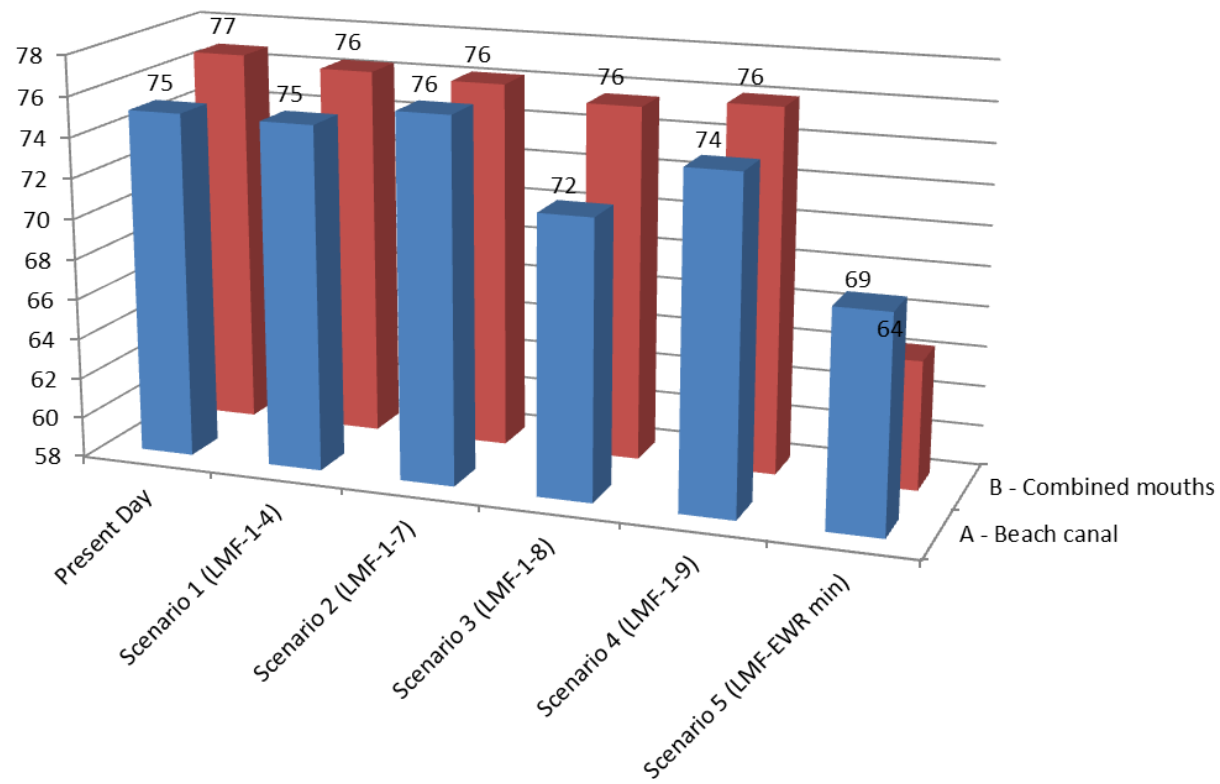


Figure 6.43. Macrophyte health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation).

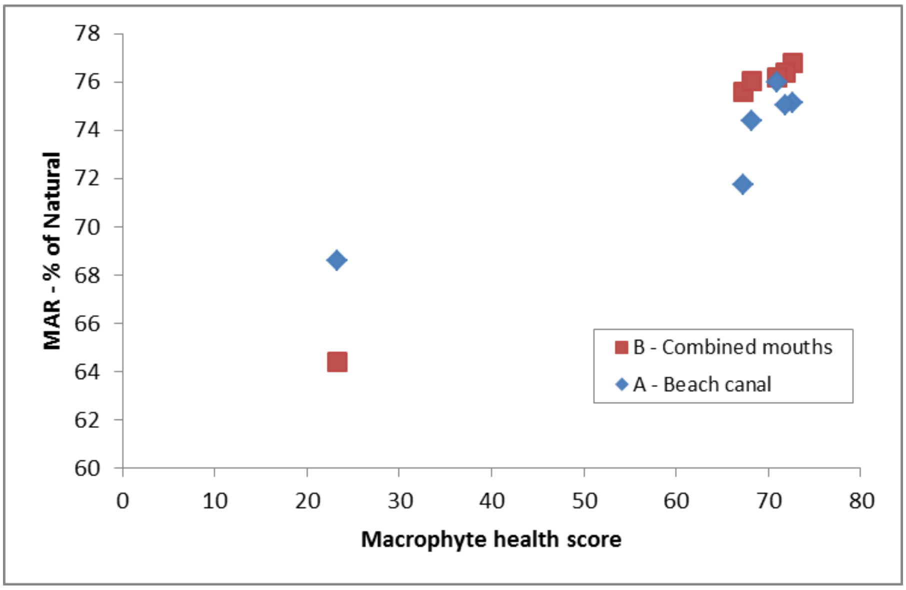


Figure 6.44. Relationship between macrophyte health and MAR in the uMfolozi.

6.3.3 Invertebrates

6.3.3.1 Variation in abundance under the operational flow scenarios

Variations in the abundance of the eight invertebrate groups (benthic estuarine, benthic marine, benthic freshwater, benthic halophilic, pelagic estuarine, pelagic marine, pelagic freshwater and pelagic halophilic) for all of the operational flow scenarios under the "Beach channel" and "Combined mouth" configurations are shown in Figure 6.45-Figure 6.60. Summary data are presented in Table 6.18. The responses to the changes in mouth configuration (Beach channel vs. after Phase 1 excavation) and the various operational flow scenarios differed for the various invertebrate groups in the different sections of the estuary (Lakes, Narrows, uMfolozi) but in general populations size were more similar to Reference for the Combined mouth (Mouth B) as opposed to the Beach channel (Mouth A) configuration except for the halophilic groups in the Lakes. (Halophilic organisms thrive under hypersaline conditions and tend to proliferate under the after Phase 1 excavation configuration where the incidence of hypersalinity rises dramatically). Population sizes for the estuarine and marine groups were on average more different to Reference than under Present Day flows, with this response being most marked for Scenario 5, followed by Scenario 3, Scenario 4, Scenario2 then Scenario 1.

6.3.3.2 Health scores under the operational scenarios

Invertebrate health scores for the operational scenarios are presented in Table 6.19 and Figure 6.61. Health scores for the operational scenarios were all in an E class (29.4-30.8) for the Beach channel configuration (Mouth A) (as was the case for Present Day) but were all in a D class (40.8-46.3) for the after Phase 1 excavation configuration (again the same as Present Day). All of the operational flow scored lower than PD under the Beach channel and after Phase 1 excavation configurations, with Scenario 5 scoring the lowest, followed by Scenarios 3, 4, 2 and 1. A strong positive correlation is evident between invertebrate health for the system as a whole and MAR in the uMfolozi (Figure 6.62).

Table 6.18. Summary data for abundance of invertebrates (% of Reference) under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation.

	Benthic estuarine			Benthic marine			Benthic freshwater			Benthic halophilic		
	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi
Present Day - A	41.4	20.8	102.8	27.5	23.0	71.0	93.8	109.6	80.9	96.9	-	-
Sc A1 (LMF 1-4)	40.9	20.3	99.4	27.0	23.3	70.5	93.8	110.0	87.8	99.6	-	-
Sc A2 (LMF 1-7)	40.2	20.2	104.8	26.6	23.1	75.3	92.2	108.6	79.8	102.2	-	-
Sc A3 (LMF 1-8)	37.6	19.9	129.6	24.6	25.2	138.5	91.6	102.0	79.9	102.7	-	-
Sc A4 (LMF 1-9)	39.7	19.3	106.0	26.1	22.6	77.4	88.4	104.3	74.0	99.7	-	-
Sc A5 (EWR min)	37.3	26.6	130.7	27.0	33.5	92.0	89.9	141.2	95.2	114.1	-	-
Present Day - B	81.5	85.6	105.6	80.0	83.4	75.2	89.2	78.4	67.5	139.1	-	-
Sc B1 (LMF-1-4)	81.4	85.4	103.3	79.6	83.9	74.9	79.6	78.6	70.1	144.3	-	-
Sc B2 (LMF-1-7)	79.5	85.4	108.7	77.7	84.0	80.4	78.1	78.5	65.9	145.0	-	-
Sc B3 (LMF 1-8)	76.5	83.1	131.6	74.7	83.5	141.4	75.3	121.5	72.5	146.0	-	-
Sc B4 (LMF 1-9)	79.4	83.5	110.3	77.8	82.3	82.8	75.5	78.1	66.2	145.8	-	-
Sc B 5 (EWR min)	68.8	81.1	136.5	69.5	79.6	93.1	78.3	121.5	79.7	142.7	-	-
	Pelagic estuarine			**Pelagic marine**			**Pelagic freshwater**			**Pelagic halophilic**		
Present Day - A	39.3	20.5	102.0	26.3	22.9	114.3	91.5	110.8	75.3	99.0	-	-
Sc A1 (LMF 1-4)	38.7	20.2	98.2	25.7	23.7	109.1	89.5	111.4	81.6	104.7	-	-
Sc A2 (LMF 1-7)	37.8	20.2	105.3	25.1	23.6	120.8	88.8	109.7	73.9	109.1	-	-
Sc A3 (LMF 1-8)	34.3	20.4	133.8	22.6	26.0	156.3	84.3	102.5	73.8	108.0	-	-
Sc A4 (LMF 1-9)	36.7	19.8	108.1	24.3	23.6	126.4	86.4	105.8	68.8	103.0	-	-
Sc A5 (EWR min)	35.9	23.4	143.3	25.8	36.1	172.3	85.4	118.8	95.6	128.8	-	-
Present Day - B	78.1	85.9	108.3	78.2	89.9	125.3	76.9	83.1	64.7	179.8	-	-
Sc B1 (LMF-1-4)	78.0	85.7	106.3	77.8	90.8	121.4	74.9	82.9	67.4	191.4	-	-
Sc B2 (LMF-1-7)	76.0	85.7	113.4	75.8	91.1	133.7	72.0	82.7	62.7	194.9	-	-
Sc B3 (LMF 1-8)	73.3	82.8	136.7	72.8	89.6	162.3	71.3	80.3	67.6	190.2	-	-
Sc B4 (LMF 1-9)	75.7	83.8	116.0	75.7	89.3	138.3	74.7	81.9	61.8	191.7	-	-
Sc B 5 (EWR min)	66.9	77.5	160.4	68.5	91.9	197.4	76.6	98.9	90.8	189.5	-	-

Figure 6.45. **Variation in the abundance of benthic estuarine invertebrates (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

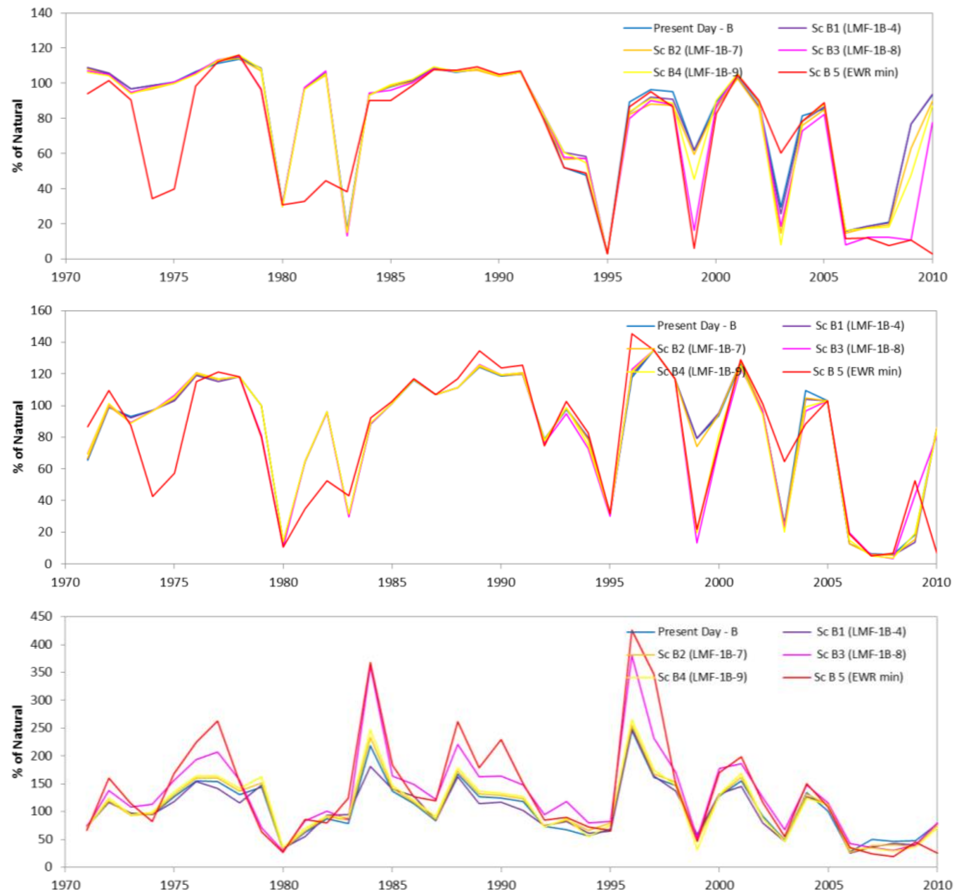


Figure 6.46. **Variation in the abundance of benthic estuarine invertebrates (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

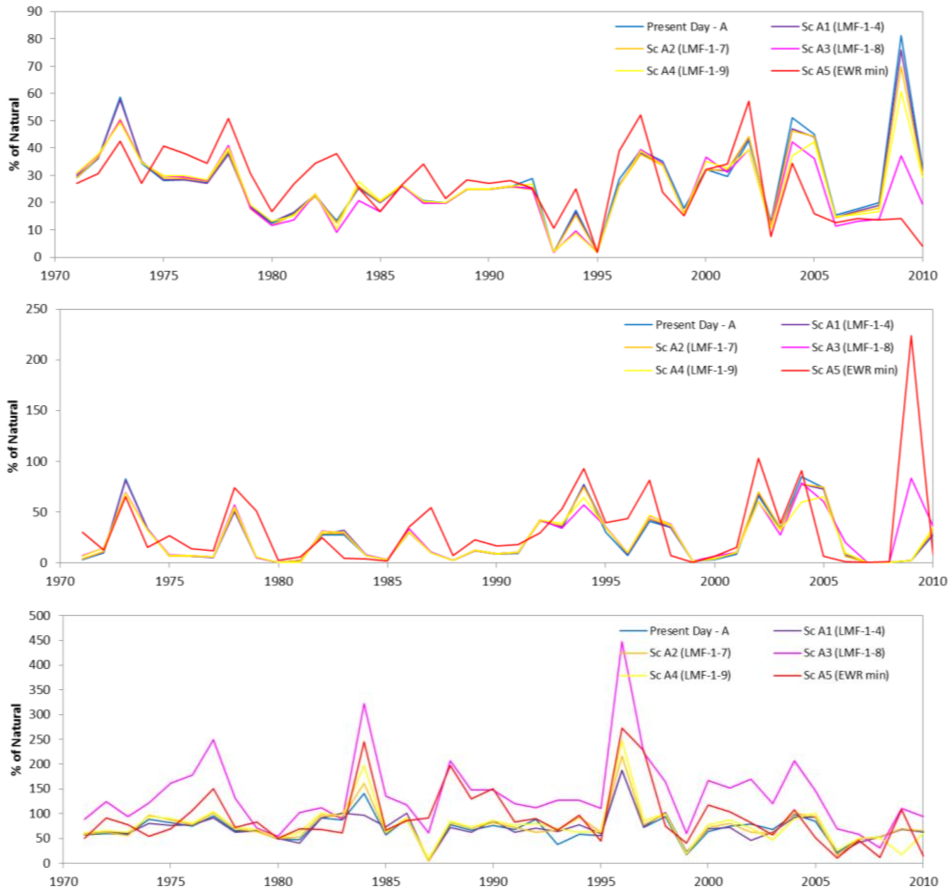


Figure 6.47. **Variation in the abundance of benthic marine invertebrates (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

Figure 6.48. **Variation in the abundance of benthic marine invertebrates (% of natural) in the Lakes (top) and Narrows (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

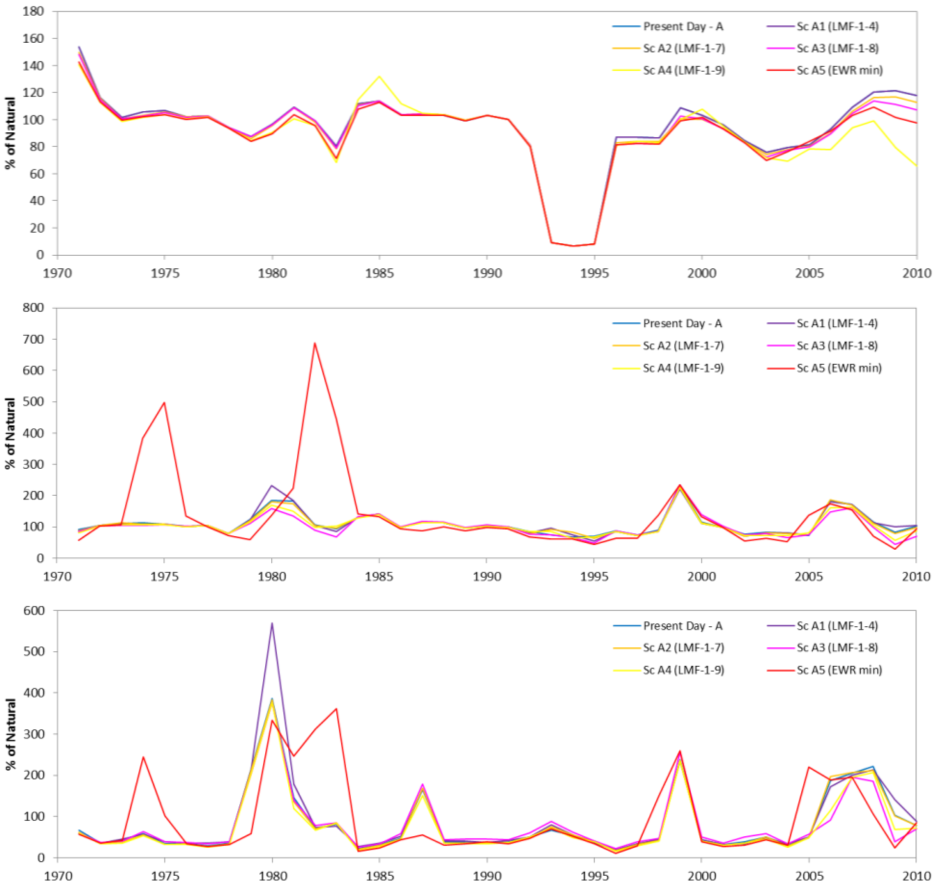


Figure 6.49. **Variation in the abundance of benthic freshwater invertebrates (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

Figure 6.50. **Variation in the abundance of benthic freshwater invertebrates (% of natural) in the Lakes (top) and Narrows (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

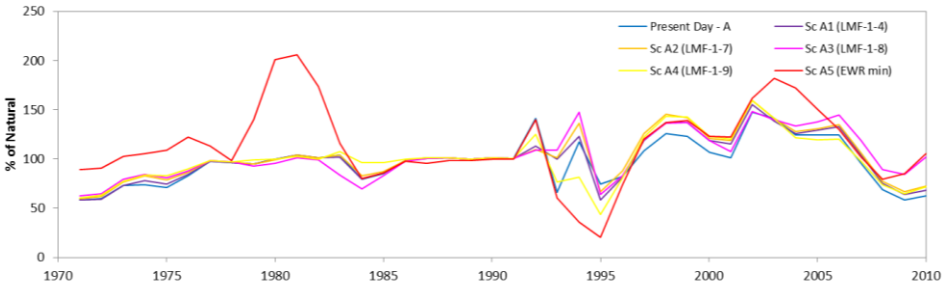


Figure 6.51. Variation in the abundance of benthic halophilic invertebrates (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

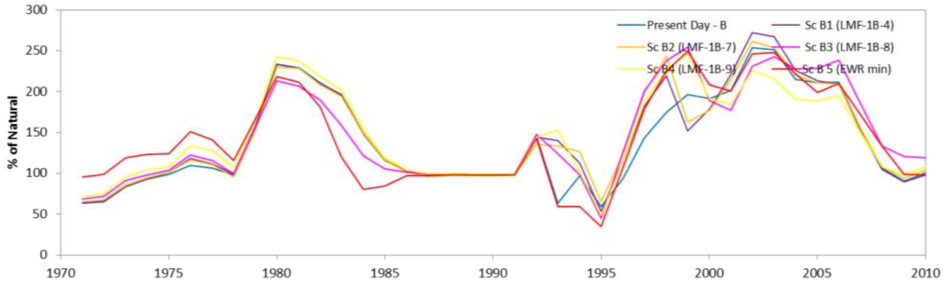


Figure 6.52. Variation in the abundance of benthic halophilic invertebrates (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

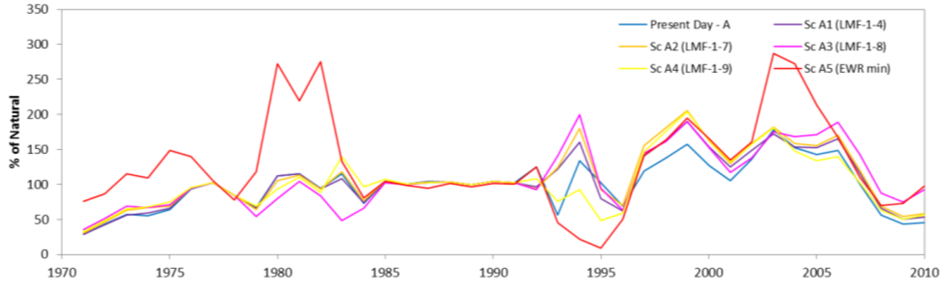


Figure 6.53. Variation in the abundance of pelagic halophilic invertebrates (% of natural) in the Narrows (top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

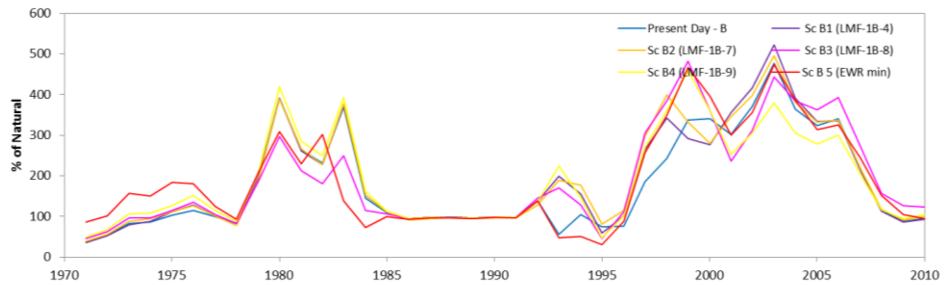


Figure 6.54. Variation in the abundance of pelagic halophilic invertebrates (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1

excavation under reference and present-day conditions and under the operational flow scenarios.

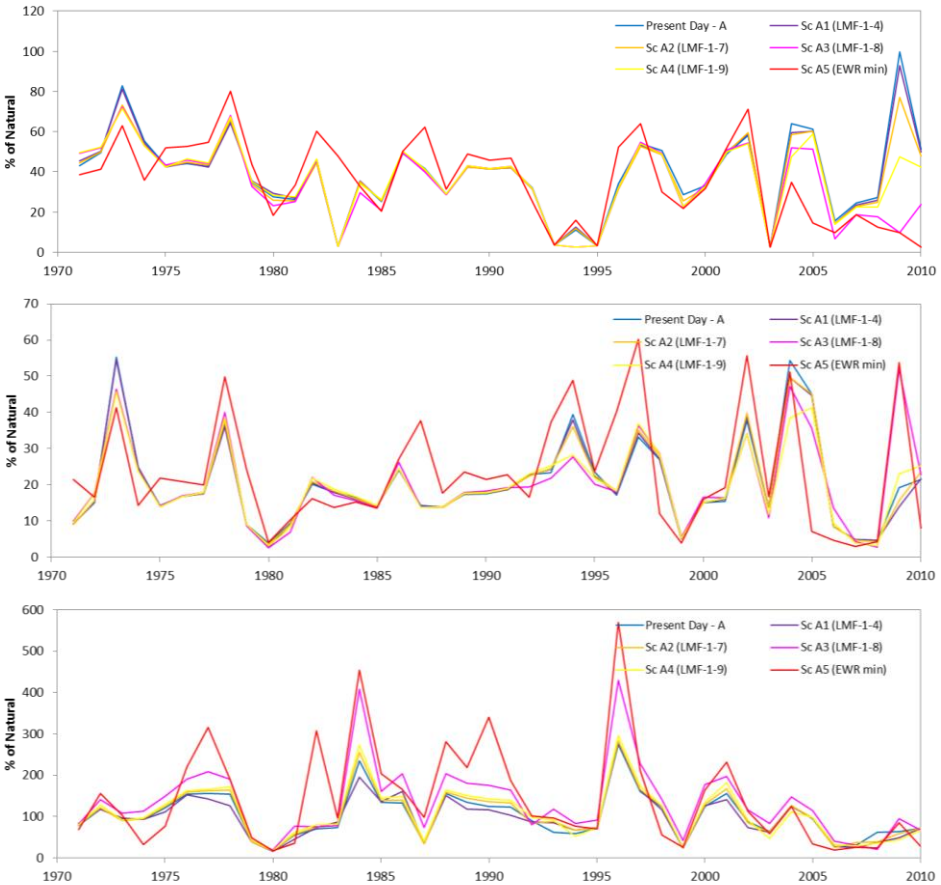


Figure 6.55. Variation in the abundance of pelagic estuarine invertebrates (% of natural) in the Narrows (top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

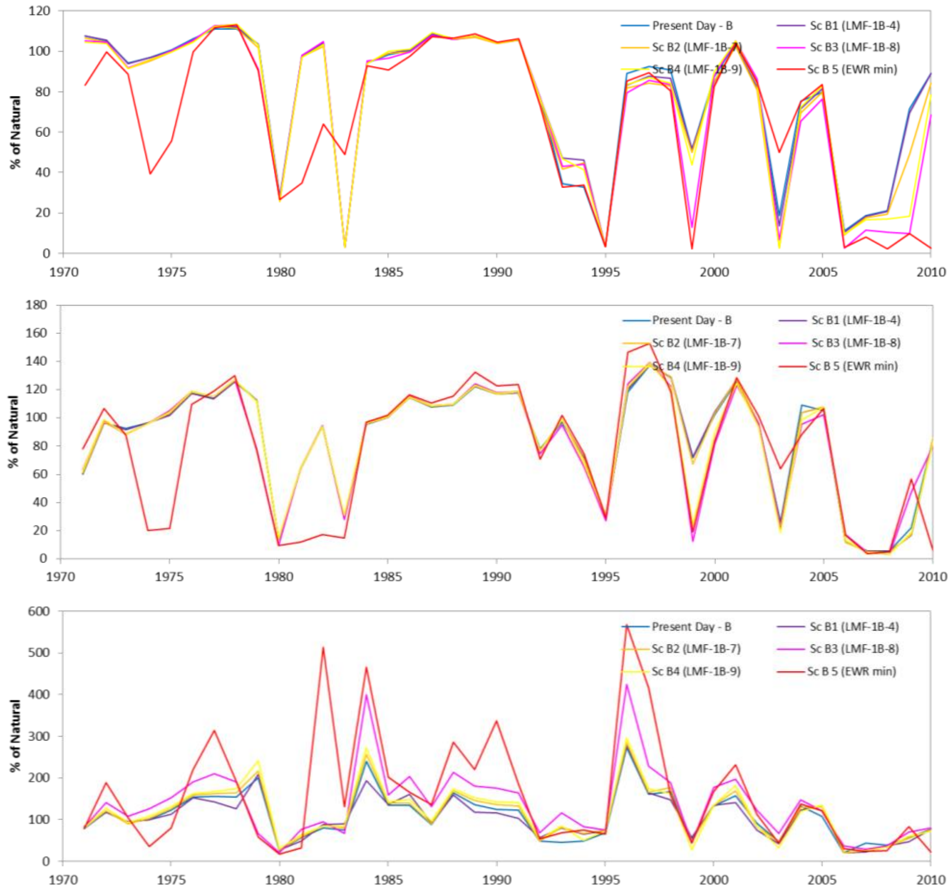
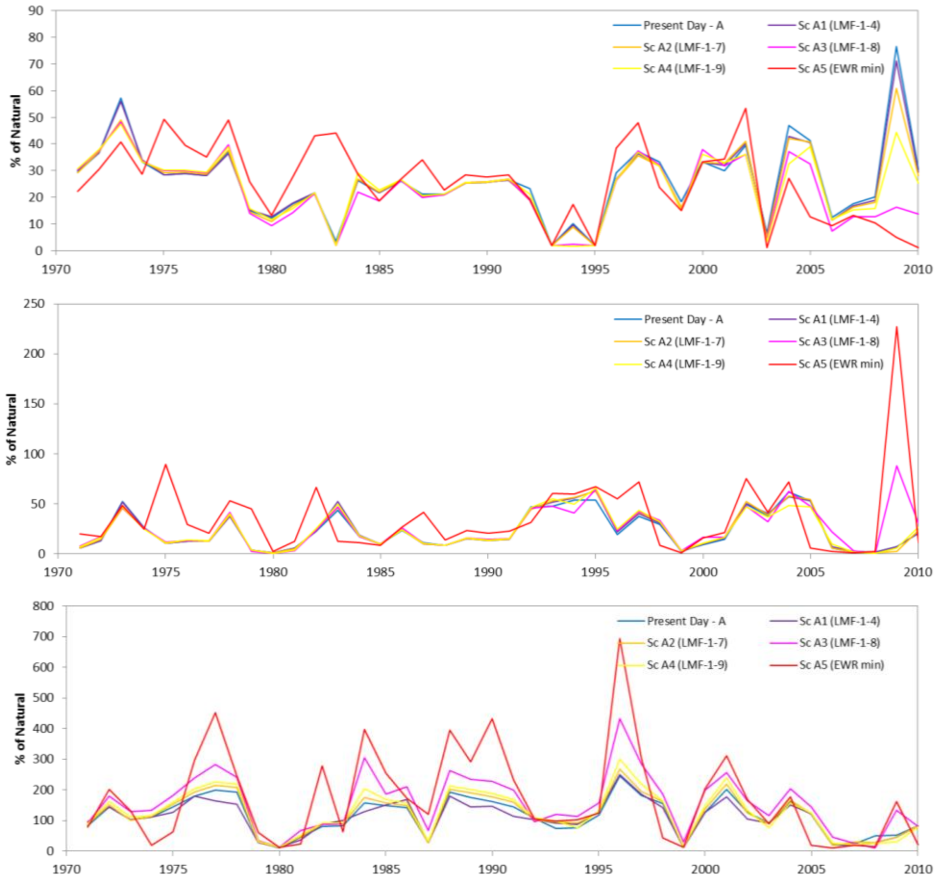


Figure 6.56. **Variation in the abundance of pelagic estuarine invertebrates (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

Figure 6.57. **Variation in the abundance of pelagic marine invertebrates (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**



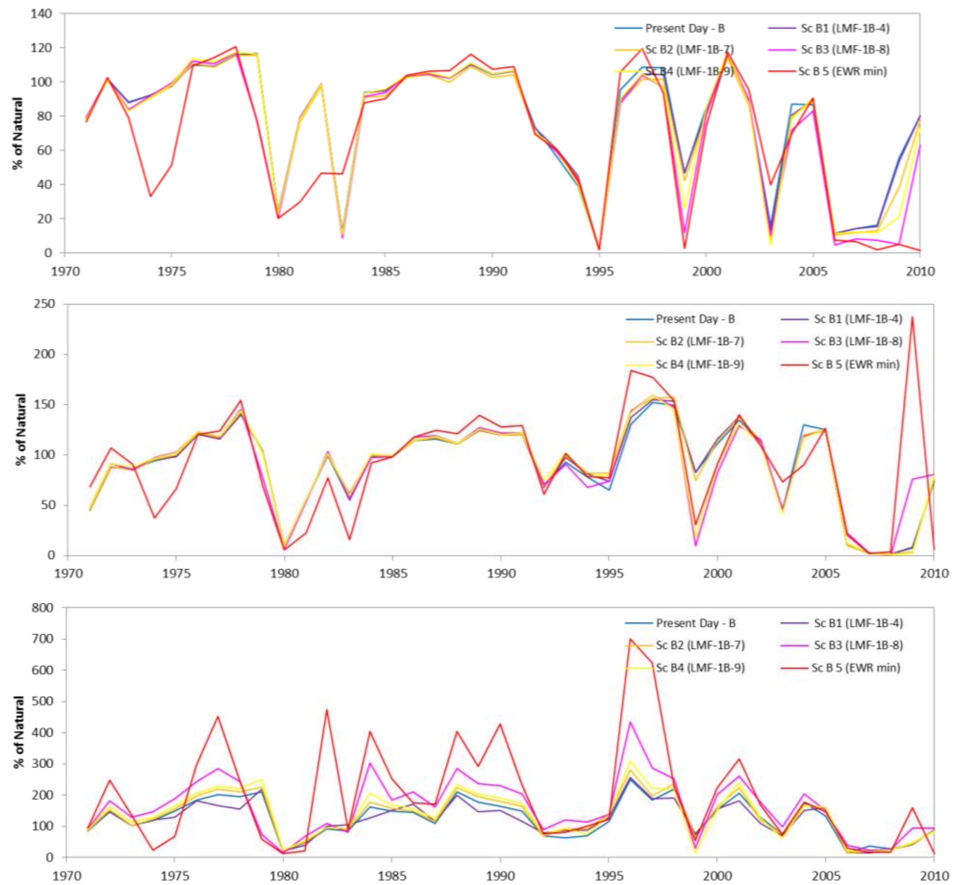


Figure 6.58. Variation in the abundance of pelagic marine invertebrates (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

Figure 6.59. Variation in the abundance of pelagic freshwater invertebrates (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

Figure 6.60. Variation in the abundance of pelagic freshwater invertebrates (% of natural) in the Lakes (top) and Narrows (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

Table 6.19. Invertebrate health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation.

	Invertebrate health score	
Present Day - A	31.3	E
Sc. A1 (LMF 1-4)	30.5	E
Sc. A2 (LMF 1-7)	30.8	E
Sc. A3 (LMF 1-8)	29.9	E
Sc. A4 (LMF 1-9)	29.9	E
Sc. A5 (LMF EWR min)	29.4	E
Present Day - B	46.3	D
Sc. B1 (LMF 1-4)	46.2	D
Sc. B2 (LMF 1-7)	45.9	D
Sc. B3 (LMF 1-8)	43.7	D
Sc. B4 (LMF 1-9)	44.6	D
Sc. B5 (LMF EWR min)	40.8	D

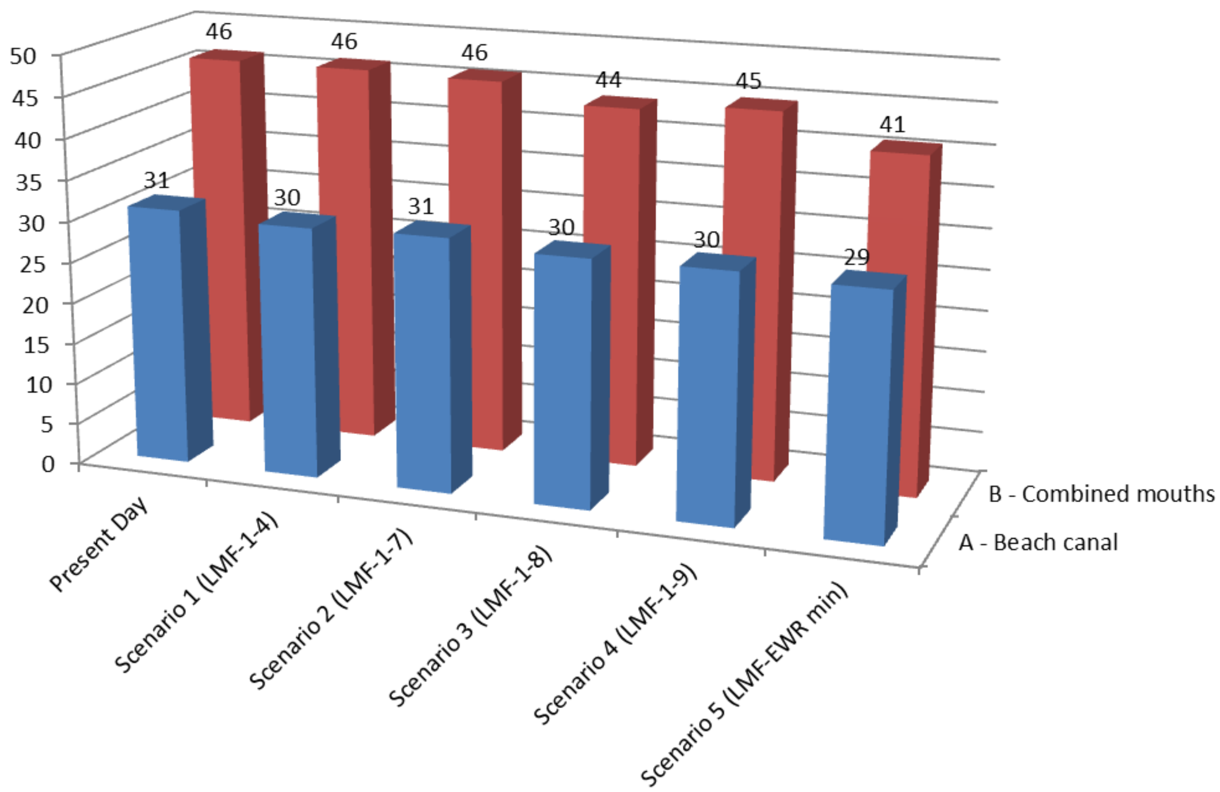


Figure 6.61. Invertebrate health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation.

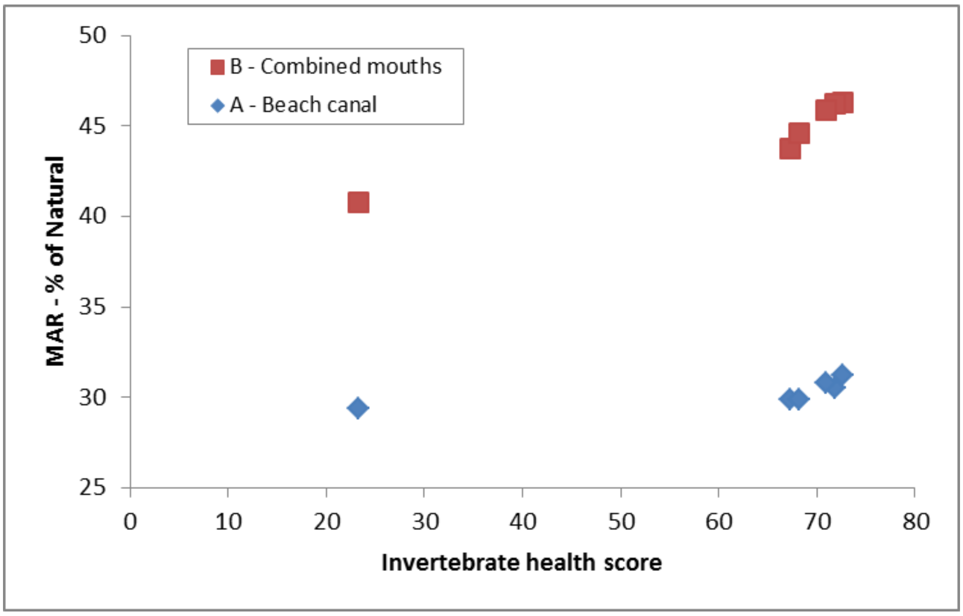


Figure 6.62. Relationship between invertebrate health in the Lake St Lucia system as a whole and MAR in the uMfolozi.

6.3.4 Fish

6.3.4.1 Variation in abundance under the operational flow scenarios

Variations in the abundance of the 11 fish groups (resident planktivores, resident benthivores, marine planktivores, marine benthivores, marine omnivores, marine piscivores, freshwater benthivores, freshwater detritivores, freshwater piscivores, catadromous detritivores, catadromous piscivores) for all of the operational flow scenarios under the "Beach channel" and "Combined mouth" configurations are shown in Figure 6.63-Figure 6.84. Summary data are presented in Table 6.20.

The responses to the changes in mouth configuration (Beach channel vs. after Phase 1 excavation) and the various operational flow scenarios differed for the various fish groups in the different sections of the estuary (Lakes, Narrows, uMfolozi) but were more similar to Reference for the Combined mouth (Mouth B) as opposed to the Beach channel (Mouth A) configuration for almost all groups. Population sizes for the estuarine and marine groups were on average more different to Reference than under Present Day flows, with this response being most marked for Scenario 5, followed by Scenario 3, Scenario 4, Scenario2 then Scenario 1.

6.3.4.2 Health scores for the operational scenarios

Fish health scores for the operational scenarios are presented in Table 6.17 and Figure 6.61. Health scores for the operational scenarios were all in an D class (42.9-48.7) for the Beach channel configuration (Mouth A) (as was the case for Present Day) but were all in a C class (60.5-60.1) for flow Scenarios 1and 2 under the after Phase 1 excavation configuration (again the same as Present Day) but dropped to a D class (51.8-57.8) under flow scenarios 3-5. All of the Operational flow scored lower than PD under the Beach channel and after Phase 1 excavation configurations, with Scenario 5 scoring the lowest, followed by Scenarios 3, 4, 2 and 1. A strong positive correlation is evident between fish health for the system as a whole and MAR in the uMfolozi (Figure 6.62).

Table 6.20. Summary data for abundance of fish (% of Reference) for the Present Day and operational flow scenarios under the "Beach channel" (A) and "after Phase 1 excavation" (B) conditions.

	Resident planktivores			Resident benthivores			Marine planktivores			Marine benthivores		
	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi
Present Day - A	97.4	62.7	88.7	36.4	45.7	91.5	26.5	24.6	64.7	30.6	16.5	43.5
Sc A1 (LMF 1-4)	96.0	62.1	86.5	35.7	45.0	90.7	25.6	24.4	60.8	29.8	16.3	45.4
Sc A2 (LMF 1-7)	94.3	62.3	92.0	35.0	45.3	94.2	24.5	24.3	70.9	28.8	16.2	46.4
Sc A3 (LMF 1-8)	87.8	61.0	114.3	32.0	45.4	130.8	22.5	23.3	102.4	26.5	15.3	88.0
Sc A4 (LMF 1-9)	92.8	61.1	93.1	34.6	44.4	95.4	25.0	22.9	73.9	29.2	15.2	47.2
Sc A5 (EWR min)	114.6	68.0	107.1	41.7	51.8	107.9	23.6	31.1	92.6	27.3	19.4	66.4
Present Day - B	85.5	85.4	89.4	75.5	82.6	95.7	62.3	78.1	73.2	59.6	64.9	46.4
Sc B1 (LMF-1-4)	83.8	85.1	88.6	74.2	82.4	95.5	62.4	78.0	71.5	59.2	64.9	50.2
Sc B2 (LMF-1-7)	78.8	85.1	94.0	70.3	82.5	99.7	57.6	78.1	82.2	54.9	65.2	50.9
Sc B3 (LMF 1-8)	80.0	83.8	116.5	69.0	81.8	134.1	58.8	76.0	110.5	55.9	62.3	91.0
Sc B4 (LMF 1-9)	83.7	83.6	94.3	73.4	80.8	100.5	62.8	76.0	81.6	58.8	63.0	52.8
Sc B 5 (EWR min)	108.3	86.7	110.9	71.3	83.2	109.8	53.7	75.3	106.7	51.0	59.0	63.5
	Marine omnivores			**Marine piscivores**			**Freshwater benthivores**			**Freshwater detritivores**		
Present Day - A	33.4	28.8	103.4	32.8	46.3	78.3	33.6	37.5	46.6	89.5	88.8	94.9
Sc A1 (LMF 1-4)	32.8	28.7	99.9	32.3	44.8	76.1	32.6	37.4	49.6	90.3	89.5	97.6
Sc A2 (LMF 1-7)	31.6	29.3	108.5	31.8	45.1	81.9	32.2	35.6	47.1	89.8	87.9	95.2
Sc A3 (LMF 1-8)	28.4	28.3	111.5	29.6	41.5	109.9	31.1	30.8	95.9	89.7	86.1	90.9
Sc A4 (LMF 1-9)	32.0	28.1	110.2	31.8	41.6	83.8	31.4	32.0	45.4	89.4	84.1	94.1
Sc A5 (EWR min)	30.7	24.1	96.4	27.0	63.9	79.3	39.4	52.2	65.3	106.9	114.1	92.7
Present Day - B	69.6	42.1	114.8	59.4	44.8	86.8	60.9	66.0	46.3	85.9	72.0	90.2
Sc B1 (LMF-1-4)	69.4	42.2	113.0	59.1	44.4	86.2	59.2	65.9	51.0	87.3	73.4	92.5
Sc B2 (LMF-1-7)	63.6	43.2	121.7	57.2	44.6	91.7	56.5	65.3	47.4	85.6	72.9	90.9
Sc B3 (LMF 1-8)	65.2	41.2	120.5	56.3	43.5	116.7	56.2	61.1	97.2	88.2	70.3	88.0
Sc B4 (LMF 1-9)	69.0	40.9	116.9	58.8	42.7	89.0	58.6	63.4	47.6	85.9	70.8	89.7
Sc B 5 (EWR min)	55.7	36.4	110.2	48.0	66.6	87.5	61.5	76.6	61.8	108.7	105.5	84.0

	Freshwater piscivores			Catadromous detritivores			Catadromous piscivores		
	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi
Present Day - A	66.6	91.6	82.5	26.5	32.4	75.1	28.4	32.3	75.1
Sc A1 (LMF 1-4)	64.9	92.9	85.2	26.4	32.5	72.5	28.3	32.4	72.5
Sc A2 (LMF 1-7)	64.1	87.8	80.6	26.1	32.4	74.9	27.9	32.3	74.9
Sc A3 (LMF 1-8)	60.9	75.0	68.8	26.4	32.6	71.5	28.2	32.5	71.5
Sc A4 (LMF 1-9)	62.1	79.7	75.8	26.3	32.5	73.7	28.2	32.4	73.7
Sc A5 (EWR min)	73.6	202.7	80.4	24.5	32.3	53.5	26.2	32.1	53.5
Present Day - B	50.2	46.8	69.0	54.3	65.0	82.9	57.4	64.8	82.9
Sc B1 (LMF-1-4)	48.8	46.1	72.0	53.2	64.9	80.7	56.2	64.8	80.7
Sc B2 (LMF-1-7)	47.7	44.3	67.8	52.6	64.7	82.3	55.6	64.5	82.3
Sc B3 (LMF 1-8)	46.9	40.1	62.0	51.2	62.3	76.2	54.1	62.2	76.2
Sc B4 (LMF 1-9)	47.9	43.3	65.2	52.6	63.3	79.8	55.6	63.2	79.8
Sc B 5 (EWR min)	66.7	179.1	70.9	45.6	57.5	60.5	48.2	57.4	60.5

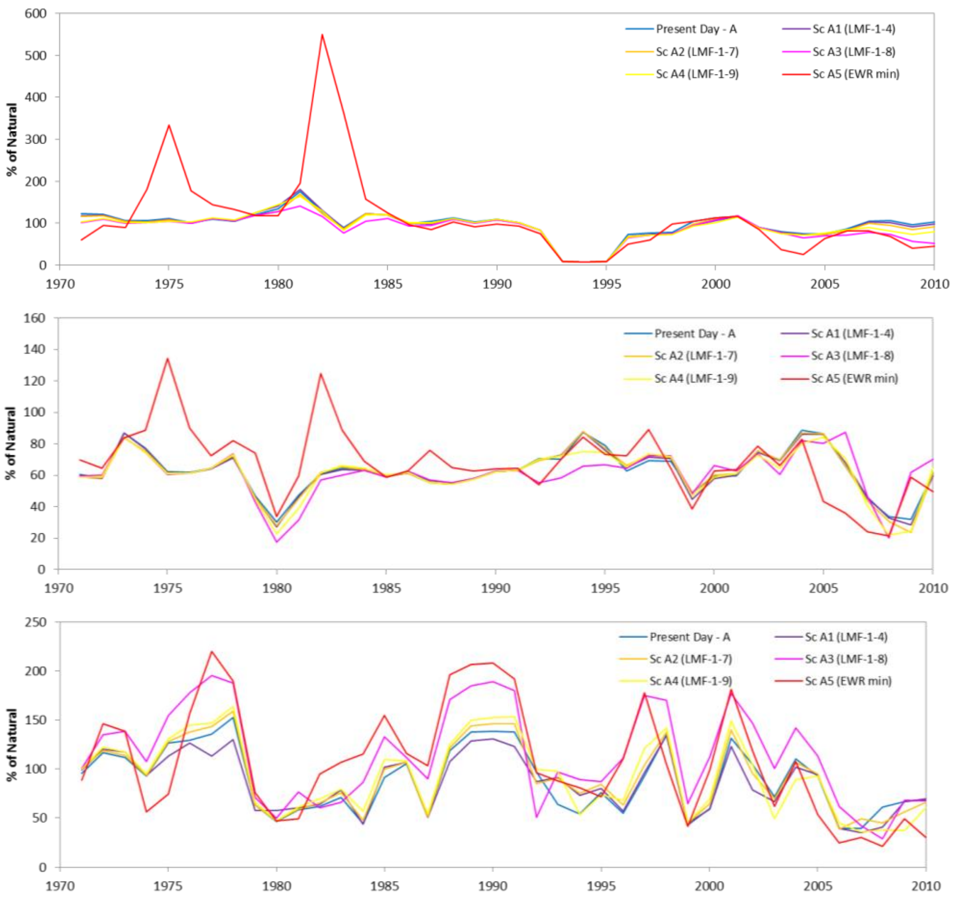


Figure 6.63. **Variation in the abundance of resident planktivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

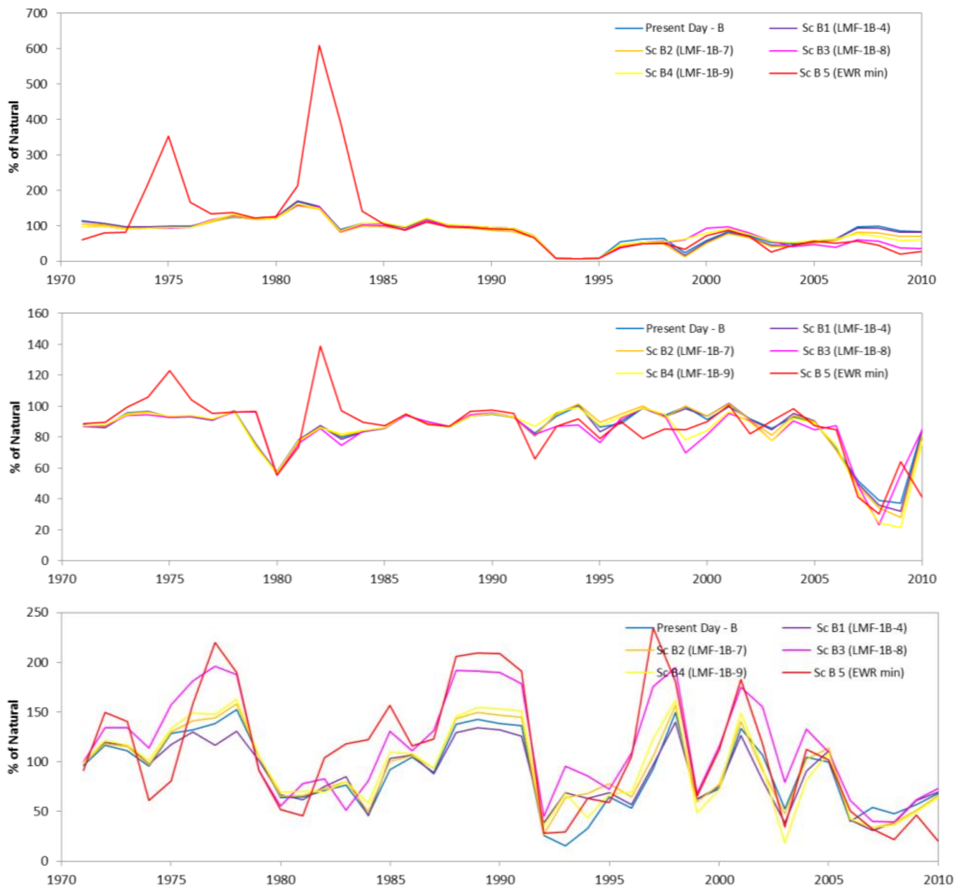


Figure 6.64. **Variation in the abundance of resident planktivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

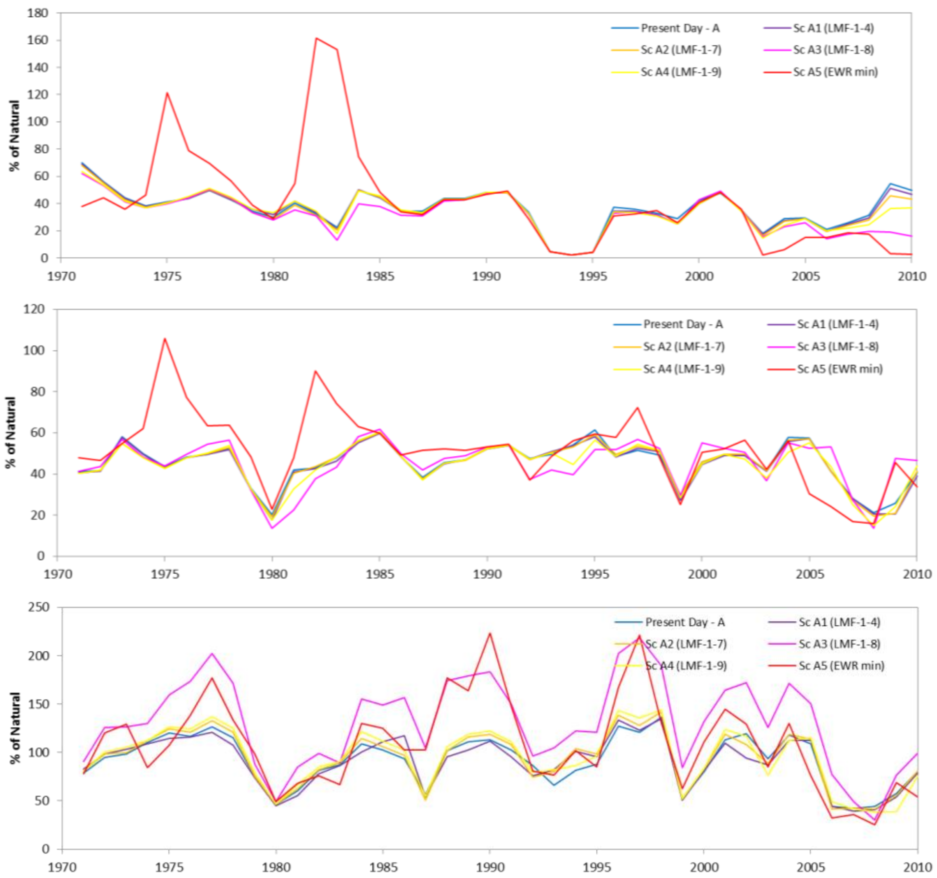


Figure 6.65. **Variation in the abundance of resident benthivorous fish (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

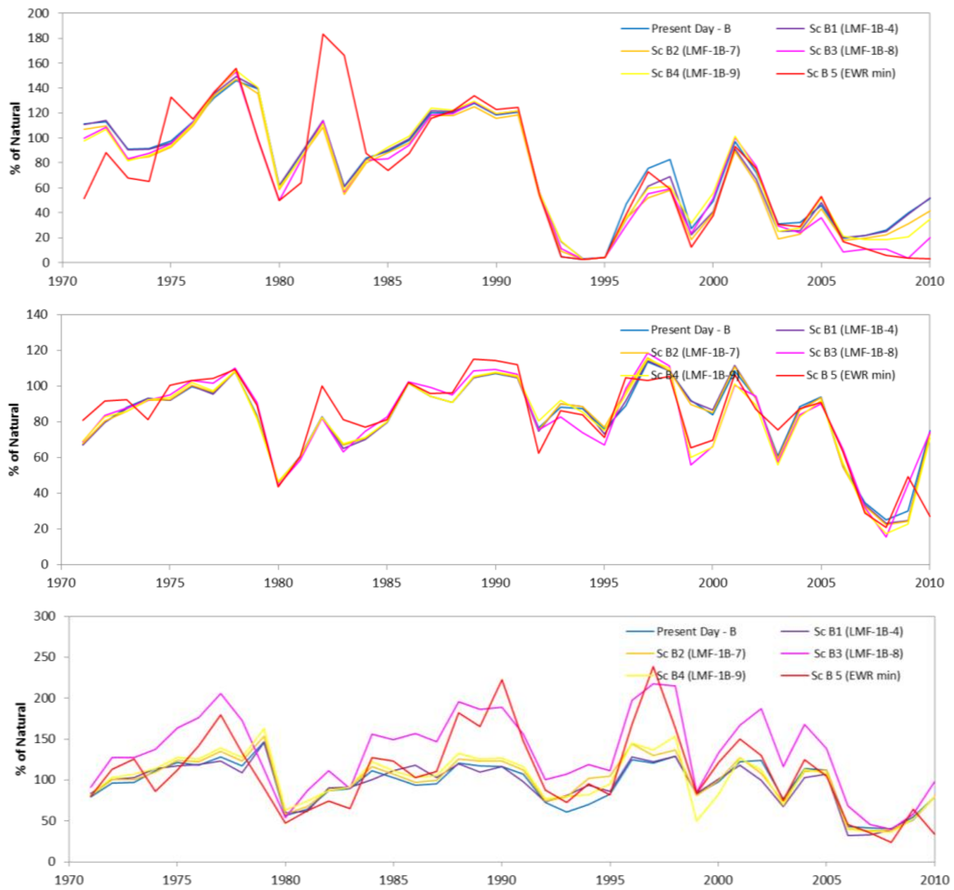


Figure 6.66. **Variation in the abundance of resident benthivorous fish (% of natural) in the Lakes (top) and Narrows (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

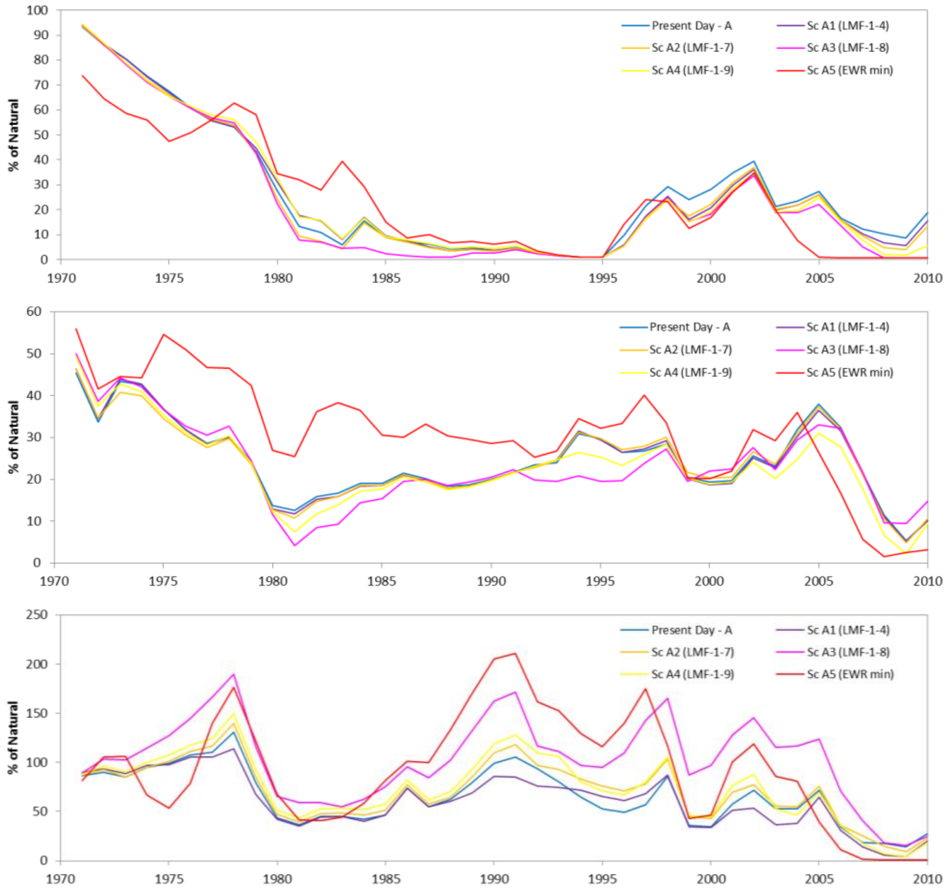


Figure 6.67. **Variation in the abundance of marine planktivorous fish (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

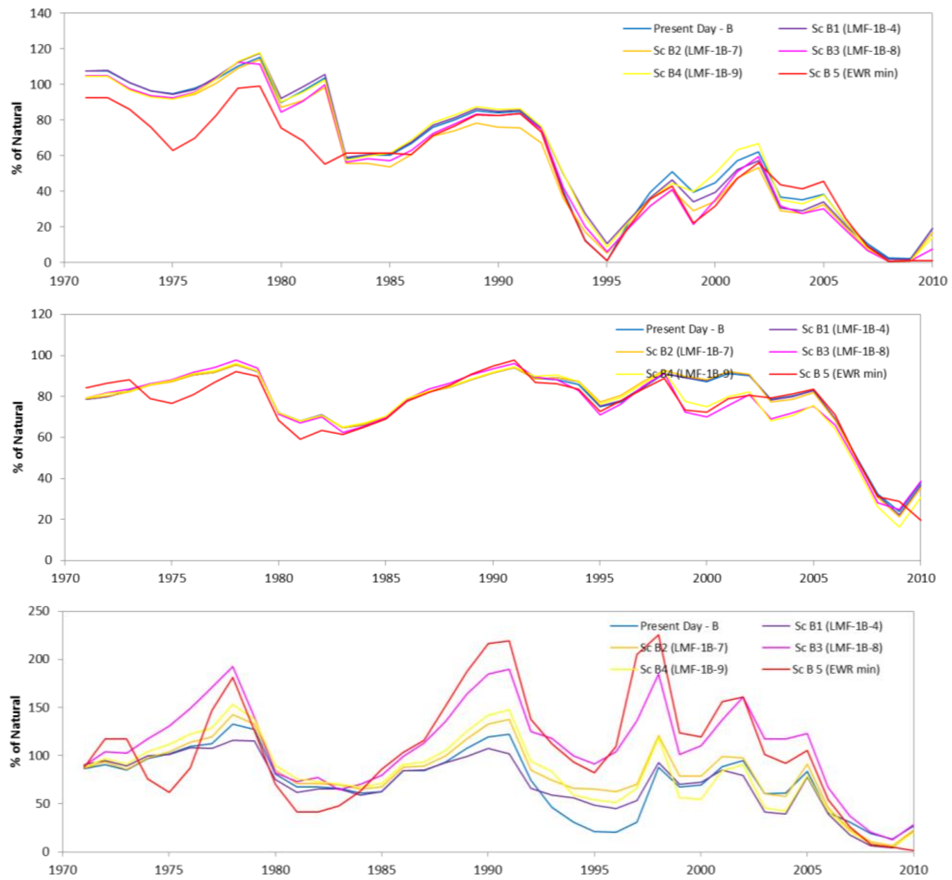


Figure 6.68. **Variation in the abundance of marine planktivorous fish (% of natural) in the Lakes (top) and Narrows (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

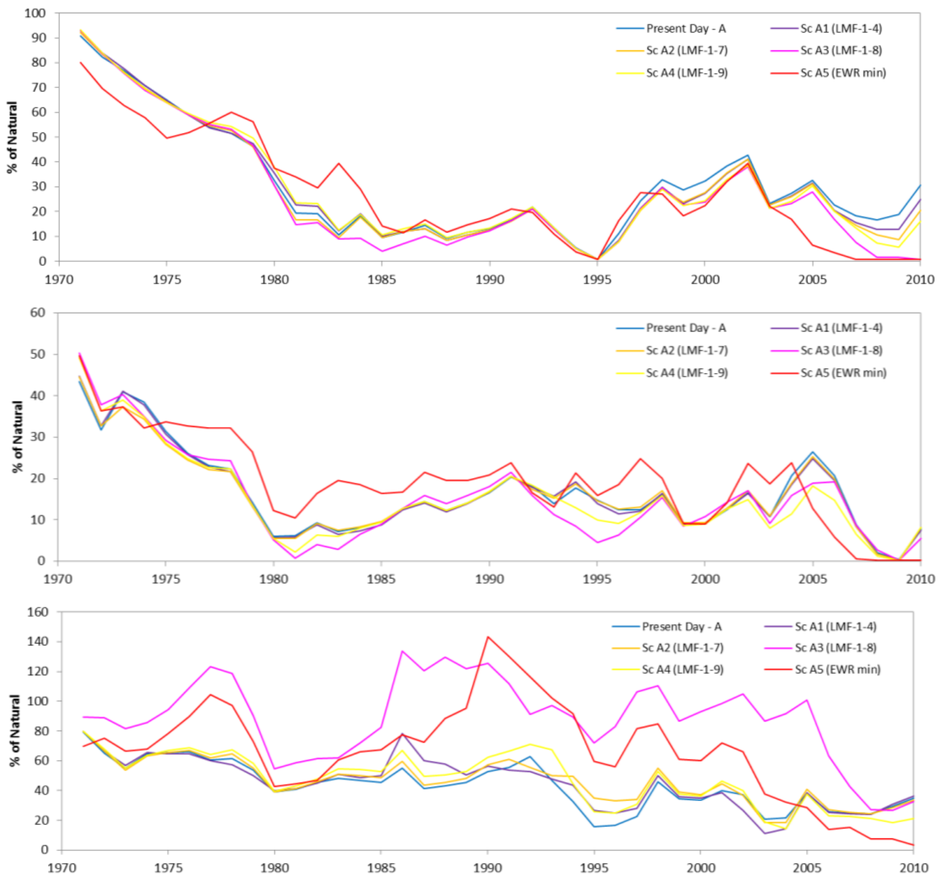


Figure 6.69. Variation in the abundance of marine benthivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

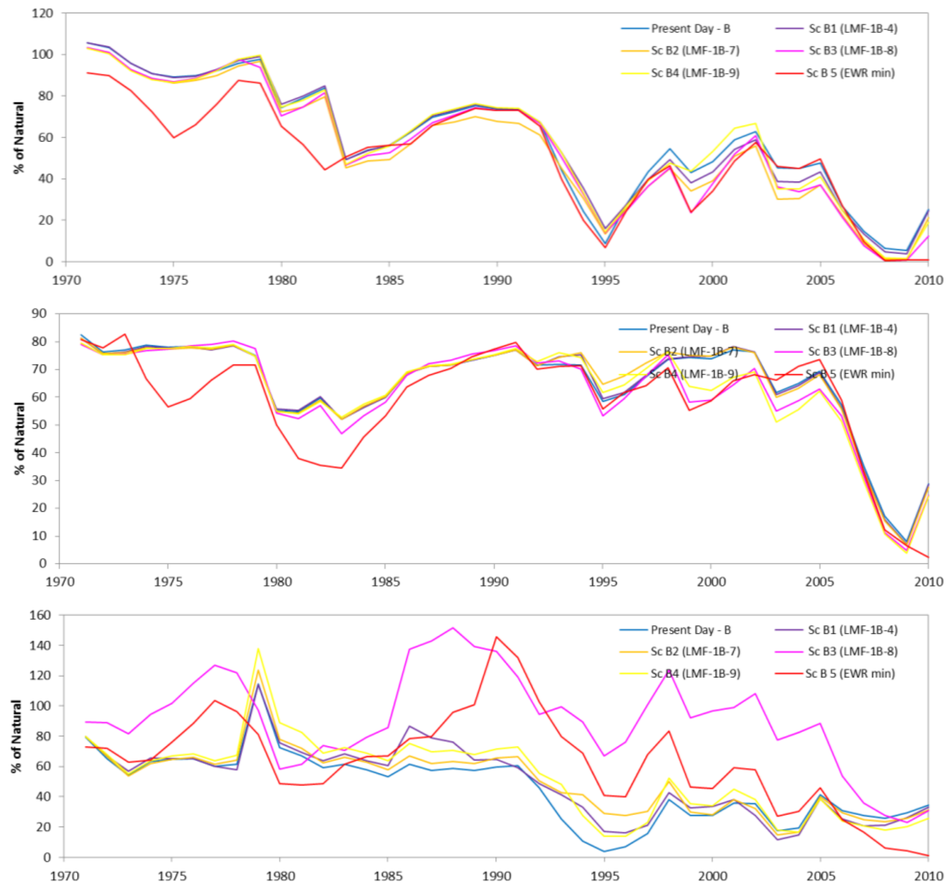


Figure 6.70. Variation in the abundance of marine benthivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

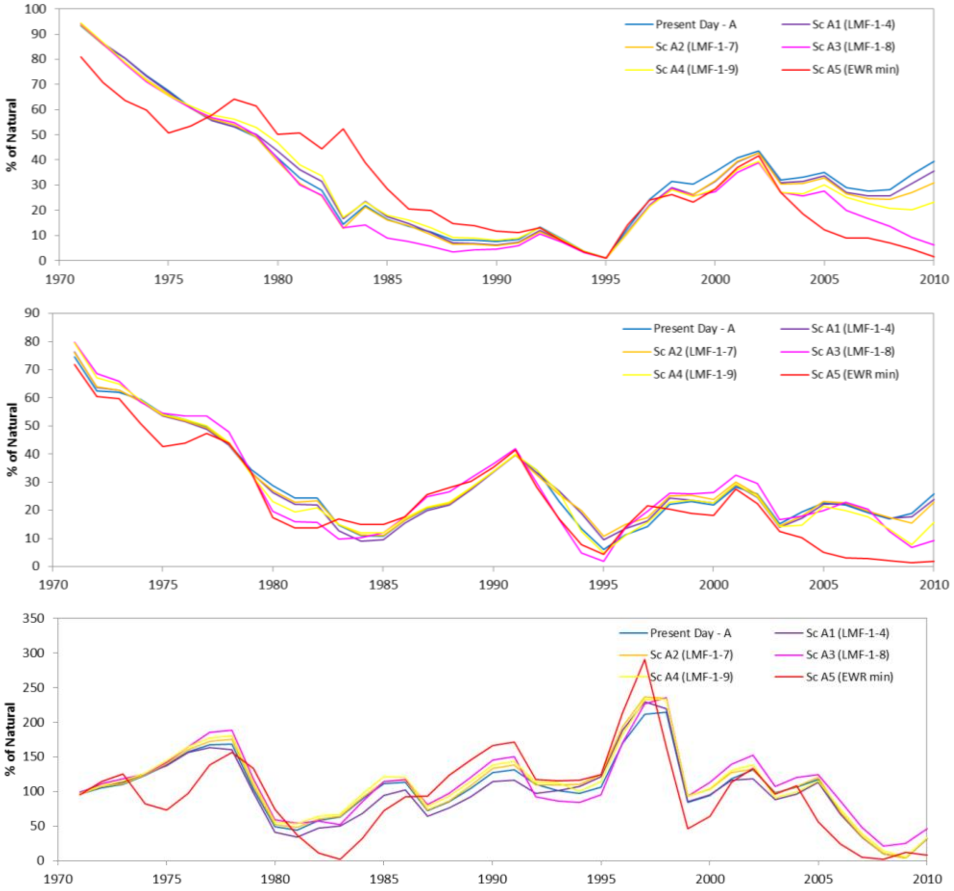


Figure 6.71. **Variation in the abundance of marine omnivorous fish (% of natural) in the Narrows (top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

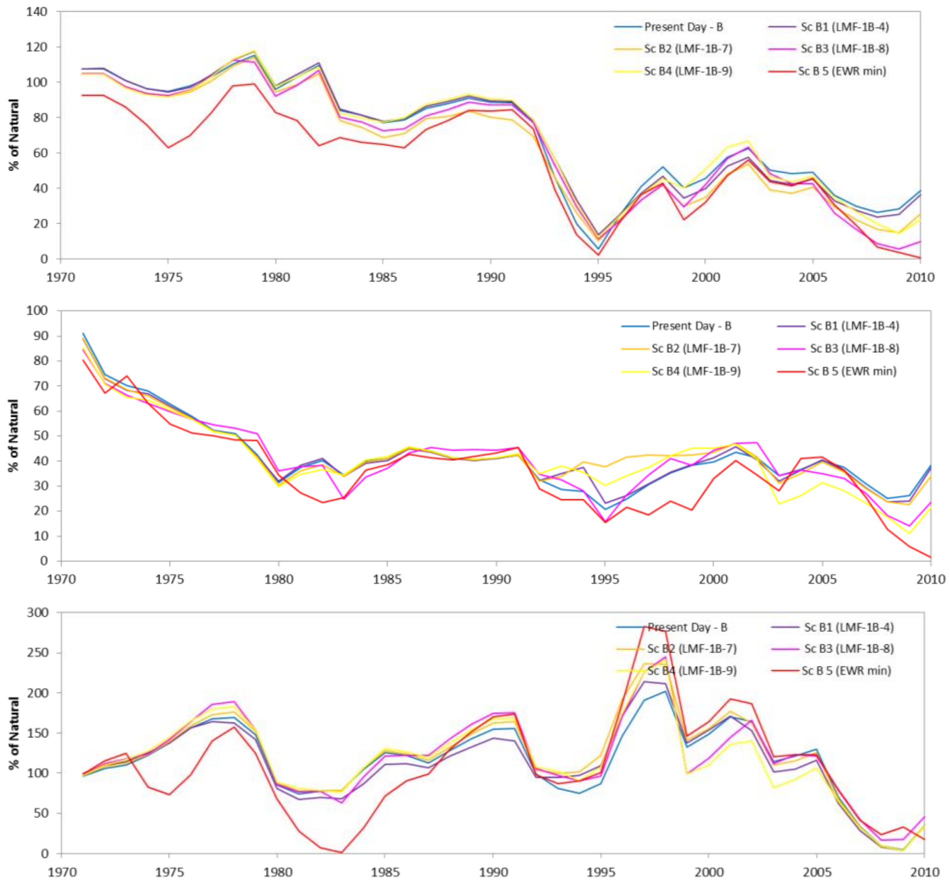


Figure 6.72. **Variation in the abundance of marine omnivorous fish (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

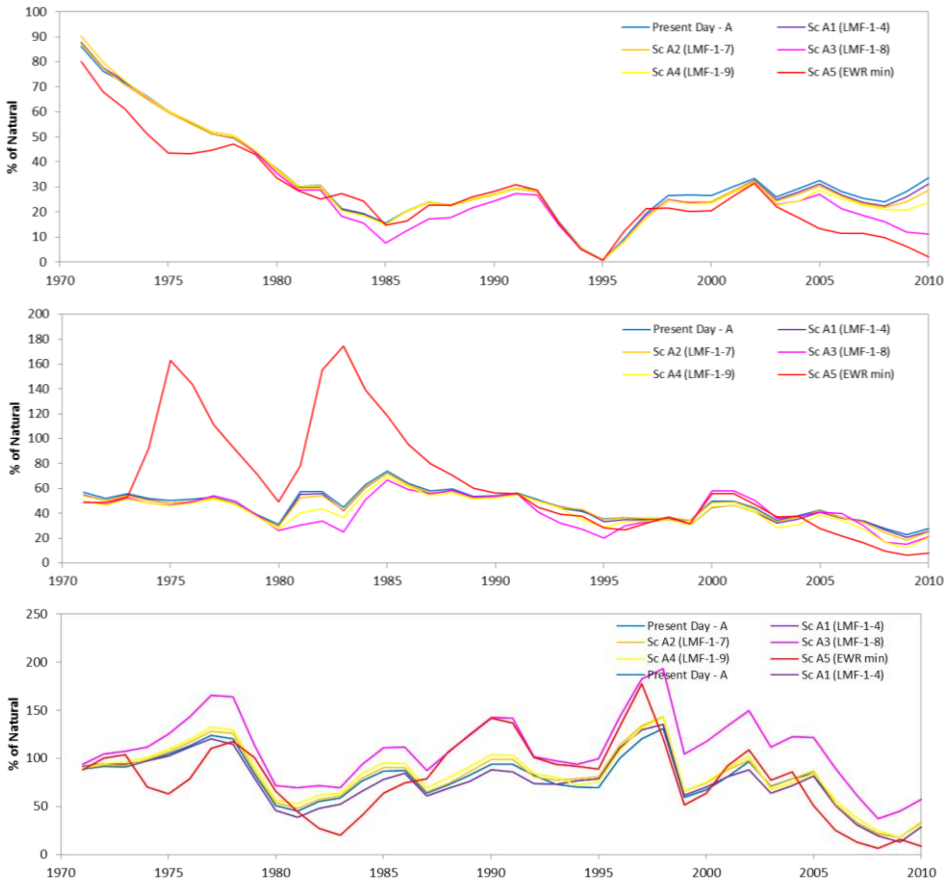


Figure 6.73. Variation in the abundance of marine piscivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

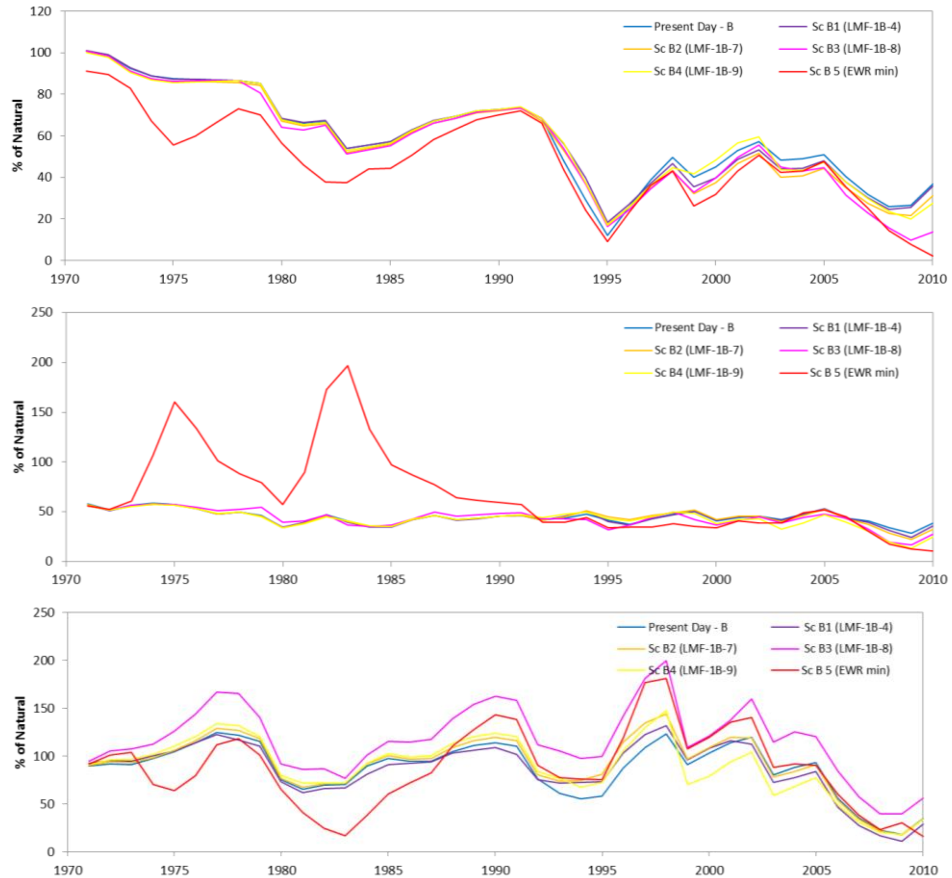


Figure 6.74. Variation in the abundance of marine piscivorous fish (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day

conditions and under the operational flow scenarios.

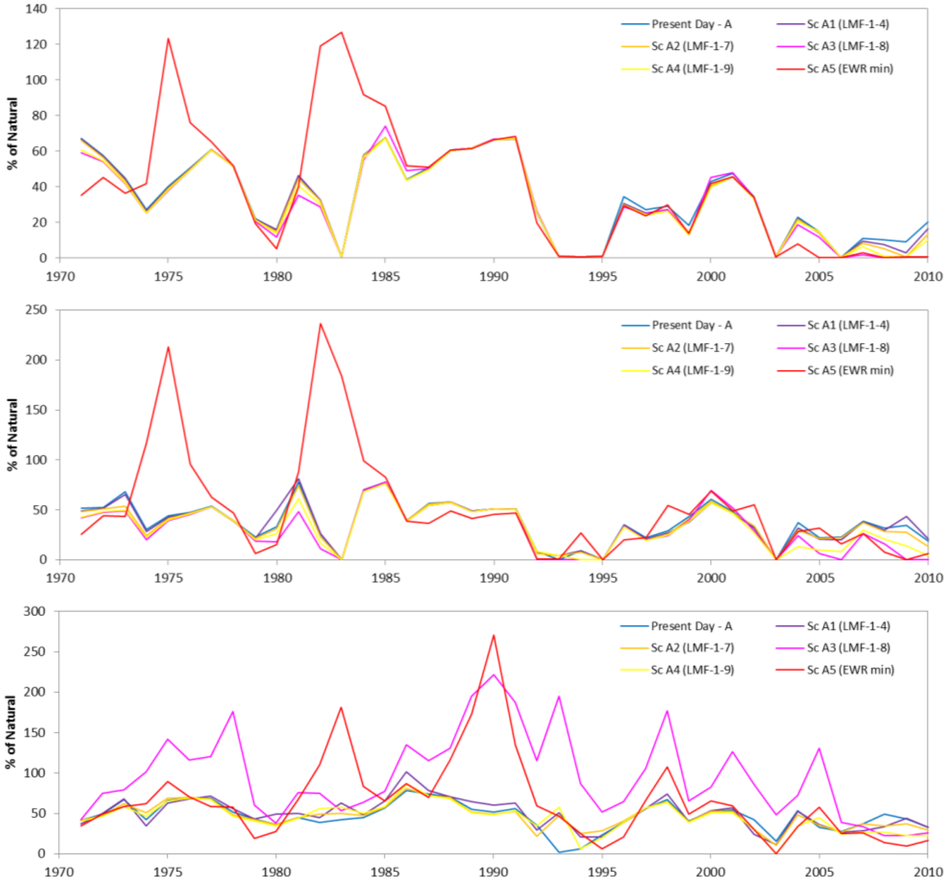


Figure 6.75. **Variation in the abundance of freshwater benthivorous fish (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel**

under reference and present-day conditions and under the operational flow scenarios.

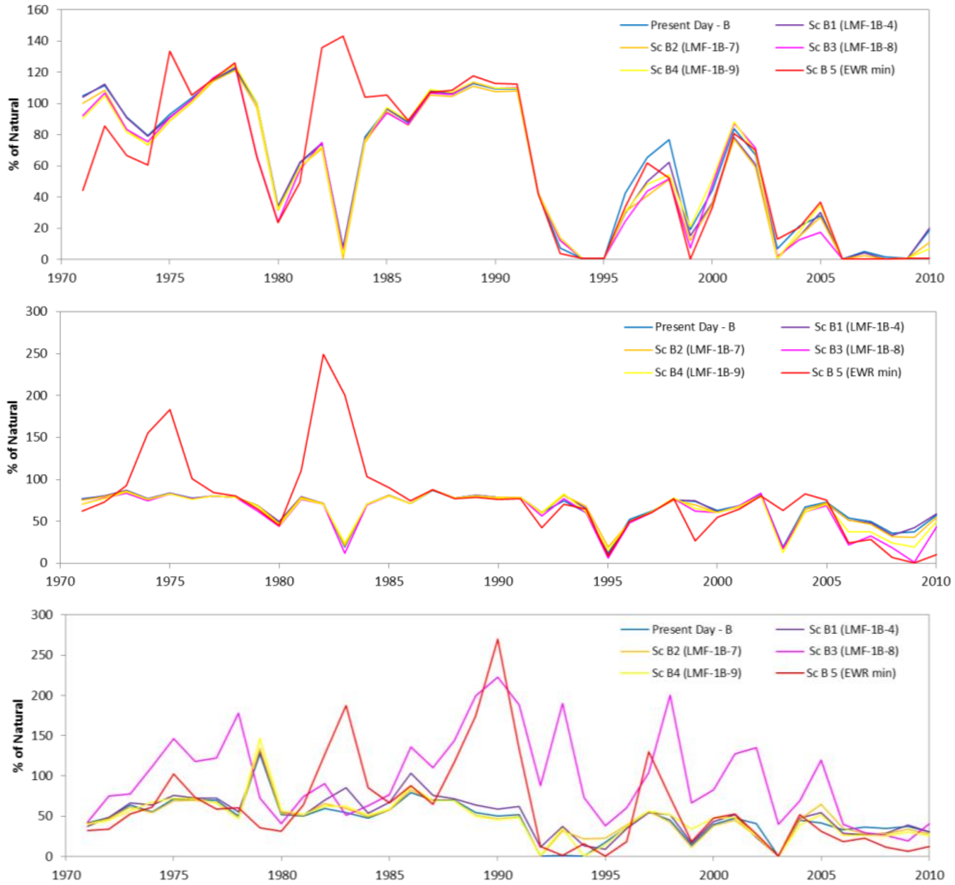


Figure 6.76. **Variation in the abundance of freshwater benthivorous fish (% of natural) in the Lakes (top)**

and Narrows (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

(top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

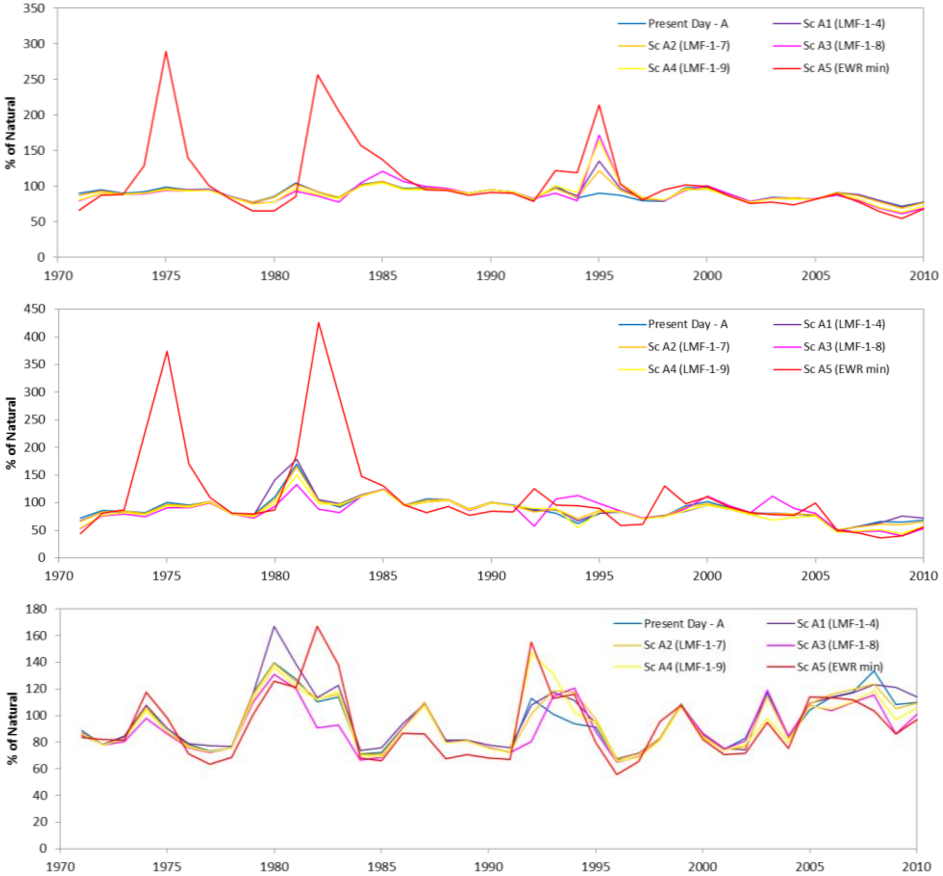


Figure 6.77. Variation in the abundance of freshwater detritivorous fish (% of natural) in the Narrows

Figure 6.78. Variation in the abundance of freshwater detritivorous fish (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

Figure 6.79. Variation in the abundance of freshwater piscivorous fish (% of natural) in the Narrows (top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

Figure 6.80. **Variation in the abundance of freshwater piscivorous fish (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

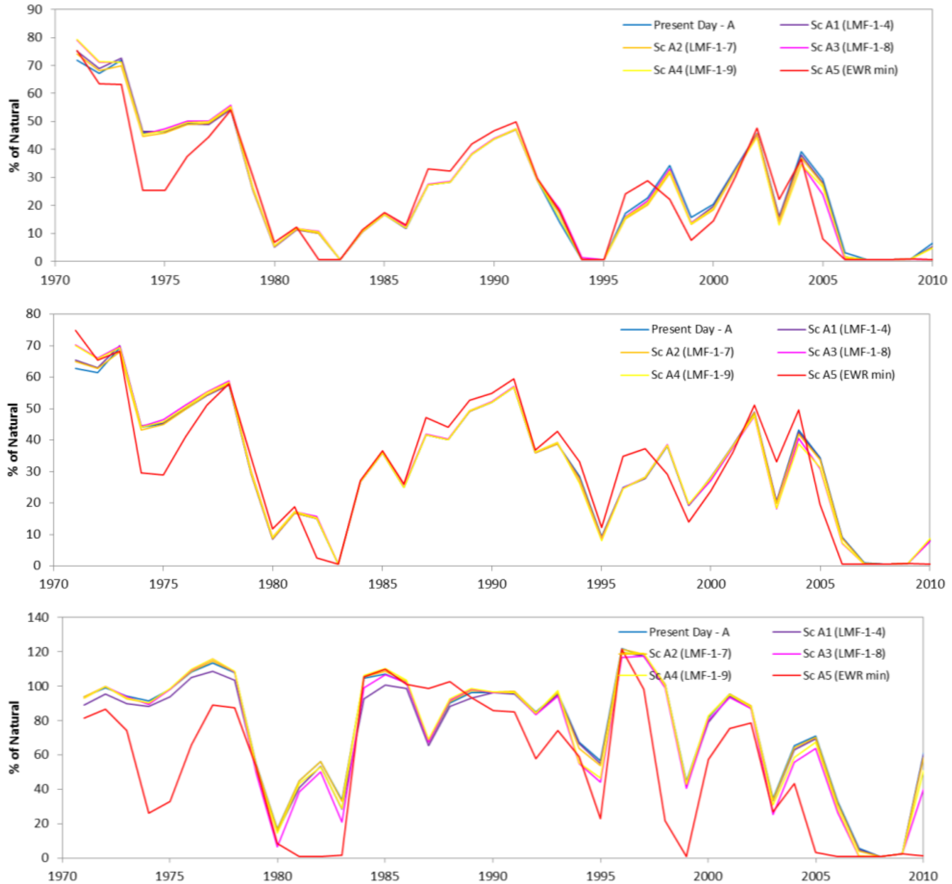


Figure 6.81. **Variation in the abundance of catadromous detritivorous fish (% of natural) in the Narrows (top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

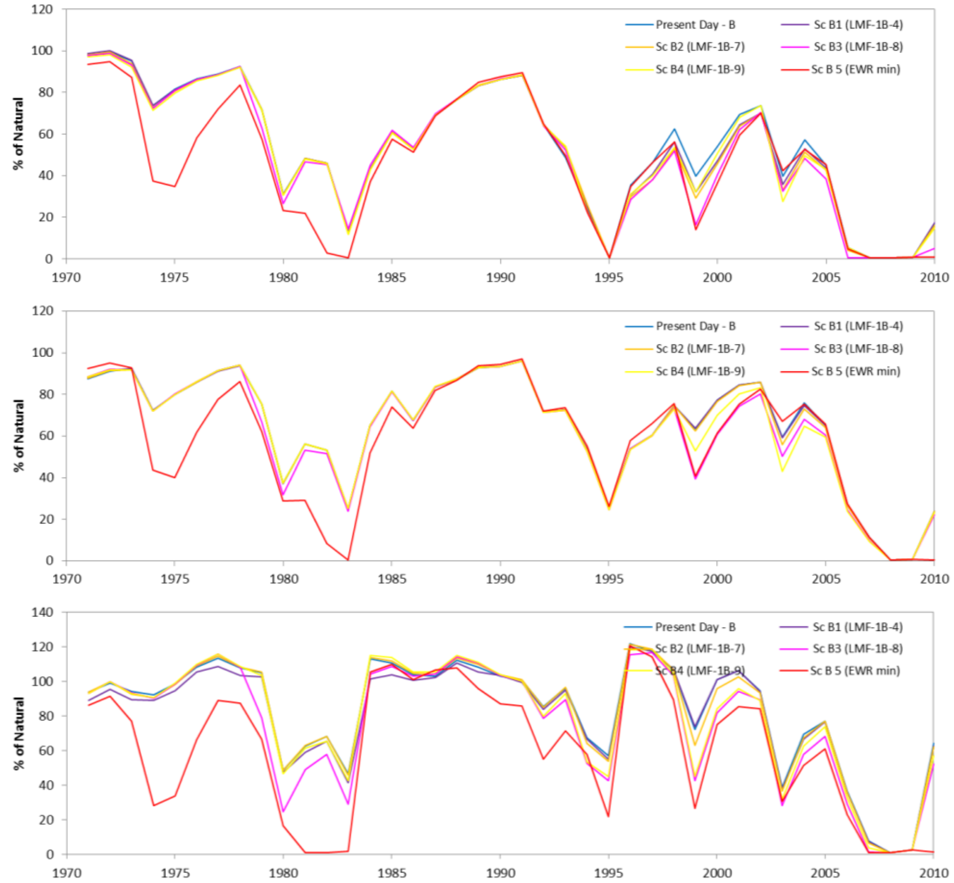


Figure 6.82. **Variation in the abundance of catadromous detritivorous fish (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

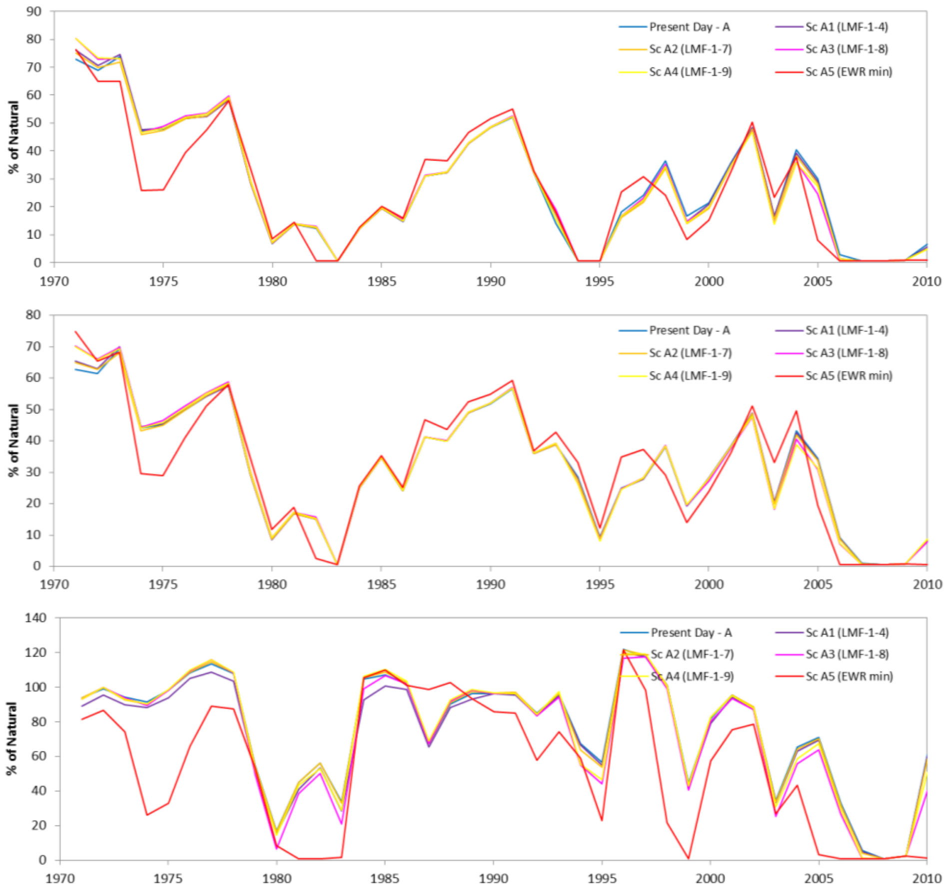


Figure 6.83. **Variation in the abundance of catadromous piscivorous fish (% of natural) in the Narrows (top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

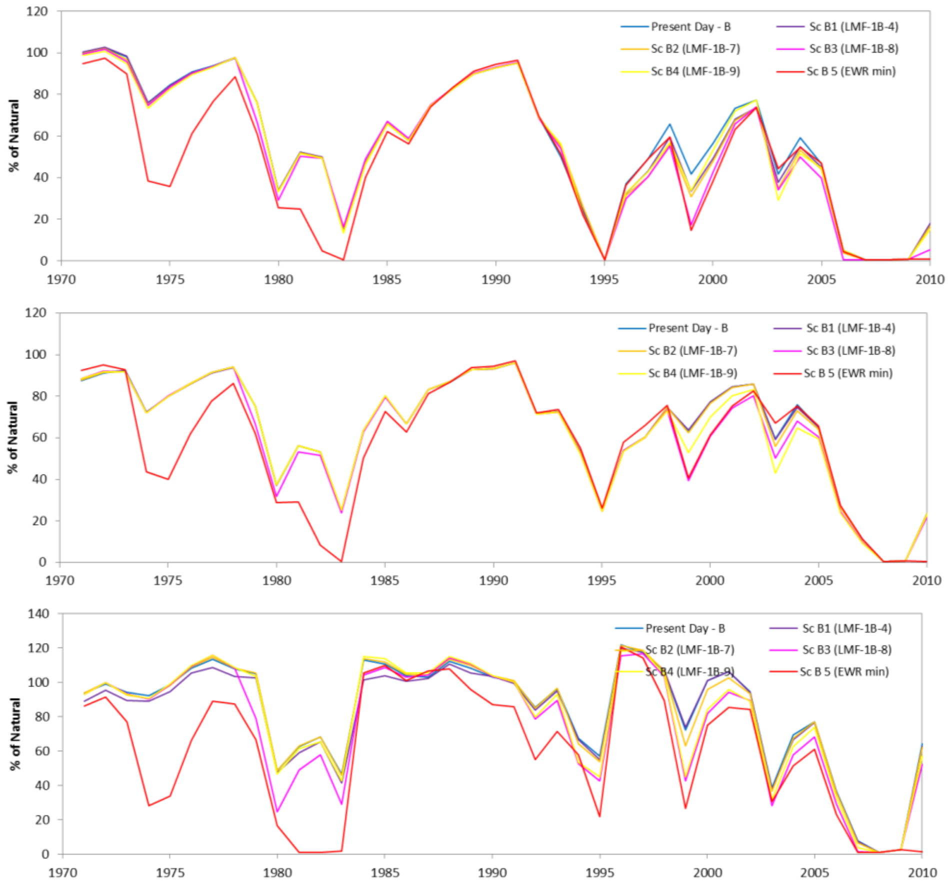


Figure 6.84. **Variation in the abundance of catadromous piscivorous fish (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

Table 6.21. Fish health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation.

	Fish health score	
Present Day - A	49.0	D
Sc. A1 (LMF 1-4)	48.7	D
Sc. A2 (LMF 1-7)	47.9	D
Sc. A3 (LMF 1-8)	46.1	D
Sc. A4 (LMF 1-9)	46.0	D
Sc. A5 (LMF EWR min)	42.9	D
Present Day - B	61.5	C
Sc. B1 (LMF 1-4)	60.5	C
Sc. B2 (LMF 1-7)	60.1	C
Sc. B3 (LMF 1-8)	57.2	D
Sc. B4 (LMF 1-9)	57.8	D
Sc. B5 (LMF EWR min)	51.8	D

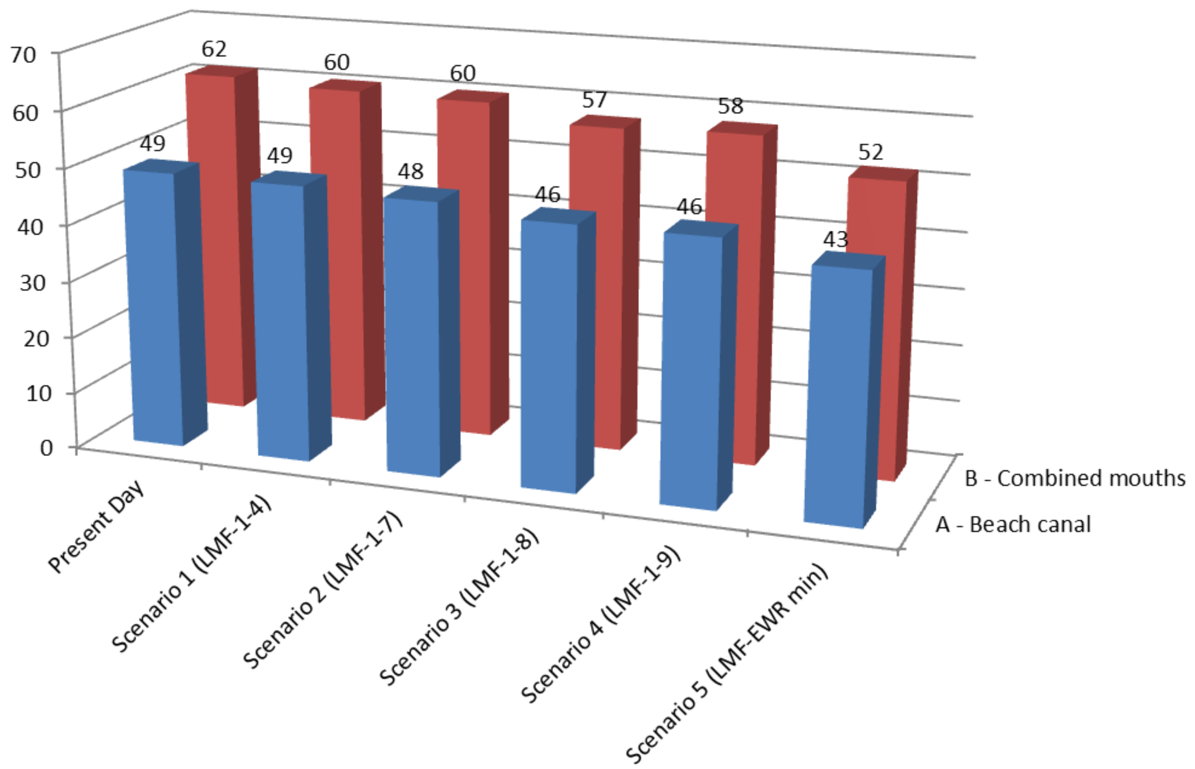


Figure 6.85. Fish health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation.

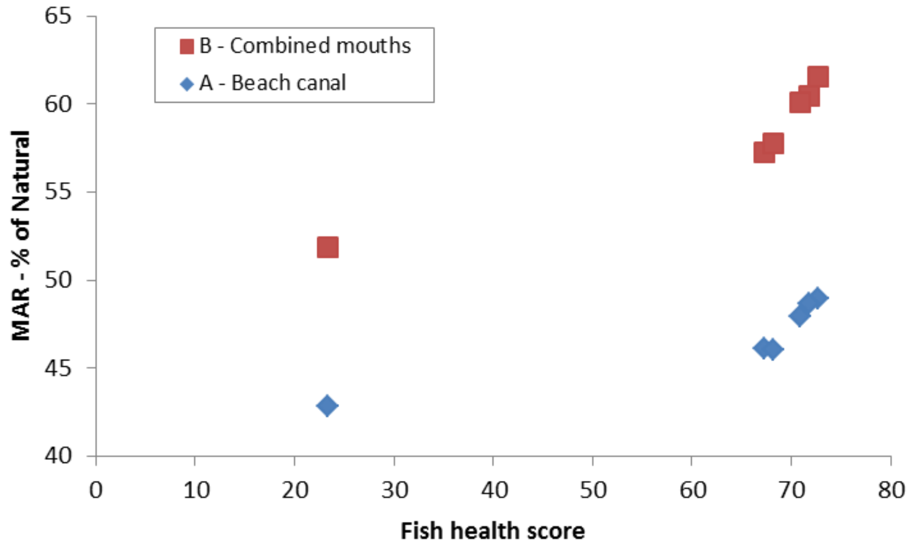


Figure 6.86. Relationship between fish health in the Lake St Lucia system as a whole and MAR in the uMfolozi.

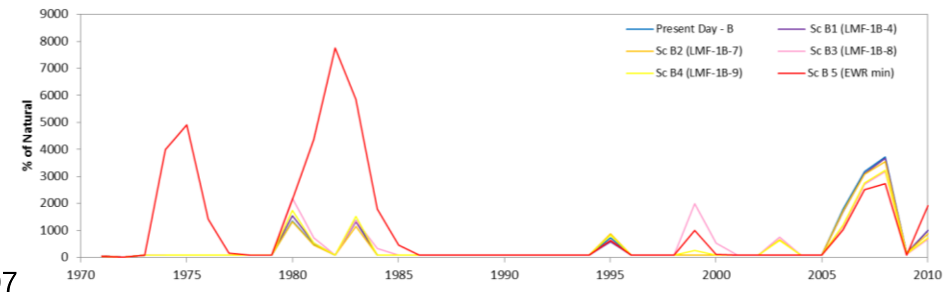
6.3.5 Birds

6.3.5.1 Variation in abundance under the operational flow scenarios

Variations in the abundance of the ten avifauna groups (flamingos, gulls & Caspian terns, pelicans, waders, other terns, waterfowl, cormorants, wading birds, perching piscivores, and Common & Little terns) for all of the operational flow scenarios under the “Beach channel” and “Combined mouth” configurations are shown in Figure 6.87-Figure 6.106. Summary data are presented in Table 6.16. Average population sizes for many of the groups in the St Lucia Lakes were estimated to be very close to the Reference state, although the fluctuations in abundance under the different scenarios are not always in sync with that projected for the Reference state. Populations of many groups in the Narrows and uMfolozi are markedly different from Reference state, however, in most cases more so for the Beach channel as opposed to the after Phase 1 excavation configuration. Responses to the operational scenarios were not consistent, and were sometimes more similar to Reference and other times diverged from Reference relative to Present Day.

6.3.5.2 Health scores for the operational scenarios

Avifauna health scores for the operational scenarios are presented in Table 6.23 and Figure



6.107

Figure 6.30. Health scores for the operational scenarios were all in an D class (54.5-59.1) for the Beach channel configuration (Mouth A) (as was the case for Present Day) but rose to a C

class (63.55-69.3) for the after Phase 1 excavation configuration (again the same as Present Day). Responses to reductions in flow under the operational flow scenarios were mostly positive and peaked under Scenario 3 or 5, for mouth configurations A and B respectively. A weak negative correlation is evident between avifauna health for the system as a whole and MAR in the uMfolozi (Figure 6.108). This is contrary to all the other biotic and abiotic indices and is presumably linked to the strong relationship between bird numbers and water level (and associated parameters) which is also negatively correlated with flow.

Table 6.22. Summary data for abundance of avifauna (% of Reference) under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation).

	Flamingos			Gulls & Caspian Tern			Pelicans			Waders		
	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi	Lakes	Narrows	uMfolozi
Present Day - A	84.5	61.1	87.9	100.6	111.1	109.0	102.0	97.7	110.6	98.0	32.7	56.1
Sc A1 (LMF 1-4)	84.1	60.1	87.4	100.5	110.9	109.6	102.4	98.6	110.5	99.2	32.7	54.4
Sc A2 (LMF 1-7)	85.5	61.1	90.2	100.4	111.0	109.3	102.4	99.7	110.9	99.2	32.7	57.0
Sc A3 (LMF 1-8)	87.2	68.8	104.3	99.7	109.4	107.5	106.2	98.3	111.3	105.1	34.1	86.6
Sc A4 (LMF 1-9)	83.5	64.3	95.2	100.0	110.3	108.6	103.6	100.8	110.7	101.9	32.7	58.8
Sc A5 (EWR min)	75.6	62.7	95.0	100.1	110.4	108.9	105.7	93.2	101.2	97.5	39.7	70.8
Present Day - B	68.6	81.3	100.7	99.8	105.1	106.6	103.3	113.6	109.8	107.5	80.2	62.1
Sc B1 (LMF-1-4)	68.5	80.3	100.9	99.8	105.1	107.1	102.8	114.6	113.3	107.3	80.2	63.0
Sc B2 (LMF-1-7)	69.2	80.5	102.9	99.8	105.2	107.1	102.3	115.1	111.1	107.0	80.1	64.0
Sc B3 (LMF 1-8)	72.1	85.5	111.3	99.4	104.4	106.1	103.6	114.6	112.0	108.3	78.9	90.4
Sc B4 (LMF 1-9)	69.2	81.7	107.2	99.7	104.9	106.7	102.4	115.1	109.7	106.4	79.0	64.7
Sc B 5 (EWR min)	71.4	77.3	107.3	99.9	106.3	106.1	103.5	105.0	101.5	100.6	78.5	76.3
	Other terns			**Waterfowl**			**Cormorants**			**Wading birds**		
Present Day - A	102.7	54.2	81.8	104.8	176.2	97.1	103.6	17.3	45.1	29.5	17.3	45.1
Sc A1 (LMF 1-4)	102.8	53.7	80.1	103.2	206.7	115.4	104.1	17.0	40.7	29.2	17.0	40.7
Sc A2 (LMF 1-7)	102.7	54.1	84.6	103.4	174.1	94.5	104.0	16.6	47.4	28.4	16.6	47.4
Sc A3 (LMF 1-8)	102.7	49.5	99.3	109.2	164.6	82.2	108.7	18.7	93.0	28.1	18.8	93.0
Sc A4 (LMF 1-9)	102.4	49.2	83.9	99.9	165.6	86.1	106.1	16.5	53.7	28.5	16.5	53.7
Sc A5 (EWR min)	102.3	62.2	83.8	132.2	248.6	152.3	110.5	28.5	76.1	33.6	28.6	76.1
Present Day - B	101.4	90.9	83.6	86.3	128.0	85.0	106.0	65.8	59.2	62.5	65.9	59.2
Sc B1 (LMF-1-4)	101.4	90.5	84.2	85.2	133.1	89.6	105.0	65.7	55.5	61.2	65.8	55.5
Sc B2 (LMF-1-7)	101.2	90.5	87.6	85.1	126.4	82.7	104.2	66.1	63.6	56.9	66.2	63.6
Sc B3 (LMF 1-8)	101.2	87.7	99.1	85.3	122.9	75.2	106.2	65.0	107.0	59.9	65.0	107.0
Sc B4 (LMF 1-9)	101.0	87.7	85.0	85.1	122.9	78.7	104.5	64.1	69.5	61.7	64.1	69.5

Sc B 5 (EWR min)	101.8	90.3	88.8	124.6	206.3	139.9	108.5	67.8	89.5	58.5	67.9	89.5

	Perching piscivores			Common & Little Terns		
	Lakes	**Narrows**	**uMfolozi**	**Lakes**	**Narrows**	**uMfolozi**
Present Day - A	64.5	53.3	69.0	73.5	58.3	85.5
Sc A1 (LMF 1-4)	63.9	52.8	68.6	73.1	57.2	84.5
Sc A2 (LMF 1-7)	62.9	53.1	74.3	72.1	57.6	88.6
Sc A3 (LMF 1-8)	60.5	51.7	99.2	68.4	51.6	102.8
Sc A4 (LMF 1-9)	62.7	50.5	76.0	71.6	51.8	87.9
Sc A5 (EWR min)	63.9	62.4	81.9	71.6	69.0	91.4
Present Day - B	80.8	91.1	76.2	85.5	93.9	86.4
Sc B1 (LMF-1-4)	80.9	90.8	77.0	86.0	93.7	87.4
Sc B2 (LMF-1-7)	77.7	90.9	81.7	83.3	93.8	90.8
Sc B3 (LMF 1-8)	78.4	88.5	100.8	83.1	90.6	102.3
Sc B4 (LMF 1-9)	80.4	88.9	79.9	85.2	91.0	87.9
Sc B 5 (EWR min)	78.4	89.7	85.3	83.1	97.5	94.1

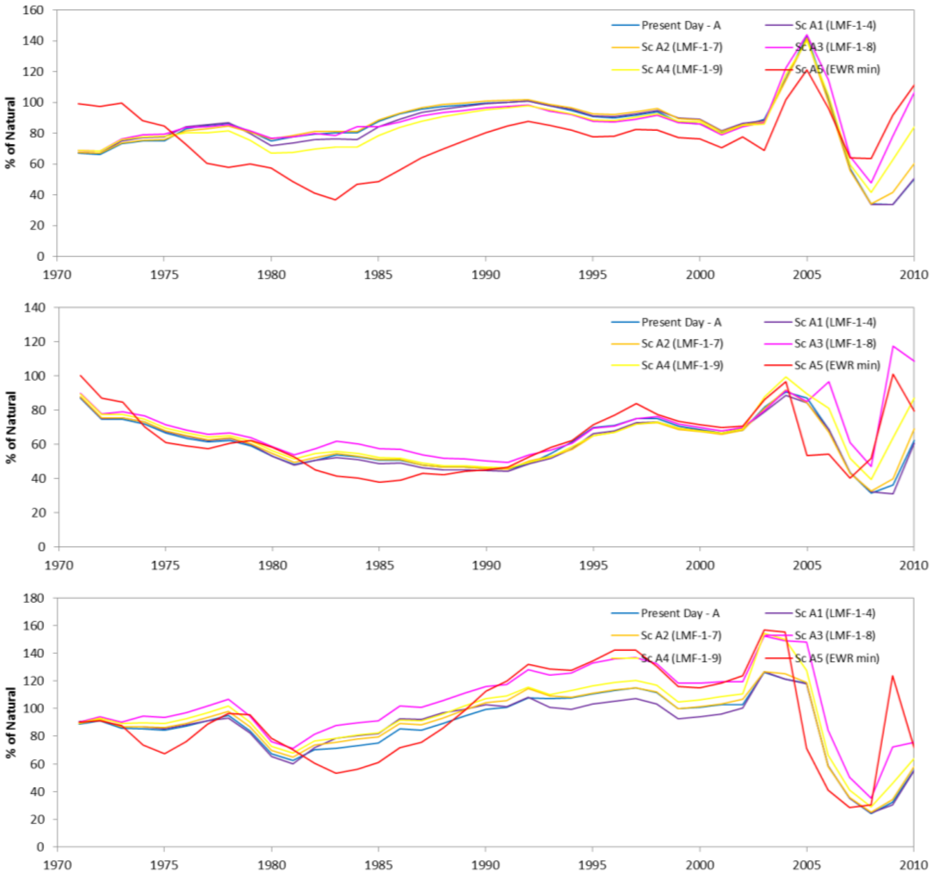


Figure 6.87. **Variation in the abundance of flamingos (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

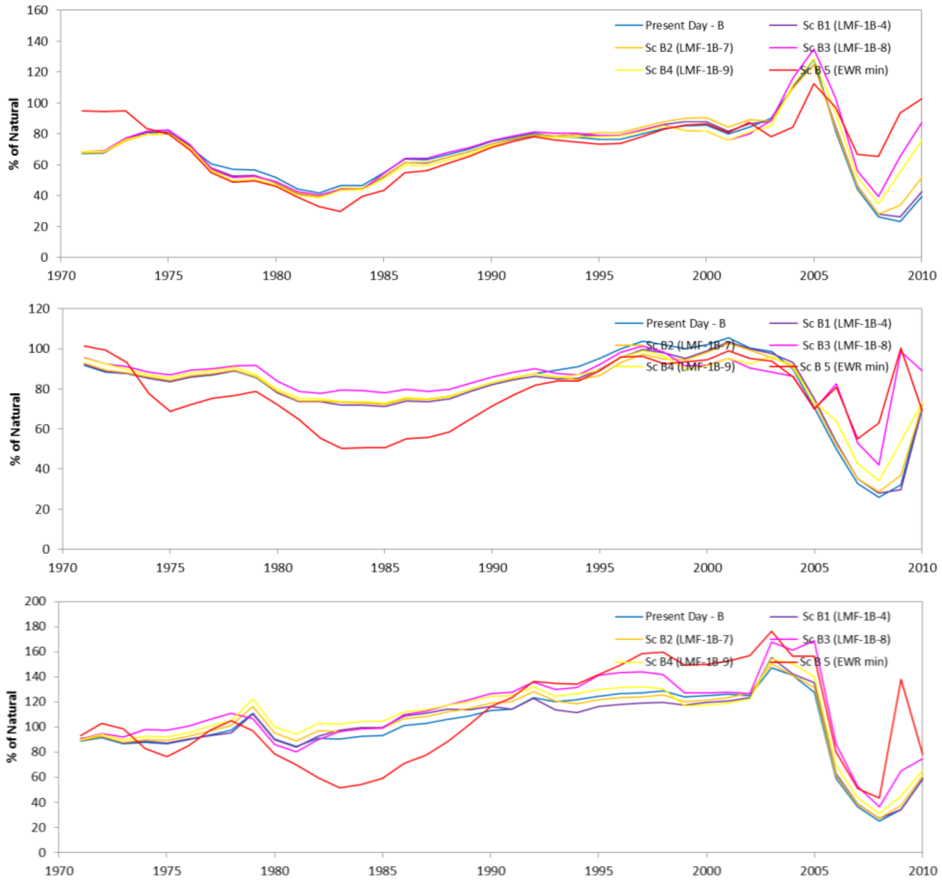


Figure 6.88. **Variation in the abundance of flamingos (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

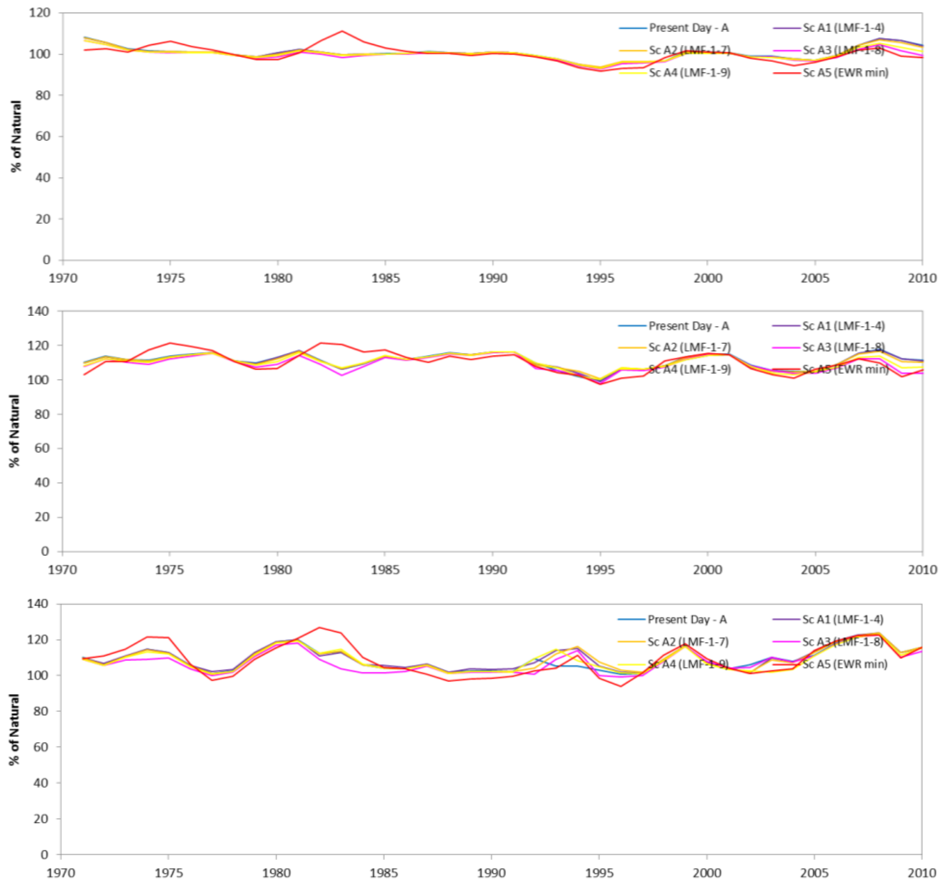


Figure 6.89. **Variation in the abundance of gulls & Caspian terns (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

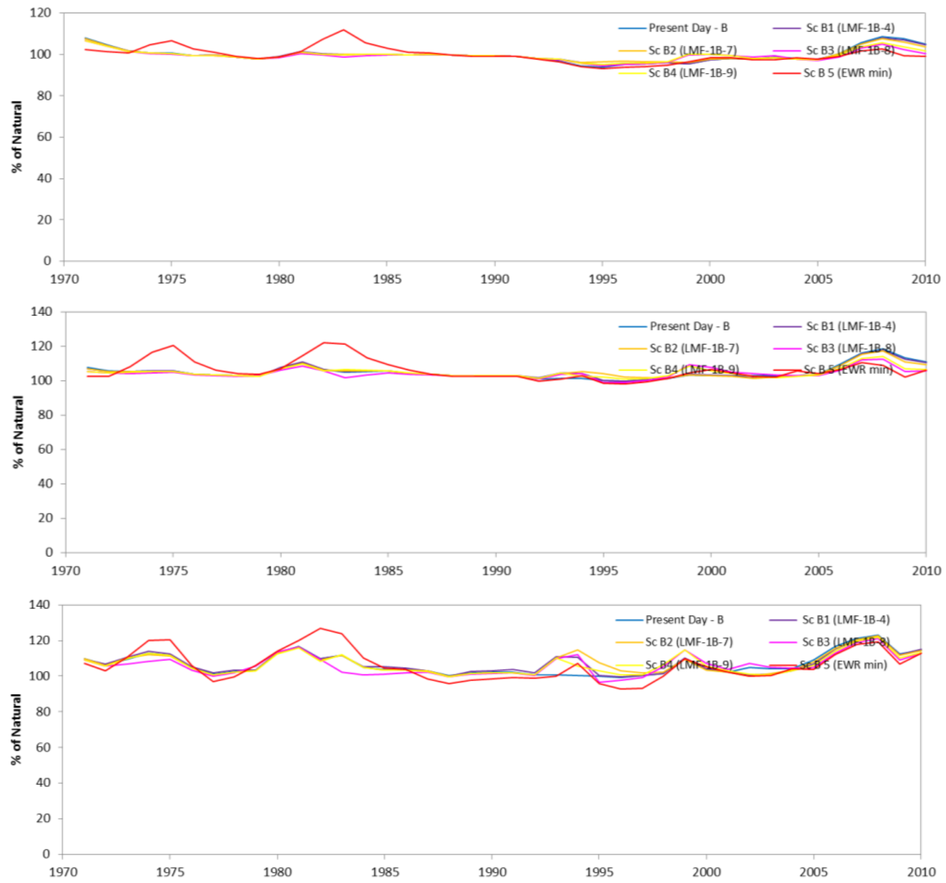


Figure 6.90. **Variation in the abundance of gulls & Caspian terns (% of natural) in the Lakes (top) and Narrows (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

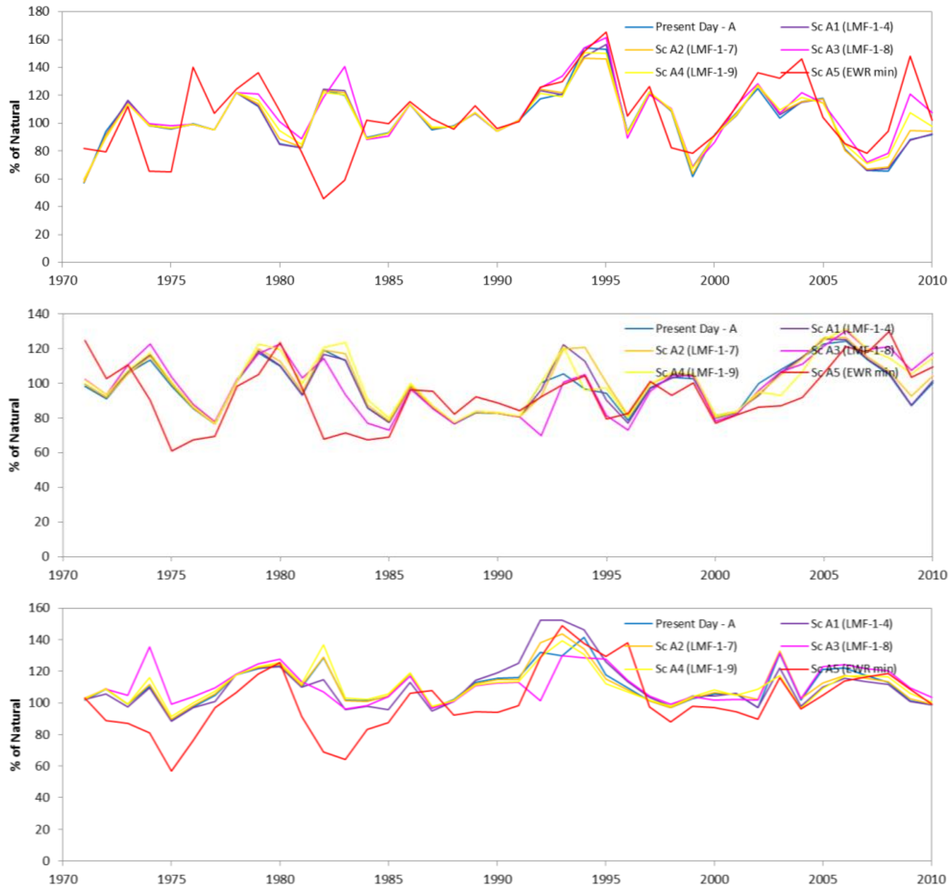


Figure 6.91. **Variation in the abundance of pelicans (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

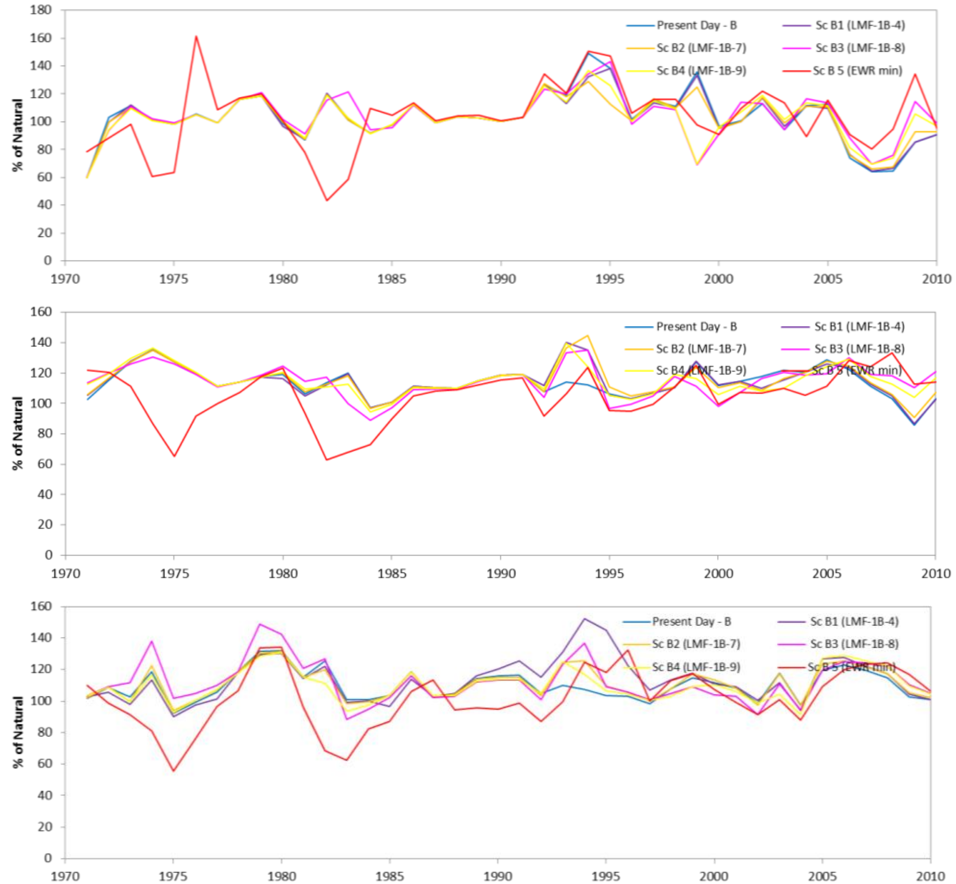


Figure 6.92. **Variation in the abundance of pelicans (% of natural) in the Lakes (top) and Narrows (bottom) with after Phase 1 excavation under reference**

and present-day conditions and under the operational flow scenarios.

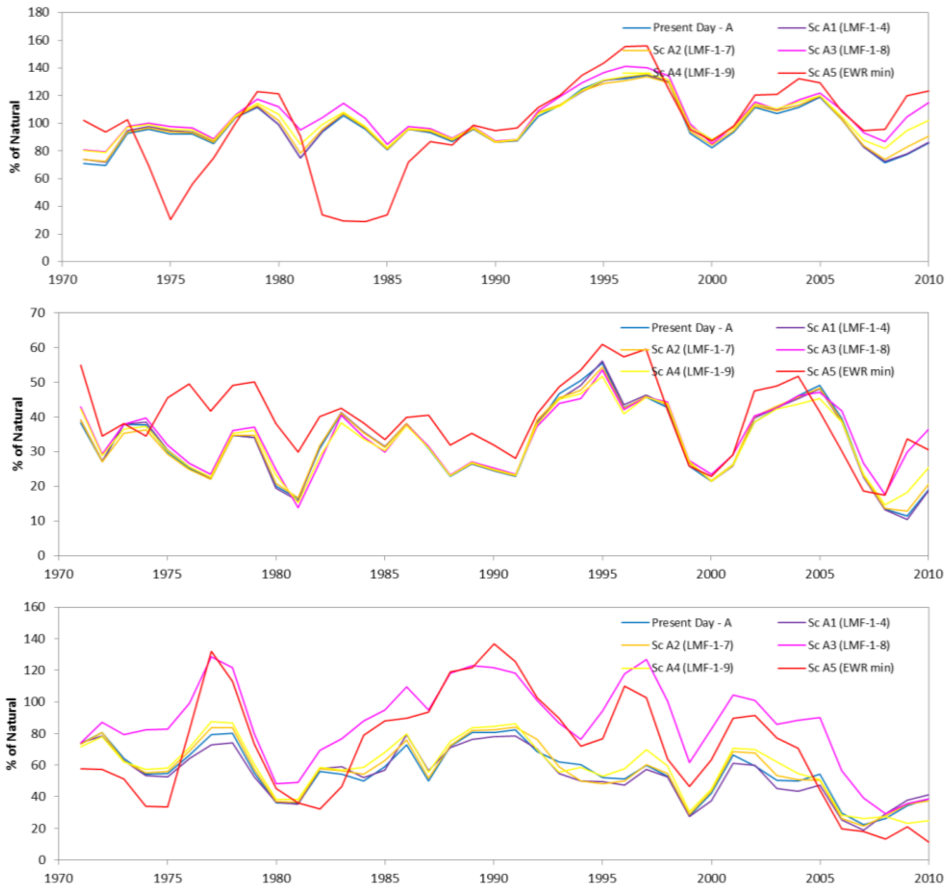


Figure 6.93. Variation in the abundance of waders (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under

reference and present-day conditions and under the operational flow scenarios.

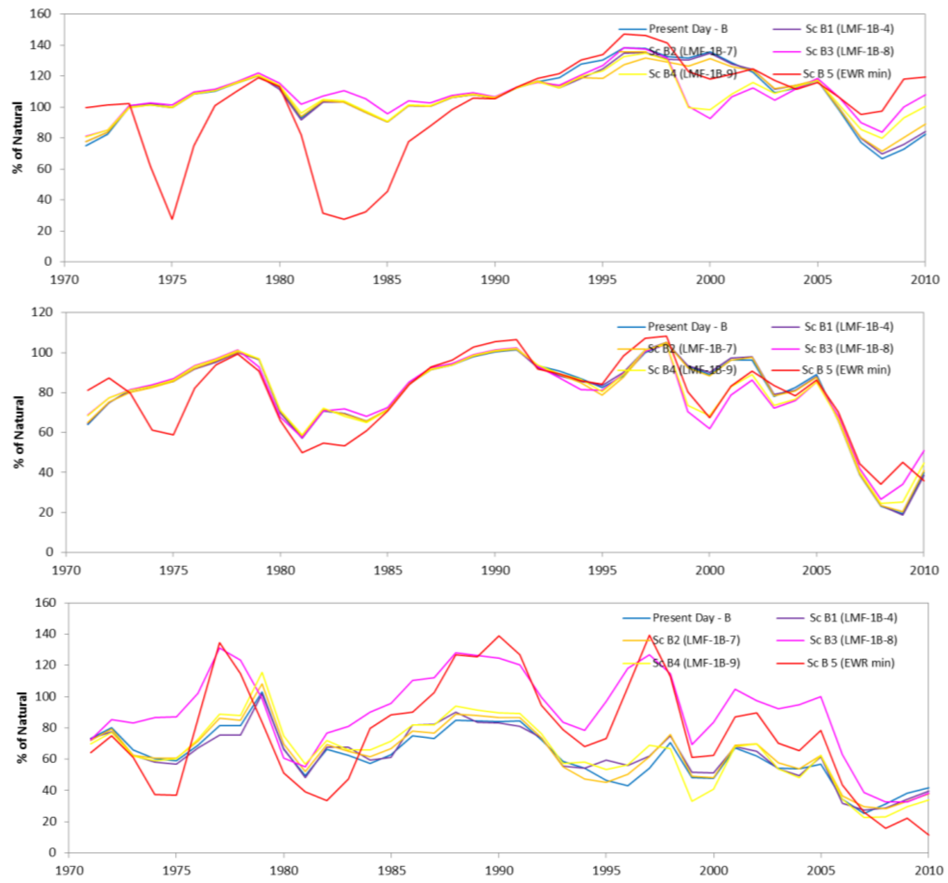


Figure 6.94. Variation in the abundance of waders (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation

under reference and present-day conditions and under the operational flow scenarios.

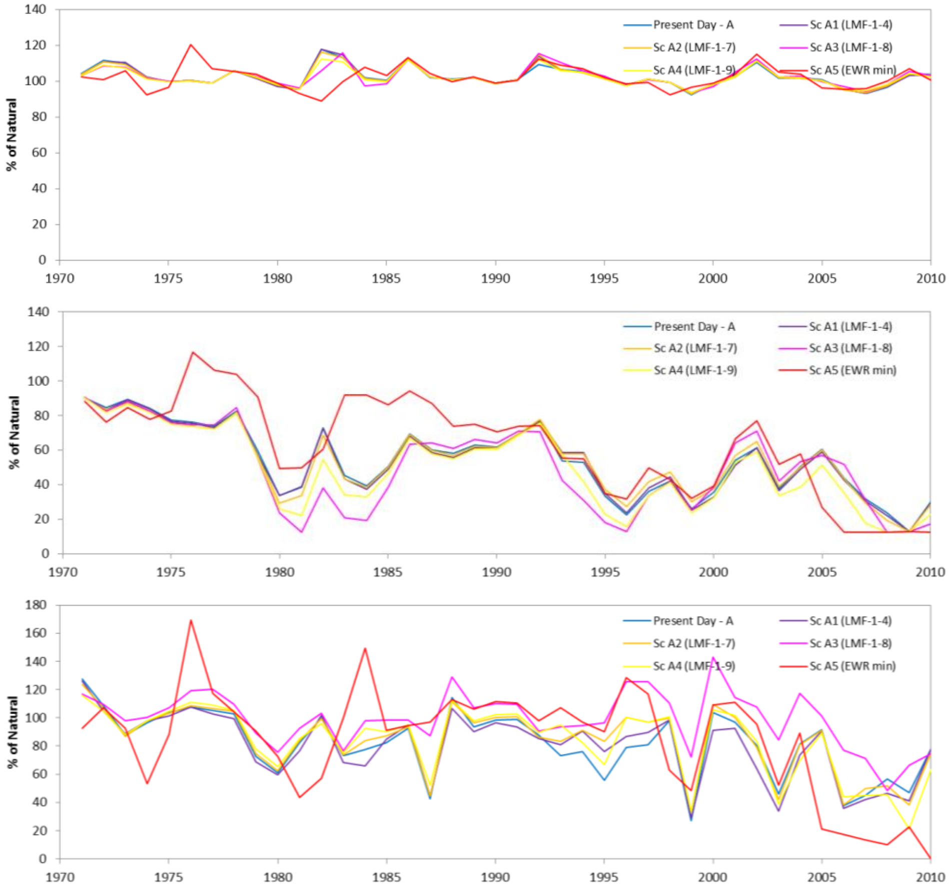


Figure 6.95. Variation in the abundance of other terns (% of natural) in the Narrows (top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

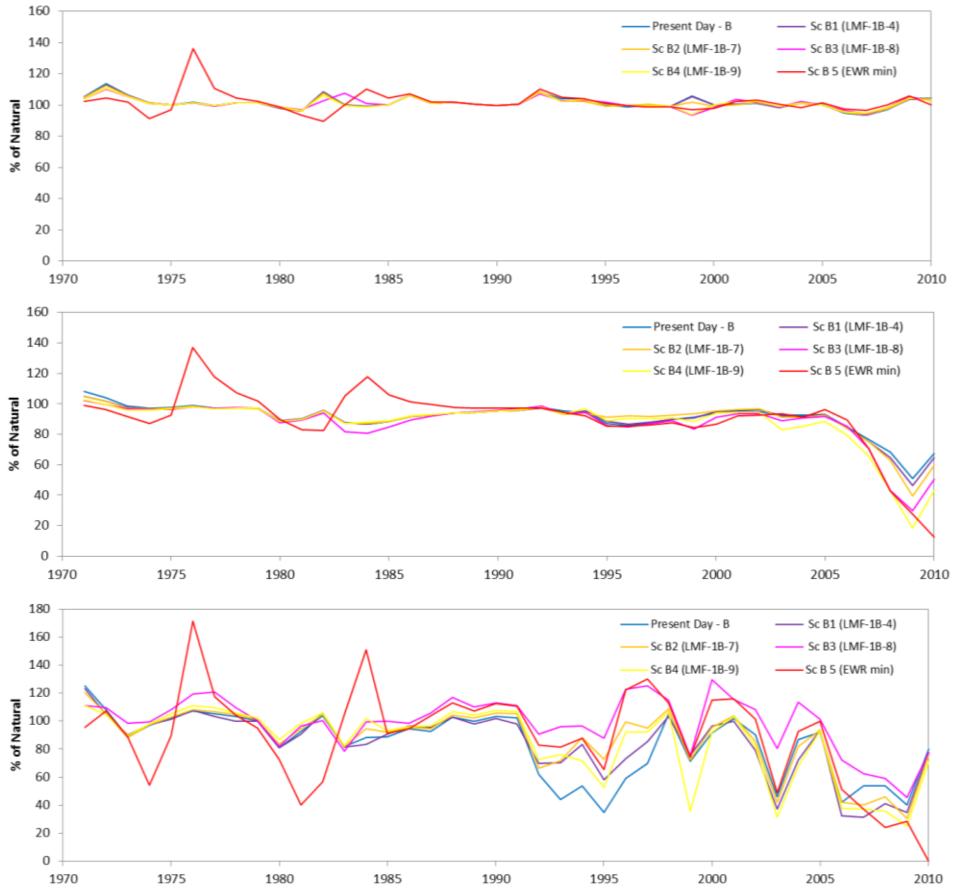


Figure 6.96. **Variation in the abundance of other terns (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.**

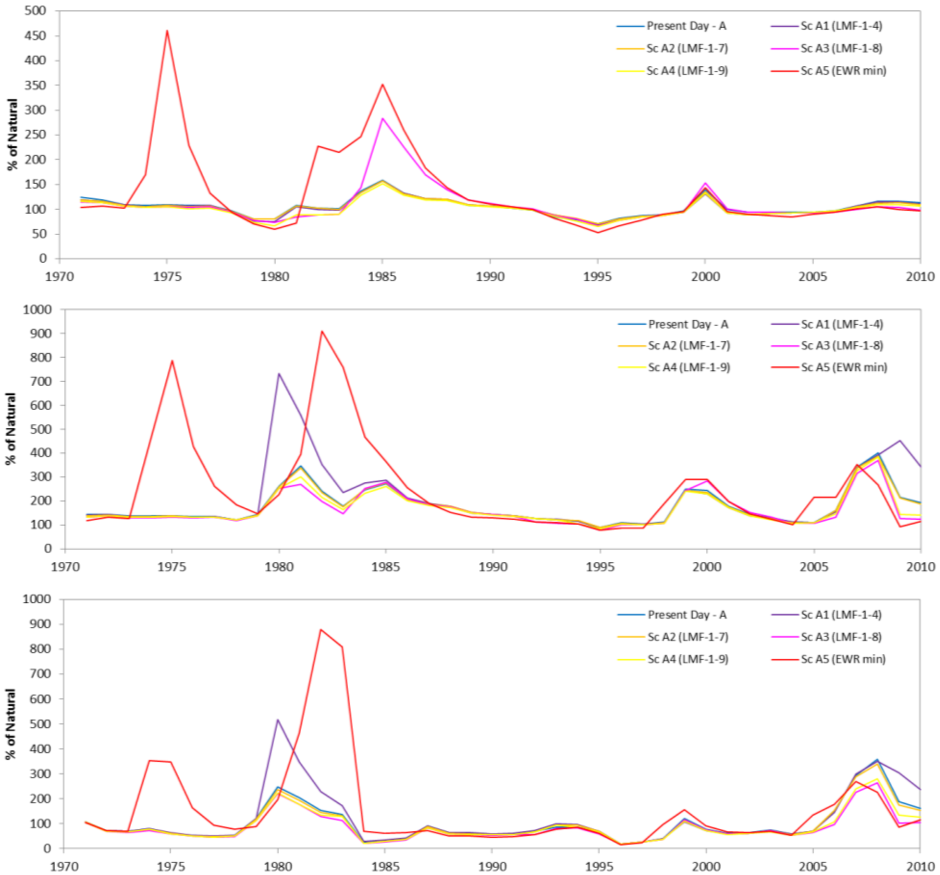
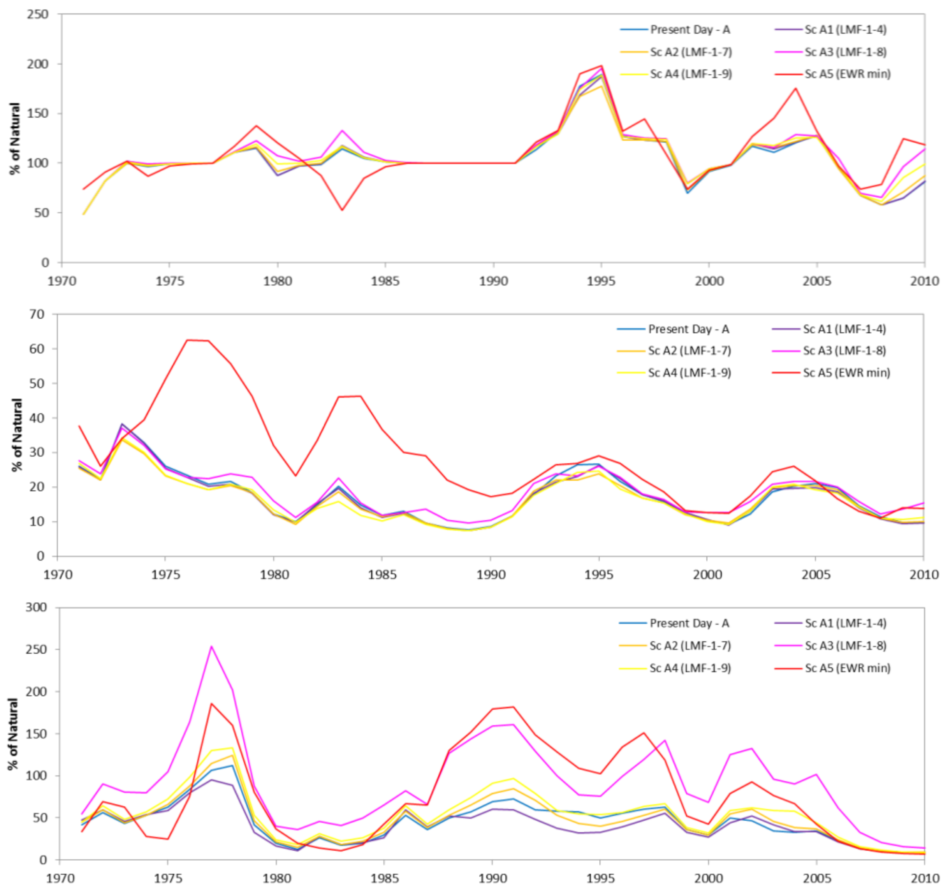


Figure 6.97. **Variation in the abundance of waterfowl (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.**

Figure 6.98. Variation in the abundance of waterfowl (% of natural) in the Lakes (top), Narrows (middle) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

Figure 6.99. Variation in the abundance of cormorants (% of natural) in the Lakes (top) and Narrows (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.



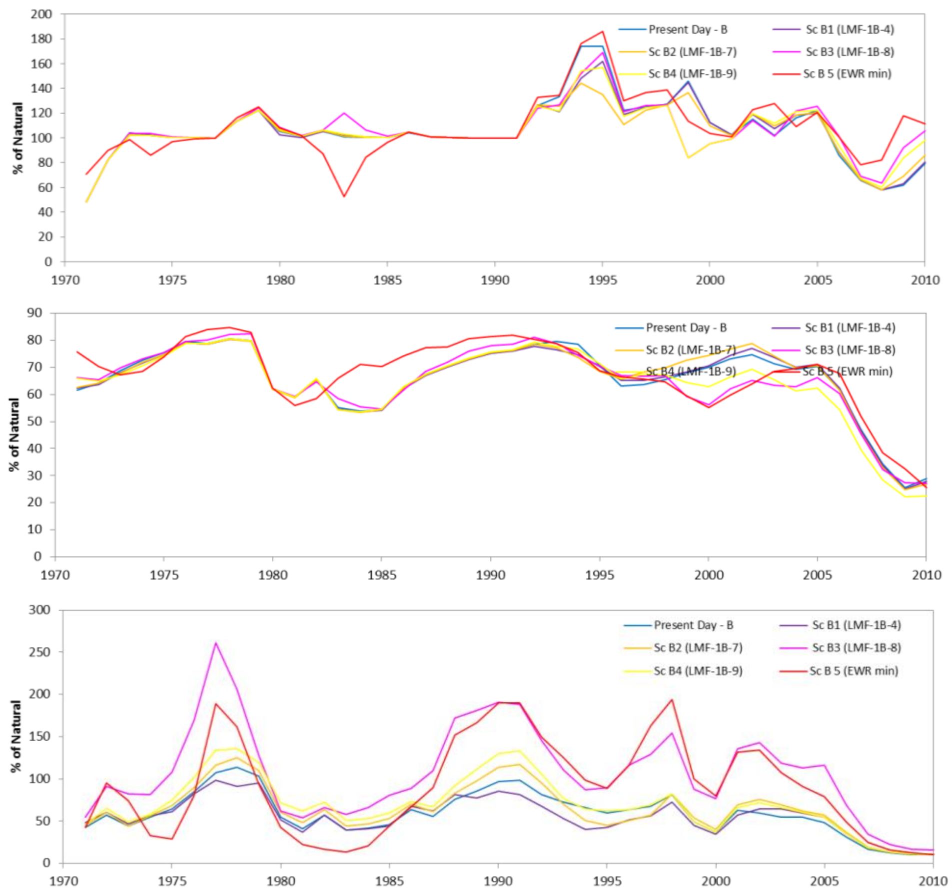


Figure 6.100. Variation in the abundance of cormorants (% of natural) in the Lakes (top) and Narrows (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

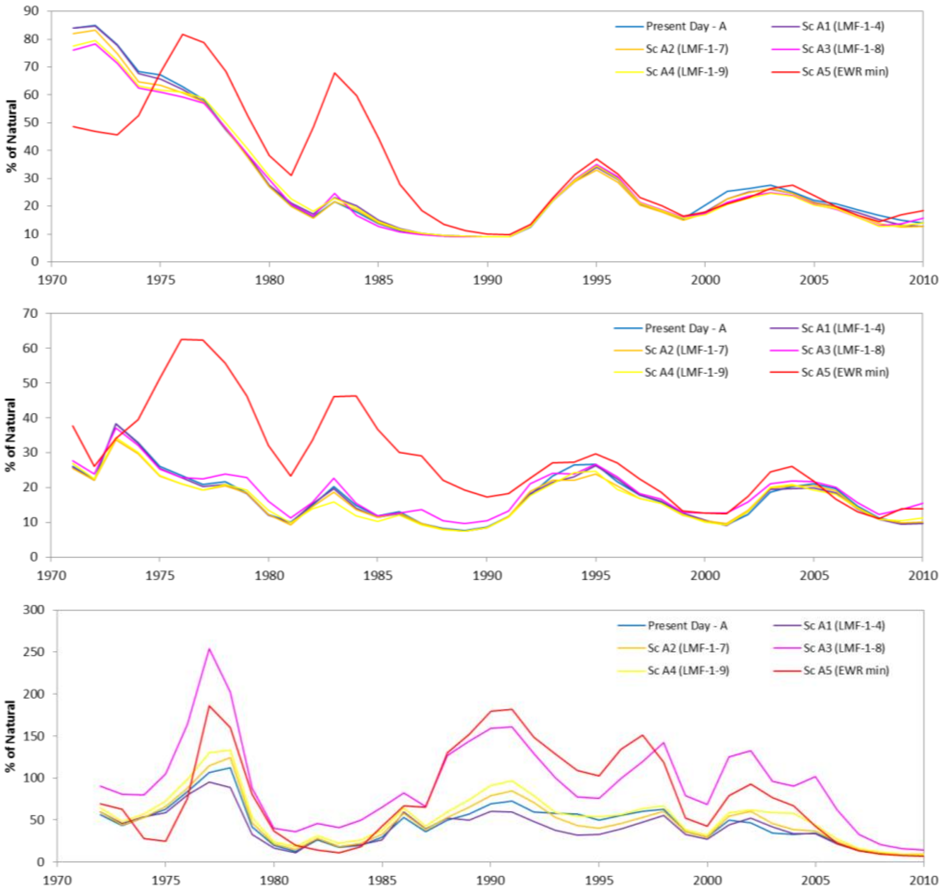


Figure 6.101. Variation in the abundance of wading birds (% of natural) in the Narrows (top) and uMfolozi (bottom) with the beach channel under reference and present-day conditions and under the operational flow scenarios.

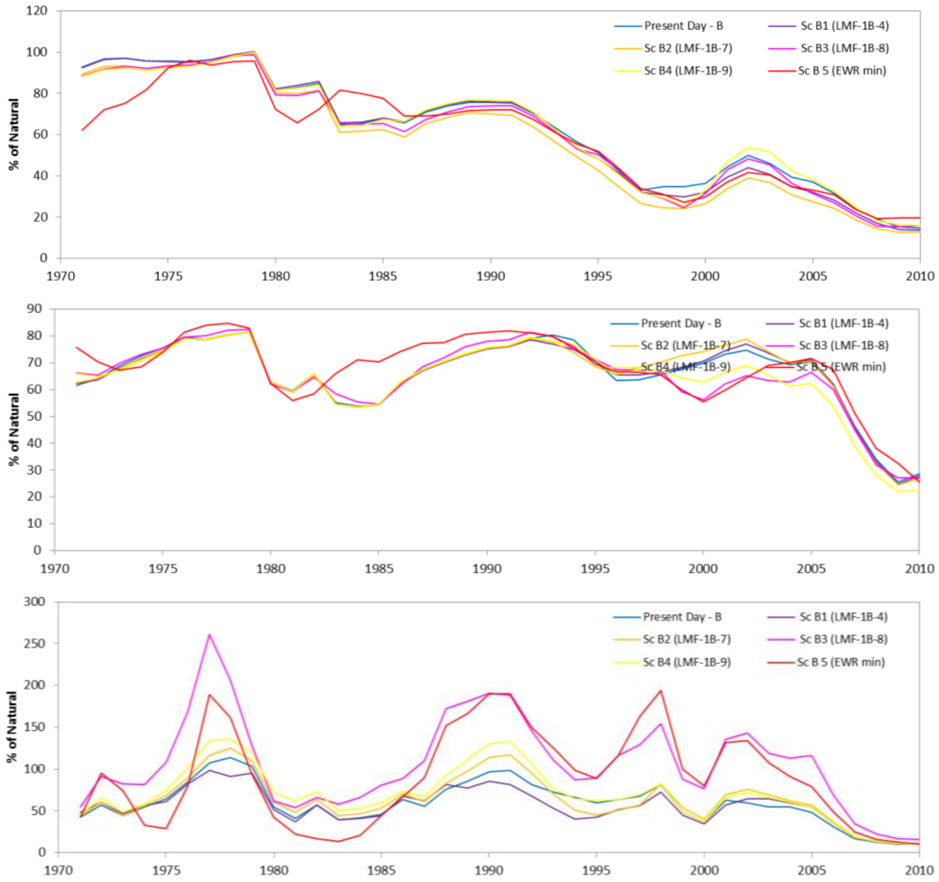


Figure 6.102. Variation in the abundance of wading birds (% of natural) in the Narrows (top) and uMfolozi (bottom) with the Beach channel under reference and present-day conditions and under the operational flow scenarios.

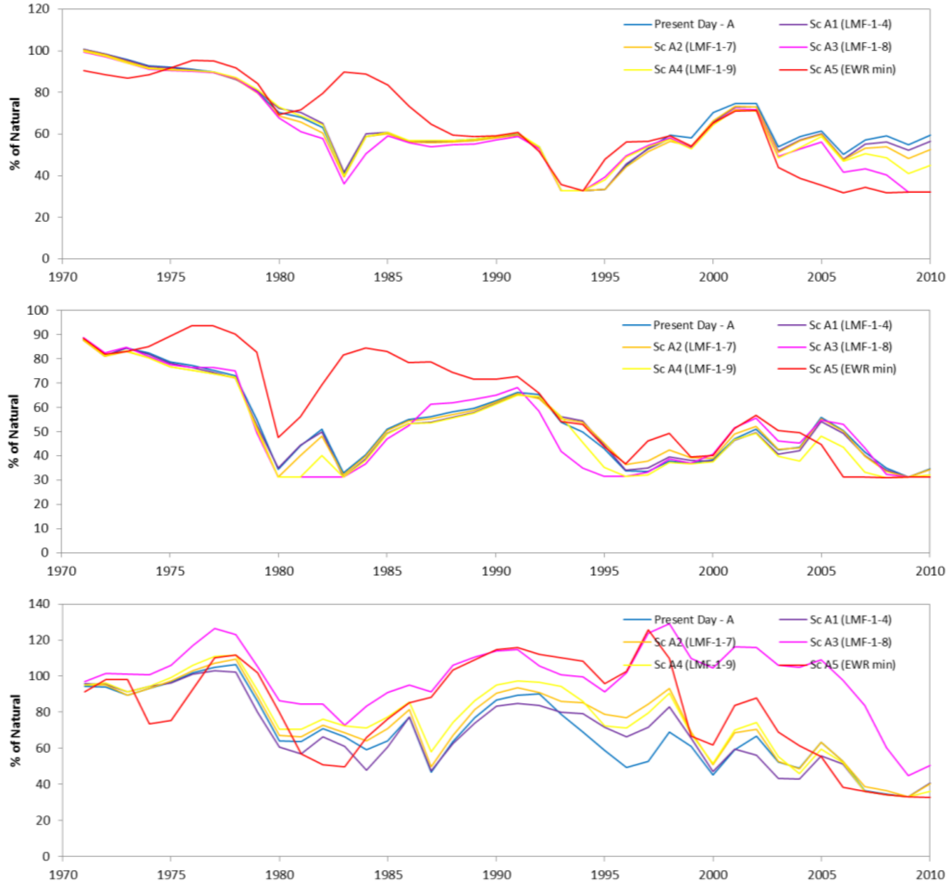


Figure 6.103. Variation in the abundance of perching piscivores (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

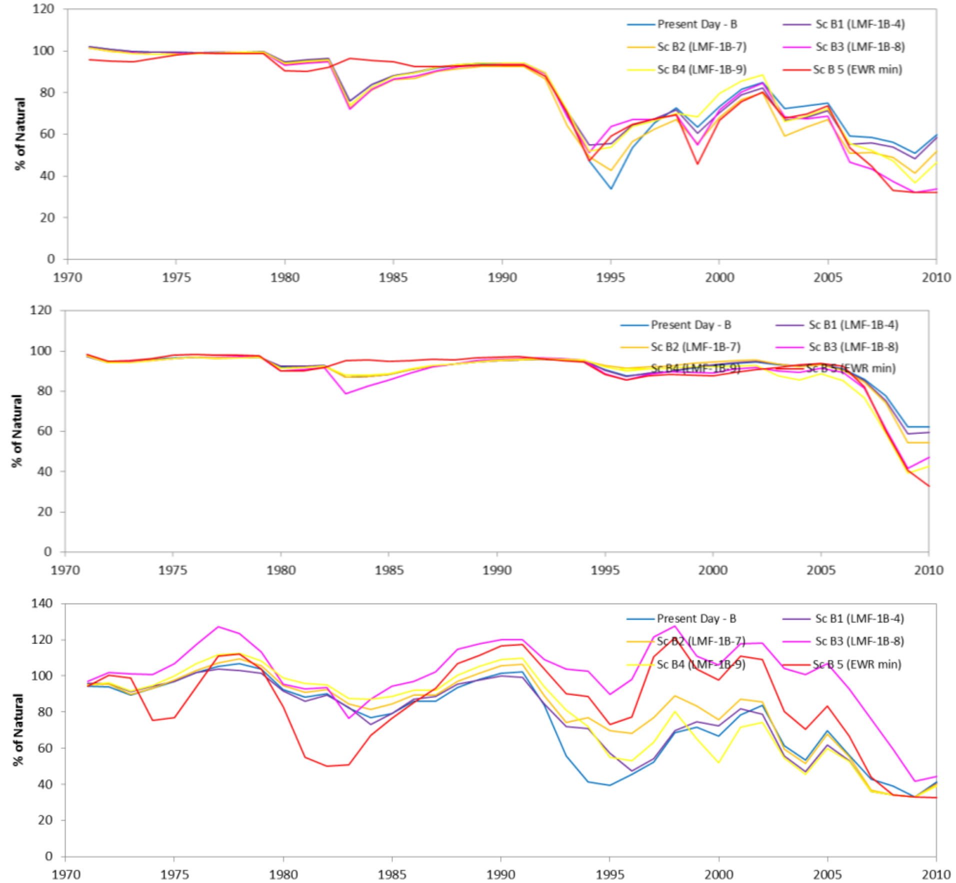


Figure 6.104. Variation in the abundance of perching piscivores (% of natural) in the Narrows (top) and uMfolozi (bottom) with the Beach channel under reference and present-day conditions and under the operational flow scenarios.

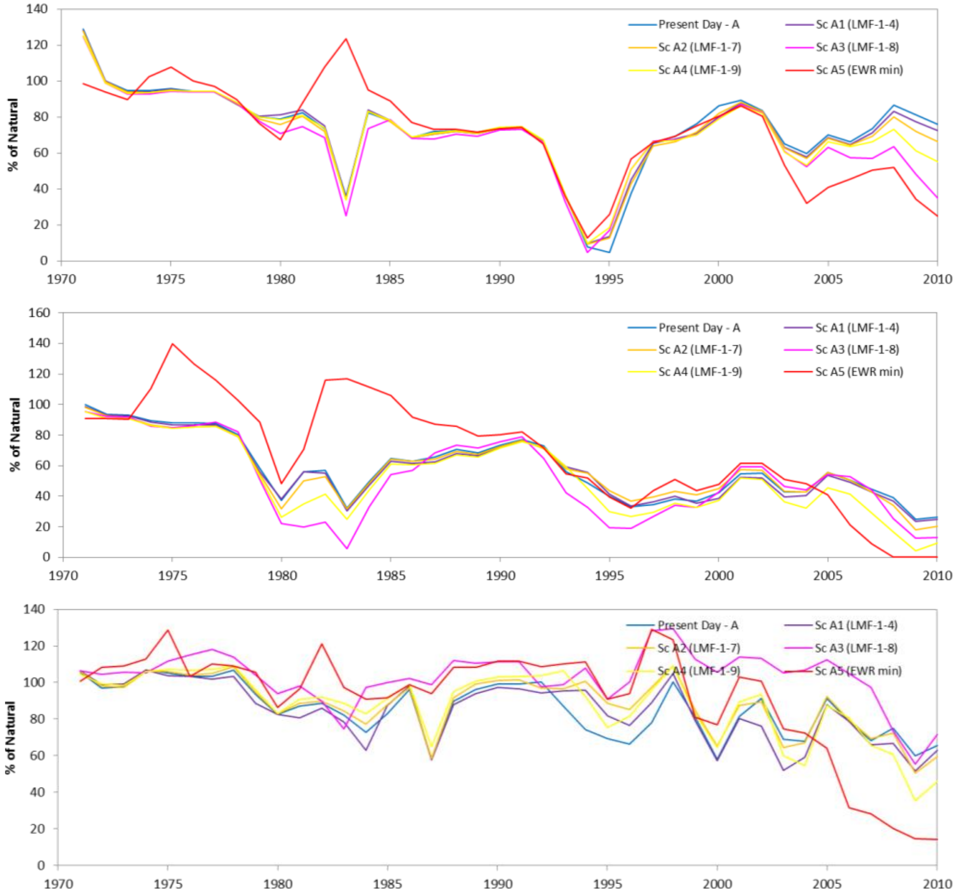


Figure 6.105. Variation in the abundance of Common & Little terns (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

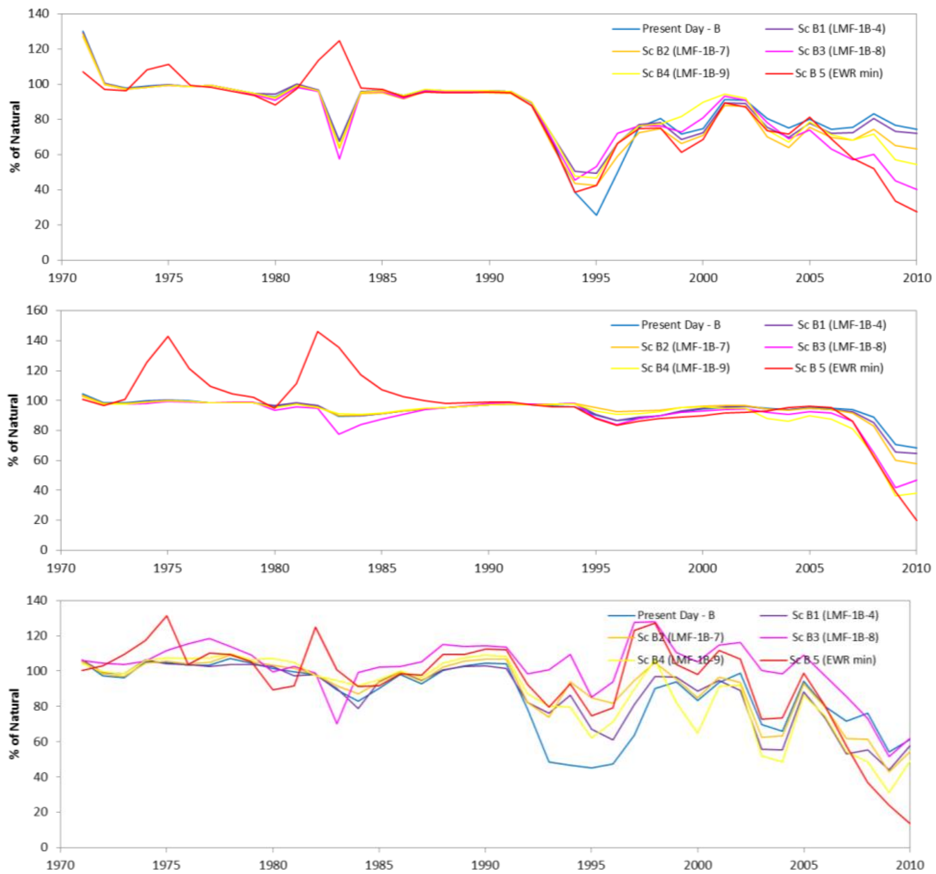


Figure 6.106. Variation in the abundance of Common & Little terns (% of natural) in the Narrows (top) and uMfolozi (bottom) with after Phase 1 excavation under reference and present-day conditions and under the operational flow scenarios.

Table 6.23. Avifauna health scores for Present Day and the Operational scenarios 1-5 for the "Beach channel" (A) and "Combined mouth" (B) configurations.

Scenario	Avifauna health score	
Present Day - A	55.3	D
Sc. A1 (LMF 1-4)	54.5	D
Sc. A2 (LMF 1-7)	55.0	D
Sc. A3 (LMF 1-8)	59.1	D
Sc. A4 (LMF 1-9)	56.1	D
Sc. A5 (LMF EWR min)	58.6	D
Present Day - B	63.6	C
Sc. B1 (LMF 1-4)	63.5	C
Sc. B2 (LMF 1-7)	63.6	C
Sc. B3 (LMF 1-8)	67.8	C
Sc. B4 (LMF 1-9)	65.7	C
Sc. B5 (LMF EWR min)	69.3	C

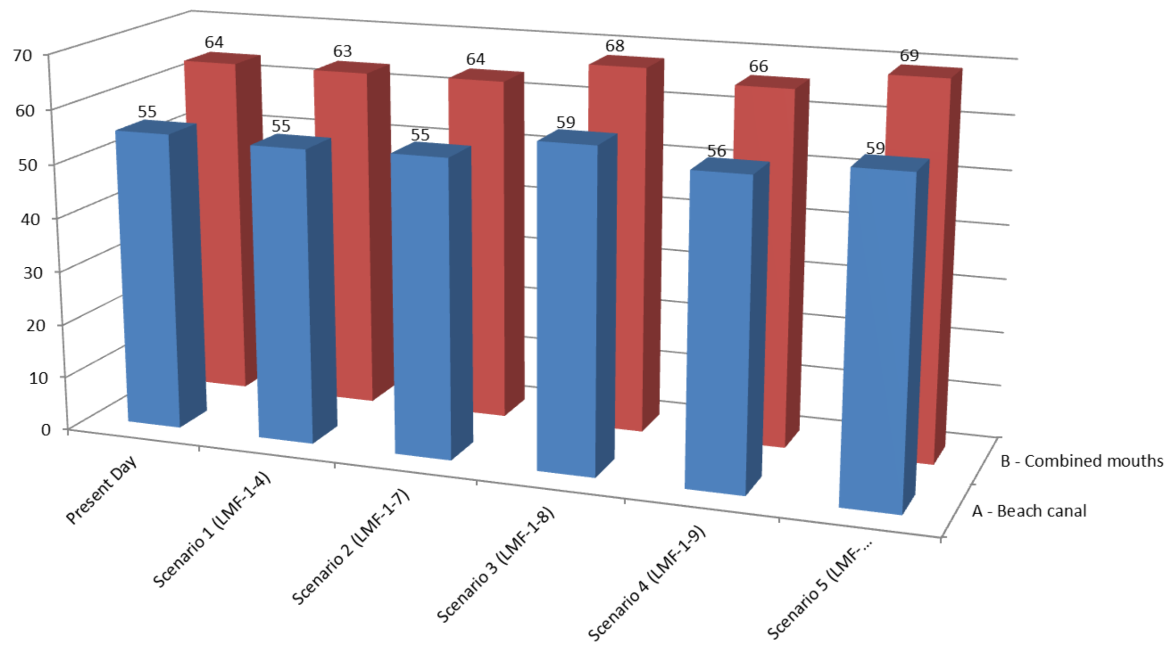


Figure 6.107. Avifauna health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation).

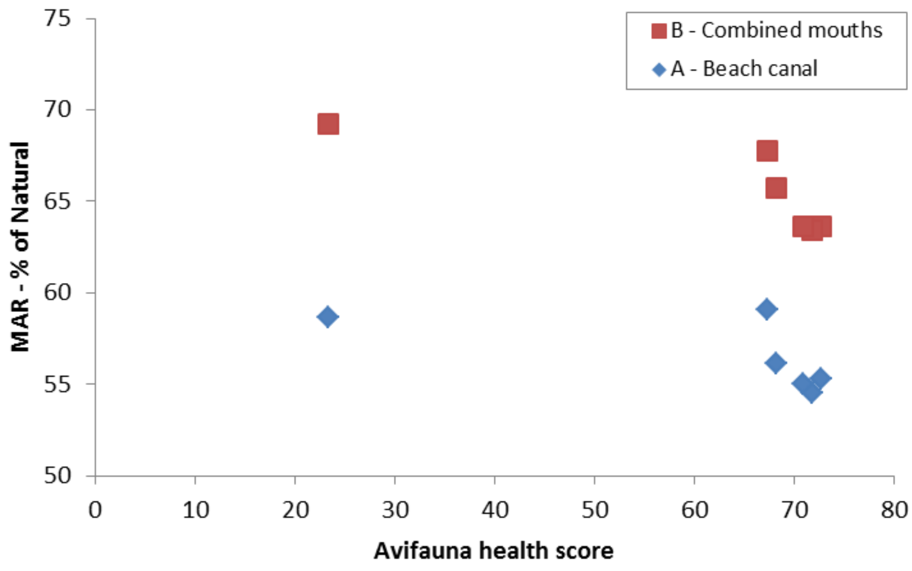


Figure 6.108. Relationship between avifauna health in the Lake St Lucia system as a whole and MAR in the uMfolozi.

6.3.6 Overall biotic health - Operational scenarios

Overall biotic health scores for the operational scenarios are presented in Table 6.24 and Figure 6.109. Overall biotic health scores for all the operational scenarios (46.0-48.4, all class D) were marginally lower than Present Day (48.6) under the "Beach channel" configuration. In the case of the "after Phase 1 excavation" configuration, abiotic health scores were similar too or slightly lower than Present Day (59.46) for all flow scenarios (54.1-59.4). A strong positive correlation was, however, evident between biotic health of the system as a whole and MAR in the uMfolozi (Figure 6.18).

Table 6.24. Biotic health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation).

Scenario	Biotic health score	
Present Day - A	48.6	D
Sc. A1 (LMF 1-4)	48.2	D
Sc. A2 (LMF 1-7)	48.4	D
Sc. A3 (LMF 1-8)	47.5	D
Sc. A4 (LMF 1-9)	47.7	D
Sc. A5 (LMF EWR min)	46.0	D
Present Day - B	59.4	D
Sc. B1 (LMF 1-4)	59.4	D

Sc. B2 (LMF 1-7)	59.4	D
Sc. B3 (LMF 1-8)	58.1	D
Sc. B4 (LMF 1-9)	58.7	D
Sc. B5 (LMF EWR min)	54.1	D

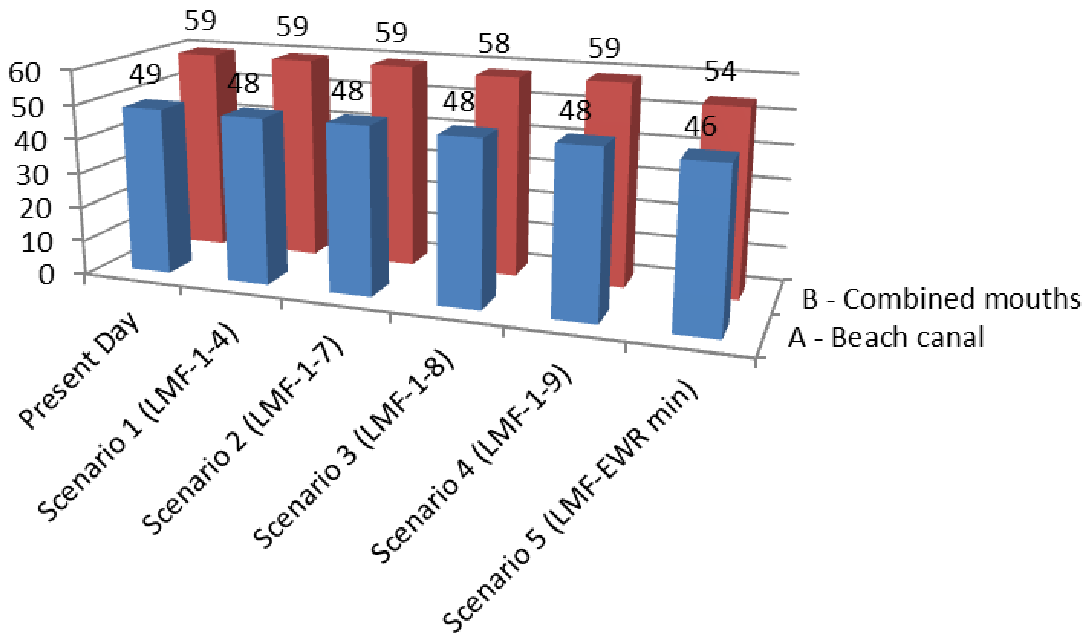


Figure 6.109. Overall biotic health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation).

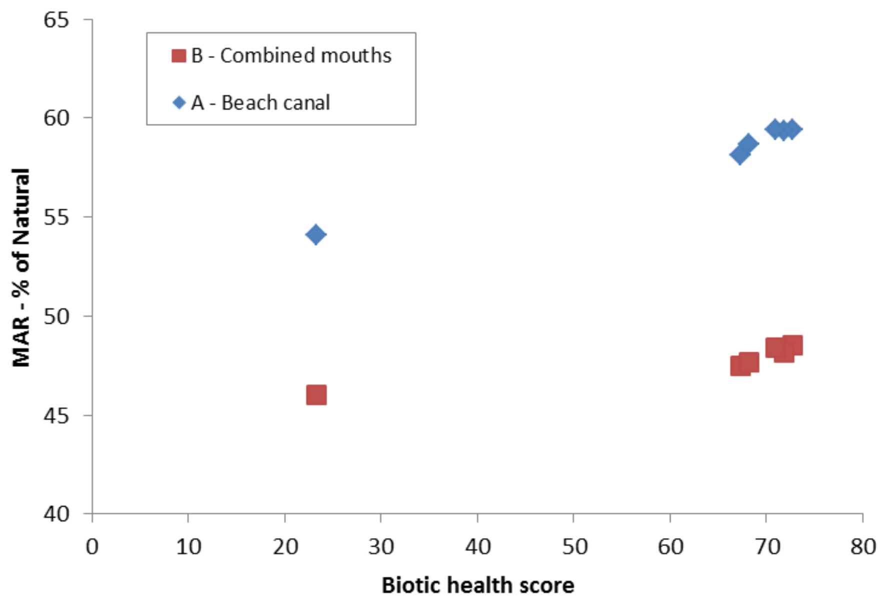


Figure 6.110. Relationship between biotic health for the Lake St Lucia system as a whole and MAR in the uMfolozi.

6.4 Overall estuary health – Operational scenarios

Overall health scores for the operational scenarios are presented in Table 6.25 and Figure 6.111. Under the "Beach channel" and "after Phase 1 excavation" configurations, overall health scores for all the operational scenarios were lower than Present Day (47.7). The differences were very small, however, in both cases except for Scenario 5. This is not surprising given the small reduction in flows between the different operational scenarios and Present Day except for Scenario 5 (Scenario 1: -1%, Scenario 2: -2%, Scenario 3: -12%, Scenario 4: -11%, Scenario 5: -72%). A positive correlation was, however, evident between biotic health of the system as a whole and MAR in the uMfolozi (Figure 6.18).

Table 6.25. Overall health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation).

Scenario	Overall health score	
Present Day - A	47.7	D
Sc. A1 (LMF 1-4)	47.2	D
Sc. A2 (LMF 1-7)	47.2	D
Sc. A3 (LMF 1-8)	46.6	D
Sc. A4 (LMF 1-9)	46.4	D
Sc. A5 (LMF EWR min)	43.2	D
Present Day - B	63.4	C
Sc. B1 (LMF 1-4)	63.2	C
Sc. B2 (LMF 1-7)	63.0	C
Sc. B3 (LMF 1-8)	62.4	C
Sc. B4 (LMF 1-9)	62.9	C
Sc. B5 (LMF EWR min)	56.1	D

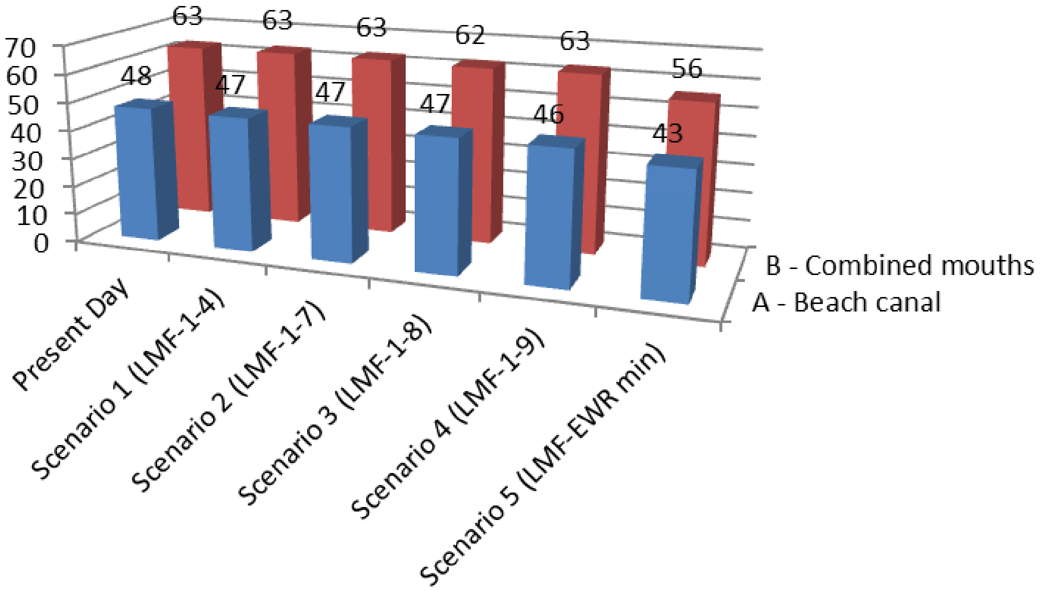


Figure 6.111. Overall health scores under present-day conditions and under the operational flow scenarios for two mouth configurations (A - with beach channel, and B - after Phase 1 excavation)..

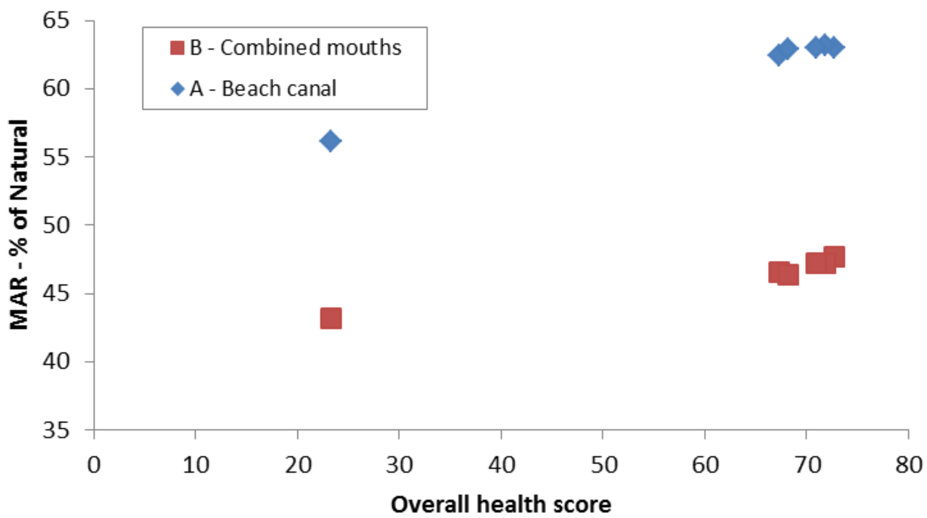


Figure 6.112. Relationship between biotic health for the Lake St Lucia system as a whole and MAR in the uMfolozi.

6.5 Overall confidence

Overall confidence in the EHI scores for the Present Day and the operational scenarios was rated as medium-low (60%), and is linked to low confidence in the hydrological data in particular, but also in the paucity of historical data on water quality and microalgae and invertebrate communities in the system. The implications of this are that the Department of Water & Sanitation will need to be very cautious and apply the precautionary principle in setting the Preliminary Reserve; and will need to collect additional baseline and monitoring data that will help to fill some key gaps in understanding, particularly hydrological data.

In respect of our low confidence in the hydrological data, it is not at all clear, for example, how accurate the estimated flow volumes in the uMfolozi are for Present Day, or indeed any of the operational scenarios. In their assessment of the flow gauging stations on the rivers feeding the Lake St Lucia system undertaken as part of the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" commissioned by the iSimangaliso Wetland Park Authority, Görgens *et al*. (2014) identified only 10 gauges in the six catchments feeding the Lake St Lucia estuary system that they described as "currently operational". Seven of these were located in the uMfolozi River catchment, one in the Mkuze River catchment, and two in the Hluhluwe River catchment. No operational gauging stations were located on the Mzinene, Nyalzai or the Mpate rivers. They indicated further that they were able to use data from only five of these stations due to the poor quality of the data (or poor state) of the remaining gauges, and provided a very unflattering account of the state of these five gauging stations, especially those close to the estuary. The best of these was a gauging station on the upper Black uMfolozi River (W2H028) which received a rating of 4 out of 5 (where 5 is excellent quality). The gauging station lower down on the Black uMfolozi (W2H006) received a much lower rating, 2.5 out of 5, the same rating being assigned to the only gauging station on the White uMfolozi (the other major tributary of the uMfolozi River, W2H005). Streamflow gauge W2H032, the only remaining gauging station on the uMfolozi River, located just above the confluence with the Msunduzi River, was described as "a non-structural, rated cross-section" that had not been rerated since 1993. Görgens *et al*. (2014) highlighted the fact that gauging stations of this nature are "notoriously unreliable" and assigned a rating of 1.5 out of 5 to this station. Only one streamflow gauging station on the Mkuze River was considered "usable", this being station W3H008. They highlighted the fact that this station hadn't been rerated since 1965, and describe the upstream pool as "unstable and heavily silted up", and rated this station as 1 out of 5. Görgens *et al*. (2014) experienced great difficulty in fitting simulated flow data generated using the ACRU hydrological model with the observed flow records. In an effort to reduce what they described as "sizeable over-simulations" they adjusted some of the model parameters beyond "the physically meaningful limits set by the *ACRU* manual", which successfully reduced the degree of apparent "over-simulation" but "mostly not to the degree required for sound calibration outcomes". Further validation of the flow in the catchments discharging directly into the St Lucia Lakes using long-terms data series on water level and salinity by the hydrodynamics team of the GEF study revealed that cumulative simulated inflows from the four contributing rivers were still much too high (Basson et al. 2015) and had to be further reduced through the application of a power factor of 0.71 to daily flow data for the Lake St Lucia catchments and a factor of 0.92 for the uMfolozi catchment. The approach adopted for generating daily flow data required for this RDM study was slightly different. Different hydrological models were used to generate simulated flow data for the various rivers feeding the Lake St Lucia system. In the case of the Mkuse and uMfolozi rivers, DWS (2015) made use of the *ACRU* configuration sourced from the GEF study, but which was "considerably refined for this study". Refinements made to the model included adjusting some of the ACRU model input parameters, disaggregating consolidated dam storages, explicitly and dynamically modelling irrigation and urban return flows, and dampening of "existing built-in excessive runoff responses of degraded areas". However, these refinement were still not sufficient to address the apparent over-simulation as evidenced by the historical lake level and salinity data, and necessitated applying a power reduction factor of 0.78 to the rainfall data and further adjustments to the *ACRU* model parameters (default drainage rate from the root-zone to groundwater was markedly increased) for the Mkuse catchment and a factor of 0.85 for the uMfolozi catchment (DWS 2015). Simulated flows for the Hluhluwe and Nyalazi River catchments were generated using the WR2012 Pitman Model configuration obtained from the WR2012 study (DWS 2015).

In addition to our concerns pertaining to the accuracy of the hydrological data, it must also be noted that none of the operational flow scenarios considered in this study allowed for increases in flow in the uMfolozi or any of the rivers that flow directly into the St Lucia Lakes. This is considered a critical omission from an environmental flow assessment of this nature. While flow in the uMfolozi is critically important for keeping the mouth of the Lake St Lucia system open, flow from the rivers feeding directly into the Lakes is also critically important for maintaining water levels in these lakes (preventing them from drying out) and also for minimising the risks of the Lakes from becoming hypersaline. Maintaining a proper balance between flows in the two "sides" of the system (uMfolozi vs. direct inflow to the Lakes) is thus critically important. Minimising flow reduction in the uMfolozi River is very important as it ensures that the combined mouth remains open as much as possible (and hence provides a means for marine fish and invertebrates to recruit into and exit from the system) this also increases seawater inputs to the system and can lead to the development of hypersaline conditions in the St Lucia Lakes if adequate flows are not maintained in the smaller rivers feeding directly into the Lakes. This is clearly evident in the results from this study where the abiotic health of the system as a whole (and some of the biotic components) actually improved with small reductions in flow in the uMfolozi due to existing severe reductions in flow in the smaller rivers feeding directly into the St Lucia Lakes.

7 RECOMMENDATIONS

7.1 Recommended ecological flow requirements for the Lake St Lucia estuary system

The Recommended Ecological Category (REC) for the Lake St Lucia estuary system, determined in accordance with methods prescribed in DWS (2012), is an "A" Class or "Best attainable State" (BAS). However, the Present Ecological Status (PES) for the system as it is at the current time (i.e. with the Beach channel in place – referred to as Mouth A in this study) was estimated to be a "D" (48% similar to natural), which is very similar to earlier assessment completed in 2015 (Clark *et al*. 2015) and 2004 (DWAF 2004). The PES is expected to improve significantly, however, to a "C" class (63%) once the first phase of removing the dredge spoil that was historically deposited between the St Lucia Narrows and the uMfolozi mouth has been completed, as indicated by the results of this study. Findings from the GEF-funded "Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system" commissioned by the iSimangaliso Wetland Park Authority (Clark *et al*. 2015), concur with these findings, and also indicate that further improvements in the health of the system can be achieved through the removal of the remainder of the dredge spoil that has been deposited around the mouth, without any restoration in flow (note that neither the GEF study nor this EWR study examined the impacts of restoring flow to the Lake St Lucia system). Results of the GEF study (Clark et al. 2015) indicated that the PES of the system was projected to remain in a "C" class but the health score increased from 63 to 72% (i.e. 3% below a "B" class). The process of removing this dredge spoil material has already been initiated, with a target of completing Phase 1 of the removal process having been set at within 12 months (iSimangaliso 2015). Additional funds have reportedly been secured to continue this process, with an ultimate goal of restoring the mouth to a position as close to natural as possible (see Section 4.1 for more details on this). Thus, we are confident that the health of the Lake St Lucia system can, and soon will be, restored to a status of at least a C+. We are also confident that even a small increase in the flows from the catchments discharging directly into the St Lucia Lakes (Mkuse, Hluhluwe, Msinene, Nyalazi, Mpate) would be sufficient to elevate the health status of the system as a whole into a "B" class. (See Section 9 – Appendix A for more details on this). This is considered to be the "Best Attainable State" (BAS) for the system and is the state for which the recommended ecological flow requirements should be set, according to the protocols prescribed in the "Resource Directed Measures for protection of water resources: Methods for the Determination of the Ecological Reserve for Estuaries" (DWS 2015).

Reductions in flow in the uMfolozi catchment that are likely to be effected in terms of the five operational flow scenarios evaluated in this study are all very modest and, aside from Scenario 5, are projected to have minimal impact on the PES of the Lake St Lucia system as a whole. The reduction in health for the operational scenarios 1-4 all amount to less than

1% for the mouth configuration B but are more significant (up to 2.7% reduction in the case of Scenario 4) for the beach channel configuration (Mouth A).

In spite of these relatively modest changes in health, however, acknowledging the national importance of the Lake St Lucia system, and in keeping with the precautionary principal that must be invoked owing to the low confidence in the findings from this study, and the fact that the impacts of increases in flow for none of the influent rivers was evaluated in this study, it is recommended that that flows in all influent rivers be maintained as they are at present (i.e. **no reduction in flow should be considered for the uMfolozi**) and that every effort be made to free up additional water in the catchments that discharge directly into the St Lucia Lakes (i.e. the Mkuze, Hluhluwe, Mzinene, Nyalazi and Mpate River). It is also strongly recommended that potential impacts of increased flow in the catchments that discharge directly into the St Lucia Lakes, to be achieved through deforestation for example, be evaluated through an environmental flow assessment process similar to that conducted for this study both in isolation (i.e. in conjunction with present-day flows in the uMfolozi) and in conjunction with one or more of the operational considered in this study.

7.2 Resource quality objectives

Ecological specifications and thresholds of potential concern for abiotic and biotic components are presented in Table 7.1 below.

Table 7.1. Ecological specifications and thresholds of potential concern for abiotic and biotic components.

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
Hydrology	Maintain freshwater inflow from all influent rivers at a level that is as close to Reference as possible but not less than under present-day conditions. Runoff from the uMfolozi is particularly important for ensuring that the estuary mouth functions in a manner that resembles Reference conditions, while runoff from the smaller rivers that discharge directly into the St Lucia lakes (Mkuse, Hluhluwe, Msinene, Nyalazi, Mpate River) and groundwater inputs are important for maintaining water level, preventing an increase in the occurrence of hypersaline conditions, and for mouth dynamics.	Mean annual runoff and/or mean monthly flows for any of the influent rivers significantly lower than under present-day conditions	Increases in abstraction of water from the catchment(s) for agricultural, domestic or industrial purposes
Hydrodynamics	The Lake St Lucia estuary mouth closes when the river flow averaged over 30 days is less than 1.5 m^3/s at the uMfolozi River DWS gauging station W2H032 and the water level in Lake at Charters Creek is less than 0.35 m MSL. Lake St Lucia estuary mouth should not be breached artificially except in emergency or when exceptional circumstances prevail (e.g. berm height rises to >3 m MSL). This will allow more river flow north through the Narrows towards the Lake during droughts and when breaching occurs naturally it will open up a large mouth with a large tidal flow. Variations in water level in the Lakes should correspond as closely as possible to natural. Mean water level in the Lakes	Flow in the uMfolozi River at DWS gauging station W2H032 drops below 3.0 m^3/s when averaged over a 30 day period outside of a defined drought period Estuary mouth is breached artificially for reasons other than an emergency Mean water level in the Lakes drops below 0.1 m MSL for more than 20% of the time outside of a defined drought period	Increases in abstraction of water from the catchment(s) for agricultural, domestic or industrial purposes Back flooding of agricultural fields on the uMfolozi floodplain Increases in abstraction of water from the catchment(s) for agricultural, domestic or industrial purposes, artificial breaching of the

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
	under Reference conditions is estimated to be around 0.545 m MSL and dropped below 0.1 m MSL less than 16% of the time.		estuary mouth
Sediment dynamics	Channel morphology and bed level in the Lakes, Narrows and uMfolozi should resemble those under Reference condition as far as possible, or where these have been substantially modified from Reference, should not diverge further from Reference than Present Day.	Change in bed level anywhere in the estuary by more than 10 cm away from Reference or present-day conditions, as applicable, except following a major (>1:20 year flood).	Increased sediment yield from the catchment due to poor land management , artificial breaching of the estuary mouth, reduced freshwater inflows to the estuary due to abstraction of water for agricultural, domestic or industrial purposes
Water quality	Water quality in the influent rivers and in the estuary itself should approximate Reference conditions as closely as possible. Important risk factors include elevated pH and nutrient levels in the influent waters and low oxygen levels in the estuary especially at night. Salinity structure in the Lakes, Narrows and uMfolozi should correspond as closely as possible with the Reference condition. Average salinity in the Lakes under Reference conditions ranged from 6.5-9.6, and exceeded 20 less than 10% of the time. Hypersaline (salinity >35) occurred very infrequently.	Salinity levels in the Lakes outside of a defined drought period, and averaged over an extended period exceeds 20. Hypersaline conditions (salinity >35) are recorded outside of a defined drought period. pH levels in influent waters at the head of the estuary rise above 7.5 Dissolved Inorganic Nitrogen (DIN) levels in influent waters at the head of the estuary exceed 1000 µg/ℓ Dissolved Inorganic Phosphorus (DIP) levels in influent waters at the head of the estuary exceed 30 µg/ℓ Dissolved oxygen levels in the estuary drop below 4 mg/ ℓ Levels of contaminants (herbicides, pesticides, trace metals and hydrocarbons) in influent water at the head of the estuary or in the estuary itself exceed SA Water Quality Guideline levels Average TSS levels in the Narrows over a period of one year or more exceeds 50 mg/L.	Reduced freshwater inflows to the estuary due to abstraction of water for agricultural, domestic or industrial purposes
Microalgae	Maintain low phytoplankton biomass throughout the estuarine lake. The system must be free of algal blooms or floating algal scum. Maintain the distribution of phytoplankton groups throughout the estuary. Cyanophyceae and Chlorophyceae dominant when the estuary is fresher and flagellates and	Phytoplankton biomass >5 $\mu g.l^{-1}$ in the estuary and > 15 $\mu g.l^{-1}$ in the lake. Observable blooms or scums. Change in the dominance of different phytoplankton groups due to changes in salinity or water retention.	Excessive nutrient levels in the water. Nutrients from agricultural input from rivers particularly uMfolozi and Msunduzi. Change in the salinity gradient or water retention time.

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
	Bacillariophyceae dominant when the system is in a brackish/marine state. Blooms of Cyanobacteria can also form under hypersaline conditions.		
Macrophytes	Maintain the distribution and diversity of macrophyte habitats throughout the estuarine lake. Extensive submerged macrophyte beds can form in the south lake around Catalina Bay and Makakatana. No invasive floating aquatic species present in the estuarine lake e.g. water hyacinth, *Azolla, Hydrilla* and *Pistia .*	Greater than 20 % change in the area covered by different macrophyte habitats due to salinity changes. Loss of dominant / characteristic submerged macrophyte species. Loss of freshwater reeds, sedges and swamp forest species due to groundwater inflow reduction. Presence of invasive floating aquatic species.	Salinity, inundation and turbidity changes away from that described for the present state (2016). Disturbance of the riparian zone due to grazing, fires, trampling, access roads. Drying of groundwater inflow, seepage areas causing the loss of the integrity of the riparian zone. Accidental alien introductions by boats. Localised increases in nutrients and disturbed areas could promote invasive aquatics.
Invertebrates	Protection of full biodiversity, four functional groups in the estuarine, marine, freshwater and hypersaline habitats. Endemic species are of special importance, particularly when restricted to the Lake St Lucia System	Phases not alternating at regular intervals, i.e. decadal shifts, as this could compromise the survival of sensitive stages. Substantial reduction of populations of micro-endemic species falling below 50% of average. Alien invasive species with potential to outcompete native species.	Imbalances between water inflow and evaporation. Prolonged mouth closure, prolonged freshwater dominance. Introduction of further alien species.
Fish	75% or more of the System acts as a nursery to a diversity of EDCII species but particularly EDCIIa species. A good trophic basis exists for predatory estuarine dependant marine species (e.g. *Agyrosomus japonicus, Elops machnata, Caranx* spp.). Estuarine resident species represented by a core group (*Glossogobius* spp., *Oligolepis* spp. *Ambassis* spp. and *Gilchistella aestuaria*).	An abundance (to be defined as an average with prediction limits) of EDCIIa species present as young juveniles in spring and early summer (*Acanthopagrus vagus, Agyrosomus japonicas, Elops machnata, Pommadasys comerssonnii, Rhabdosargus holubi, Terapon jarbua*) is not reached. The four dominant mullet species *(Mugil cephalus, Liza macrolepis, L.dumerelii* and *Valamugil cunnesius*) do not occur throughout the system represented by a full array of size classes.	Hydrological (flow and mouth condition related) and habitat (sediment dynamics) changes. Water quality changes (toxic impacts, persistent low oxygen levels (< 4 mg/L) or intermittent fish kills. Changes in salinity gradients resulting from flow and/or mouth condition changes Water quality impacts, primarily changes in salinity gradient and mouth closure.

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
	Oreochromis mossambicus limited to the upper reaches under estuarine conditions. Species assemblage comprises indigenous species only. Connectivity to a healthy transitional marine-estuary-freshwater system is maintained for 75% of the time. Connectivity between the uMfolozi and St Lucia is maintained even during dry cycles.	Any one of the species in bullet one above does not occur in the estuary in two consecutive years. *Oreochromis mossambicus* distribution (in large numbers) extends into the bulk of the lake for more than a three consecutive years during a hypersaline period. Alien fish species occur. A decline in nearshore linefish catches (e.g. *Rhabdosargus sarba*) occurs (not related to gear changes or bag limit restrictions). uMfolozi water does not enter the mouth area of St Lucia. Loss of connectivity between uMfolozi and St Lucia estuary.	Loss of trophic base (prey fish). Loss of transitional marine-estuary-freshwater connection. Loss of connectivity with upper freshwater input into the estuary. Lake of connectivity between the uMfolozi and St Lucia System. Excess abstraction during low flow periods.
Birds	The estuarine lake system should contain a diverse avifaunal community that includes representatives of all the original groups, and that sustains the populations for which the system has acquired its conservation status.	Numbers of waterbirds on the entire system, other than those that have or are increasing regionally such as Egyptian Goose, drop below **50 species or below 8000 birds** for three consecutive counts. Dramatic reduction in numbers of any of the colonially-breeding waterbirds, especially if not balanced by the establishment/growth of colonies elsewhere in the region Dramatic reduction in the diversity (evenness) of the avifaunal community, e.g. due to dominance by a few species.	Reduction in variability in water level and/or salinity(e.g. consistently high and fresh) Loss of suitable conditions for breeding, e.g. availability of predator-free island areas Reduction in availability of food resources (invertebrates, fish etc) Changes in conditions in the region or distant breeding grounds.

7.3 Monitoring requirements

It is considered absolutely imperative that good data are available to monitor long-term changes in the hydrological, hydrodynamic, and ecological health and functioning of the Lake St Lucia estuarine system, as this is the largest and one of the most important estuarine systems in the country. This is particularly pertinent when consideration is being given to implementing changes to the historic long-term management approach for the system (mouth state) and its hydrological regime (freshwater inflows). It is also important to monitor the affected economic activities (sugar, tourism and marine fisheries), the status of neighbouring communities and anthropogenic pressures on the lake system. Much of this monitoring already takes place, by iSimangaliso and a range of government and private organisations. In this section we elaborate on the ecological and socio-economic monitoring requirements that will need to be co-ordinated by the iSimangaliso Wetland Park Authority and the Department of Water & Sanitation (DWS). It is assumed that the sugar industry will continue to conduct its own monitoring, and marine fisheries monitoring will continue to be conducted by the Department of Agriculture, Forestry and Fisheries (DAFF).

7.3.1 Ecological monitoring

It is recommended that the ecological monitoring studies span a broad range of biophysical aspects from the quantity and quality of river inflows to the biota of the system, and that monitoring of physico-chemical aspects is particularly intense over the initial period, starting as soon as possible (i.e. before implementation if possible) until five years after rehabilitation work commences. Thereafter, monitoring can be continued at reduced intensity. A comprehensive monitoring programme, taking account of the biophysical monitoring requirements for a high confidence reserve determination study (DWA 2012) as well as recommendations tabled in the preceding volumes of this study, is thus presented below.

The **quantity and quality of river inflows** are critical parameters to be monitored, as they reveal the changing pressures from the catchment on water inputs into the system. While these should be routinely monitored by DWS, this will require infrastructural upgrades, which means there is a high risk that these data are not available during the initial intense period of monitoring. Thus an urgent appeal needs to be made to DWS to immediately upgrade their monitoring setup for the inflowing rivers. In the interim it is strongly recommended that iSimangaliso undertakes this monitoring using whatever means at their disposal.

The **mouth condition** will need to be monitored on a daily basis by trained observers and/or a camera setup. The latter could include an unmanned aerial vehicle (UAV)[3] with programmed photograph positions. Changes in the bathymetry of the lower mouth and beach area will also need to be monitored regularly, but given the cost of undertaking bathymetric and LIDAR surveys, there will be a trade-off between the size of the area covered, the resolution of the study and the frequency of monitoring. It is recommended that

[3] Known in laymans terms as a drone, but the term is frowned upon because of its military connotations.

the lower estuary area, including the narrows below the bridge, is monitored annually during the intense monitoring phase, and that the entire estuary system is monitored every 5-10 years. If area-frequency tradeoffs are to be made, it would be better to maintain the frequency, and focus on the lower parts of the system, but an attempt should be made to include the entire system at least every 15 years.

Water level and water quality monitoring instruments will need to be installed to generate continuous data on water level, salinity, turbidity, oxygen and temperature at key locations within the system. It is recommended that this monitoring is continued at the existing three stations (St Lucia bridge, Charters Creek and Lister's Point) and that a fourth station is established in the lower uMfolozi-uMsunduze, as close to the mouth as possible. Water quality samples should be collected from these stations on a monthly basis, to monitor concentrations of DIN and DIP in the water-colum. Additional water quality measurements and samples should be collected in conjunction with faunal sampling at 20 locations throughout the system, as described below.

Monitoring of **sediment** characteristics and origins will help to confirm or improve current understanding of sediment dynamics in the system. This will need to be carried out at at least 20 locations throughout the system that correspond to the faunal sampling locations described below.

The biotic responses should be monitored across all taxonomic groups, but at different frequencies that are appropriate to the typical response rates of each group and that also take the relative return to monitoring costs into account.

It will be necessary to monitor changes in primary producers both in terms of microalgal and macrophyte abundance in the system. Changes in **vegetation** are fundamental to the overall health of the system. This study has produced high-resolution aerial photography from which an accurate baseline map of vegetation should be prepared and ground-truthed. Again, it could be possible to undertake some of this ground truthing in the less accessible areas through the use of UAVs to obtain close-up images. Ideally, this should be complemented by a significant effort to complete a comprehensive survey of the plant species present in the system. A series of about 20 permanent transects need to be established in different parts of the system, in which a variety of measures are recorded including water level, salinity, turbidity, sediment moisture content, depth to water table and ground water salinity, as well as vegetation characteristics. The monitoring of these transects needs to be carried out in conjunction with aerial surveys at the same time. Following the completion of the comprehensive baseline study, it is recommended that aerial and transect surveys are carried out in the lower estuary region (encompassing the mouth area, narrows and lower uMfolozi-uMsunduzi floodplain areas) annually for the first five years, following which, monitoring of the whole system is carried out every 5 years. However, it is also recommended that a programme of more intense monitoring is carried out for particular habitats or populations that are of special conservation concern. This should include harvested plant resources as well as the mangroves as these habitats are going to change in response to future changes in sediment / silt input, water level and salinity.

For **microalgae**, the measurement of Chlorophyll a would be the main measure of microalgal abundance, which should be undertaken quarterly throughout the system. Assessing relative abundance of different microalgal groups also provides a good indication of conditions, but is relatively labour intensive, and can be undertaken at a lower frequency, such as every three years. A special effort should be made to monitor the health state of the populations of the micro-endemic species that have recently been described (e.g. *Edwardsia isimangaliso*, *Potamonautes isimangaliso* etc.) from the estuarine lake. However research studies should continue to investigate the use of microalgal species as indicators of change with a particular emphasis on harmful algal bloom (HAB) species potentially introduced from the uMfolozi/Msunduzi system.

Invertebrate abundance and composition should be monitored on a regular basis to understand changes in food resources for higher taxa, as well as to monitor the status of exploited resources (crabs and prawns). Recognising that there are some species that tend to be found in benthic or pelagic habitats, while others move between these habitats, it is important to sample both.

Monitoring of **fish** populations is particularly important and will help to inform the management of exploited species. Monitoring should be sufficiently intense as to provide the data required to perform regular stock assessments and to be able to model stock dynamics in relation to fishing effort with greater accuracy.

Monitoring of **microalgae, invertebrates and fish** should ideally take place at the same locations in order to be able to analyse relationships between these components, along with corresponding measurements and samples for water quality and sediments (in addition to the water quality sampling described above). This will also maximise sampling efficiency. In all cases, the ideal monitoring frequency would be quarterly monitoring, due to the seasonal dynamics of the system that may compound difficulties in understanding of the interannual fluctuations. These groups also require wide sampling coverage due to high levels of spatial variation in the system both between different areas, and along depth gradients. Given the size and diversity of the system, it is recommended that at least 10 sampling locations are established throughout the system. Within the broad locations identified in Figure 7.1, a transect line perpendicular to the shore should be identified for each discipline that is then sampled consistently. In the case of benthic microalgae and invertebrates, sampling stations should be established at three depths. Fish sampling would take place wherever the shoreline intersects with the transect line. In all cases, three replicates should be collected at each sampling station.

As in the past, monitoring of **birds, crocodiles and hippos** should be by census rather than sampling, recording numbers of each species in the different parts of the system. The existing sampling protocols have yielded highly valuable datasets and should be continued.

It is important to recognise that in some cases, decades of monitoring may be required in order to improve our current understanding of the system dynamics. Given the fact that this is a highly variable system, the more data points in a time series, the faster this understanding will be achieved. The recommendations given above (and summarised in Table 7.2) are considered to be the minimum level of study required. However, every effort should be made to intensify the frequency of monitoring, through involvement of university research programmes, volunteer efforts, and the like. It should also be noted that if any changes are brought about in the way in which data are obtained, e.g. changing from aerial photography to satellite data, or changing between boat, aircraft or UAV-based surveillance of fauna, then there should be a suitable period of overlap in order to calibrate the changes in detection ability. If trade-offs need to be made between coverage and frequency, then these should favour coverage over frequency, so that the coverage adequately captures the spatial variation in the system. If resources are limited, it would also be possible to monitor certain high priority stations more regularly than others.

7.3.2 Tourism

In keeping with iSimangaliso's policies of development through tourism, it already monitors tourism activity in the park, and keeps track of the beneficiaries of its development projects. It is recommended that iSimangaliso expands its current monitoring of tourism activities.

Numbers of visitors entering the Park gates is already recorded on a monthly basis. It would be useful to expand this to include information on the origin or nationality/residence status of the visitors. This could be more easily achieved with a tiered pricing system.

Surveys of Park visitors are carried out twice a year. It is recommended that these are continued. If additional resources are available, it would be useful to include a survey during the August-October period to capture the peak period for overseas visitors.

An inventory of tourism accommodation and activity businesses operating in and around the park needs to be maintained and updated on a regular basis (e.g. every three years). Informal businesses need to be included as far as possible.

A selection of different accommodation establishments (hotels, backpackers, camping, self-catering establishments, luxury lodges, B&Bs and guesthouses) should be monitored each year and bed occupancy data collected from each establishment selected for monitoring. It is also recommended that these establishments are asked to record information about their guests, such as nationality, length of stay and the activities they participate in. Similarly, a selection of tourism activity providers operating in the study area should be asked to provide relevant data on sales and client characteristics, including whether visitors were overnighting in the area, on an annual basis.

Through this approach any changes to tourism in the study area can be consistently evaluated over time. It is recommended that the data be collated an analysed at a maximum of 5-yearly intervals.

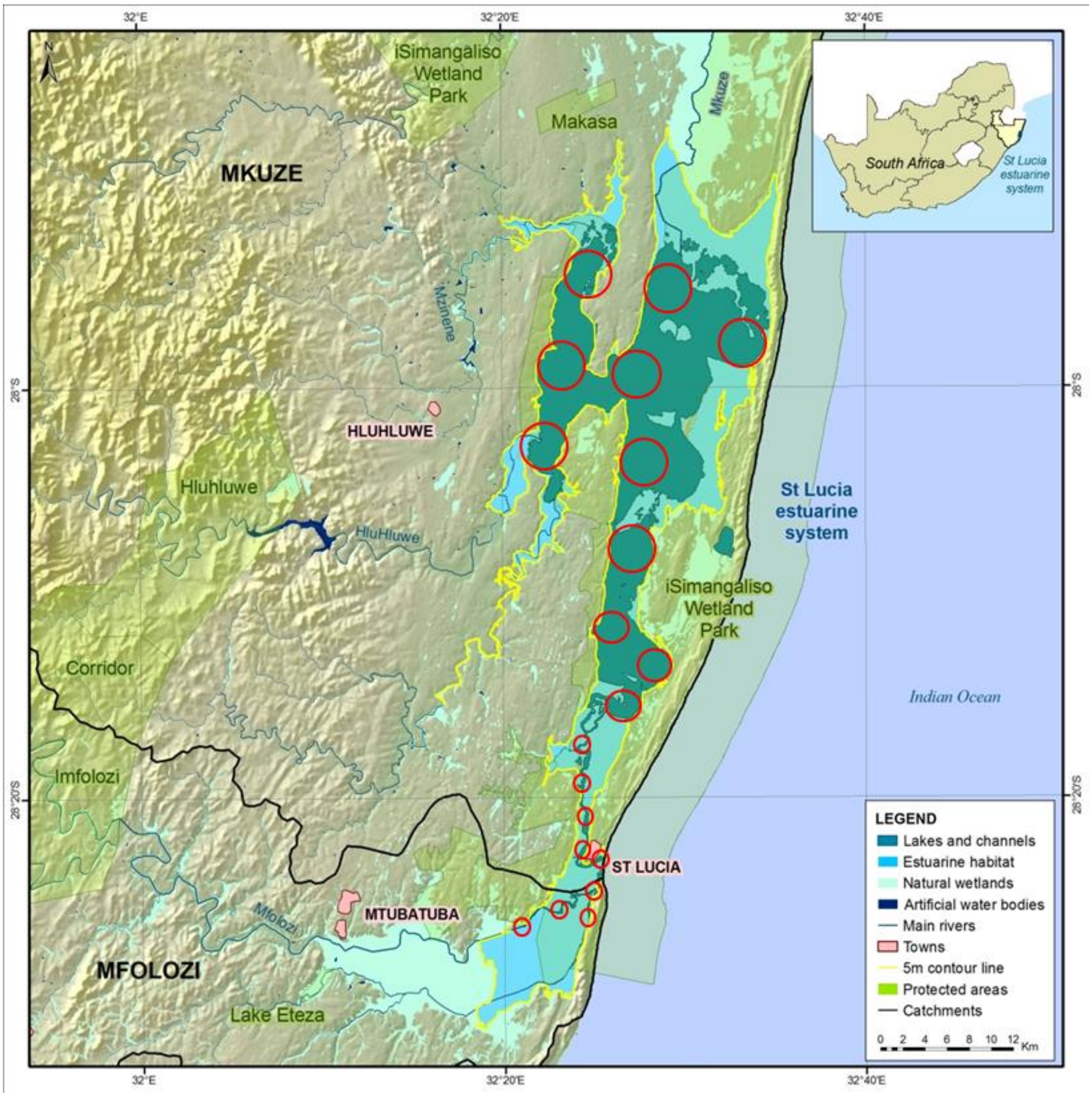


Figure 7.1. Map showing proposed monitoring locations for microalgae, invertebrates and fish.

Table 7.2 Monitoring recommendations for the Lake St Lucia estuarine system.

Component	Monitoring action	Location	Frequency and timing
Quantity and quality of river inflows	Flow gauging to be undertaken in the lower reaches of all contributing river catchments. As far as possible existing streamflow gauging stations should be upgraded to enable accurate measurement of river stage for both low and high discharges.	At least one station on each of the Mkuze, Hluhluwe, Msinene, Nyalazi, Mpate and on the uMfolozi and uMsunduze River, in the region of the 5m contour or as close the confluence with the lakes as possible	Continuous
	Water quality sampling to be undertaken	As above	Monthly
Mouth state	Record mouth state – open/closed/overtopping	Estuary mouth	Daily
Bathymetry and aerial photography	Bathymetry, LiDAR and high resolution aerial photographic surveys; with bathymetry grid survey lines corresponding to those of the baseline mouth area survey	Lower estuary and mouth region (including Narrows up to St Lucia bridge, lower uMfolozi and uMsunduze)	Annually from present until five years after commencement of berm removal, then every five years (the latter under open-mouth conditions)
	Bathymetry, LIDAR and high resolution aerial photographic surveys of the rest of the system; longitudinal profile and cross sections every 100 m in the Narrows and uMfolozi, and grid pattern on the Lakes with 500 m spacing (alignment of transects to correspond with those surveyed as part of Task 1 of this study)	Whole estuary including surrounding floodplains	Every five years
Water level	Record water level using continuous water level recorders	At the existing three stations (St Lucia bridge, Charters Creek and Lister's Point) and in the lower uMfolozi-uMsunduze, as close to the mouth as possible	Continuous
Estuary water quality	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, and inorganic nutrients	At water level monitoring stations in the uMfolozi, lower uMsunduze, the Narrows (at the St Lucia town bridge), Lakes (South Lake, North Lake, False Bay)	Continuous monitoring of temperature, salinity, oxygen and turbidity Monthly sampling for measurement of suspended solids, dissolved inorganic nitrogen (DIN) and phosphorus (DIP)
Sediments	Sediment grab or core for analysis of particle size distribution (PSD), Total Organic Content (TOC), and origin (using microscopic observations), 3 replicates at each station.	Entire estuary, at the 20 faunal sampling stations	Annually during, and for at least five years following, any works undertaken in the mouth region (e.g. removal of dredge spoil), then every 3 years thereafter

Component	Monitoring action	Location	Frequency and timing
Macrophytes	Complete comprehensive baseline description based on ground-truthed aerial photography from Lidar surveys, species inventories and a series of transects. Establish and monitor permanent transects to record water level, salinity, turbidity, sediment moisture content, depth to water table and ground water salinity, as well as vegetation characteristics (cover, species, height etc.). Continue to update aerial photography of entire system, or make use of high resolution satellite imagery, depending on relative efficiency of available technology.	Entire estuary for aerial surveys 20 transects, located near the faunal sampling stations as far as practical	Immediate completion of comprehensive baseline study Annual monitoring of lower estuary vegetation until 5 years after intervention Annual monitoring of habitats/populations of concern (e.g. harvested resources) Aerial and transect monitoring of entire system every 5 years
Microalgae	Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, as well as from subtidal and intertidal benthic samples, using standard techniques, e.g. HPLC, fluoroprobe; 3 replicates per sampling location. Collect samples of phytoplankton (3 replicates at each of 3 depth zones per sampling location) and benthic microalgae (3 replicates per `sampling location) for estimation of relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae	At 20 locations, throughout the system.	Chlorophyll-a sampled every 3 months (Summer, Autumn, Winter, Spring) Summer and winter survey every 3 years and during extreme (e.g. hypersaline) events.
Invertebrates	Collect benthic invertebrate samples for assessment of species composition and abundance/biomass, using van Veen type grab samples of minimum 10 litres capacity at three depth stations, with 3 replicates per station. Collect zooplankton samples for assessment of species composition and abundance/biomass, using a bongo net, WP-2 net or semicircular net mounted on a hyperbenthic sled; 3 replicate hauls per sampling location.	At 20 locations, throughout the system.	Every 3 months (Summer, Autumn, Winter, Spring).
Fish	Collect fish samples for assessment of species composition and abundance/biomass, using large and small beach seine nets, and gill nets of a range of mesh sizes	At 20 locations, throughout the system.	Every 3 months (Summer, Autumn, Winter, Spring)
Birds	Undertake counts of all water associated birds, identified to species level.	Entire estuary, divided into counting sections as at present.	Winter and summer surveys every year

Component	Monitoring action	Location	Frequency and timing
Crocodiles	Aerial surveys to count adults, nest surveys during the breeding season	Entire estuary, divided into counting sections as at present	Annual
Hippos	Aerial surveys to count adults	Entire estuary, divided into counting sections as at present.	Annual

7.3.3 Status of neighbouring communities

The results of this study suggest that there may be small changes in income to households as a result of the project, with these changes being likely to occur in households that benefit from employment or business associated with small-scale farming or commercial sugar farming in the lower uMfolozi floodplain, with tourism, or with legal or illegal natural resource harvesting in the Lake St Lucia system. These potential changes will be difficult to detect at a community level, especially in the light of ongoing development initiatives and other changes, and might be best evaluated by tracking changes in tourism, sugar farming and associated employment, as well as changes in fishing activity.

Nevertheless, it is of interest to the Park to monitor the status and wellbeing of neighbouring communities, in order to be aware of changes in pressures on the system, e.g. due to changes in population size or composition, changes in levels of poverty or health, or changes in other livelihood sources, such as government welfare or involvement in forestry. Monitoring the local communities will also allow iSimangaliso to evaluate the cumulative impacts of its conservation and development programmes.

The monitoring of neighbouring communities should seek to track changes in factors such as population size and movements, demographic characteristics, assets, living conditions, access to services, health, education, levels of income, household activities and dependence on natural resources, conservation, and the tourism and sugar industries, social capital (i.e. quality, intensity and density of community relations), levels of personal security, quality of natural environment and food security. It should also track measures of stated wellbeing.

It is recommended that monitoring of surrounding communities takes the form of regular household surveys. This could be a panel survey, in which the same households are surveyed in subsequent years, or repeated random surveys. While the former has many advantages, the latter is probably better suited to the relatively dynamic population of the area, and would avoid certain biases. As with any impact evaluation, the monitoring programme should be designed to allow the estimation of the counterfactual, which is the hypothetical situation that would occur in the absence of the interventions or programmes. It will therefore be important to devise a sampling design that includes appropriate controls from which to construct the counterfactual.

7.3.4 Compliance monitoring

Collecting data during law enforcement patrols is important as it provides information on changes in the levels of illegal harvesting in the park and allows management to respond appropriately when illegal fishing effort increases. In order to ascertain if levels of illegal fishing effort are indeed changing, quantitative data are required on compliance effort (i.e. number of patrols and person hours per month invested, and their location) as well as on the number of transgressions, arrests, and/or amount of equipment or illegal catch confiscated. Current record keeping does not include adequate detail on effort or location. These data then need to be expressed in the form of catch-per-unit-effort e.g. arrests or confiscation per patrol hour.

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9 APPENDIX A: RECOMMENDATION ON MINIMUM FLOWS REQUIRED TO MEET THE RECOMMENDED ECOLOGICAL CATEGORY (REC) FOR THE LAKE ST LUCIA ESTUARINE SYSTEM

Based on the following studies:
DWS (2016): Reserve Determination Study for the Usutu Mhlatuze WMA, - Hydrodynamic modelling of salinity and suspended sediment in the St Lucia System
and
Basson et al. (2014) Hydrodynamic and sediment modelling studies. Vol III. In: Clark, B.M & Turpie, J.K. (eds.) Analysis of alternatives for the rehabilitation of the Lake St Lucia estuarine system. Anchor Environmental Consultants Report no. AEC/1487/3 submitted to iSimangaliso Wetland Park Authority.

Prepared by G.R. Basson, D.E. Bosman, O.Sawadogo & A.J.C. Visser

9.1 Background

In the two studies above, a hydrodynamic model was set up of the uMfolozi and Lake St. Lucia system which runs on a daily time step. The model was set up on historical data and was successfully calibrated against historical water levels and TDS data. The ACRU model supplied the daily runoffs which were used as boundary conditions for the hydrodynamic model. The ACRU model rainfall data was scaled to achieve the required Lake inflows for the period 1962 to 2010. The accuracy of the MARs of the freshwater inflows to the Lake is estimated to be 10%.

Figure 9.1 shows a log section of the Lake from north to south, the Narrows and the mouth, from the LHS to the RHS. Note that the Lister point (False Bay) and Northern Lake zones of the Lake are completely cut off from the southern Lake at Charters Creek during droughts (This is confirmed by observed data such as the drought conditions of 2003 (Figure 9.2) and the current drought). (The red dotted line was the maximum water level simulated over 50 years for the specific scenario).

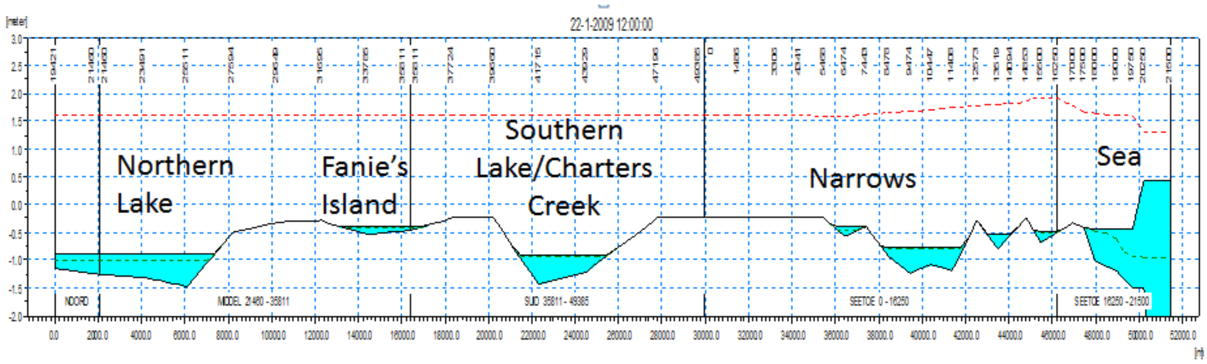

Figure 9.1 Drought conditions as simulated by the hydrodynamic model

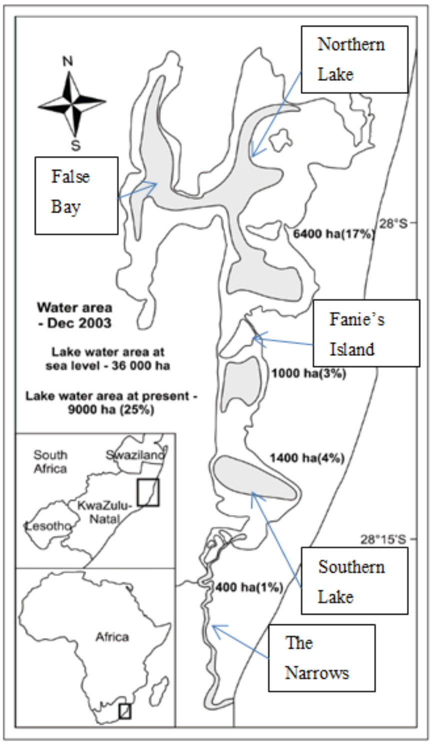

Figure 9.2 Water coverage of Lake St Lucia in December 2003 reduced to 25% of surface area (Cyrus et al., 2011; Original figure compiled by Ezemvelo KZN Wildlife)

While the calibrated hydrodynamic model simulated detailed daily output in the three main zones of the Lake, the ecological model of the DWS (2016) study used a single point (Lister's Point) in the Northern Lake and was run using an annual time step (average and maximum values for each year. Figure 9.3 shows the simulated Lake water levels at Lister's Point, Northern Lake and Charters Creek for the Reference scenario, from 1962 to 2010. The critical ecological Lake level of 0.15 m MSL as considered in the GEF (2015) study is indicated by dotted line while the solid black line indicated the approximate Lake isolation level. The water level data of all three parts of the Lake are more or less in agreement under normal conditions, but when the Lake level drops below the black line, the Northern parts of the Lake drops much further during droughts with resultant higher TDS extremes. The choice of Lister's Point as a representative site for the Lakes in the ecological model thus presents a worst case scenario for water levels and TDS values. This should be considered in the interpretation of the environmental recommendations of the DWS (2016) main report.

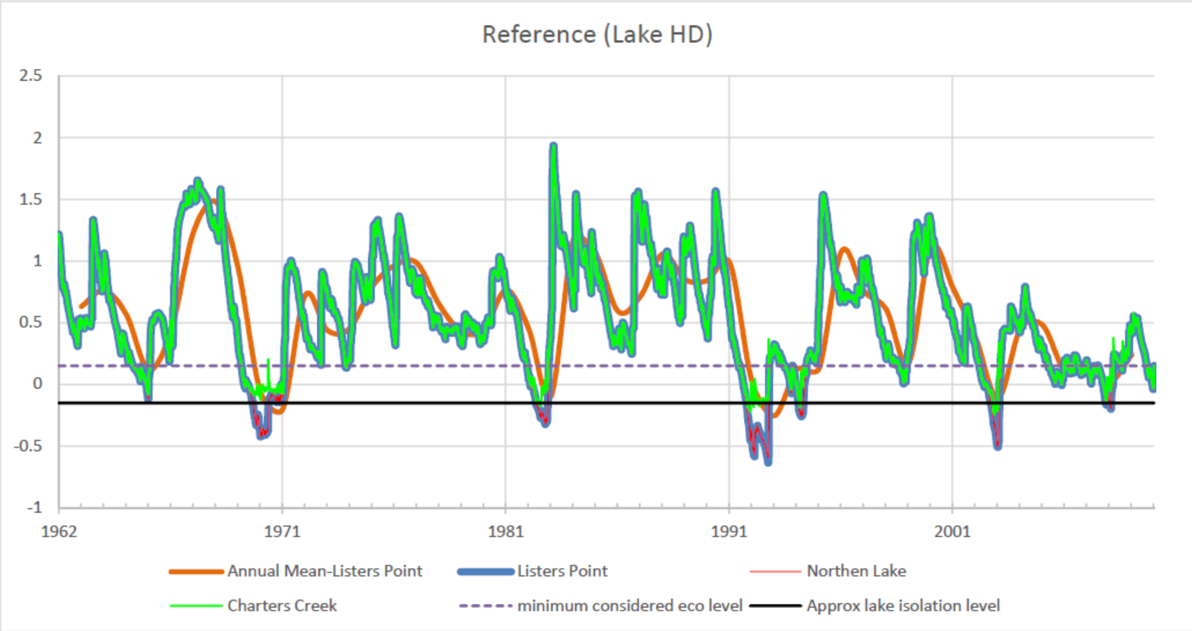

Figure 9.3 Simulated water levels in the Lake with critical Lake levels for the Reference scenario (m MSL)

The GEF (2015) study recommended a single mouth scenario without artificial beaching of the beach berm, with mitigation measure to remove the dredges spoil dump at the mouth. The current first phase removal of the dredging material is underway and the channel which links the uMfolozi River with the Lake estuary is the only scenario considered in this report for the EWR determination (called Mouth scenario B, DWS (2016)).

Figure 9.4 and Figure 9.5 show the simulated TDS concentrations at Lister's Point and Charters Creek, respectively, for the scenarios of the DWS (2016) study. Under Reference conditions the concentrations remained below 35000 mg/l at Lister's Point, but at Charters Creek the Reference TDS peaks were higher, but still less than 70000 mg/l. The most problematic zones in the Lake in terms of extremes in TDS are definitely the False Bay and Northern Lake zones, for the Baseline and future scenarios (DWS, 2016). In our assessment ofEWR flows required to improve the Present Day Lake water levels and TDS, we believe that more water is firstly required at the Northern Lake via the Mkuze River as priority, and secondly from the uMfolozi River, especially when the mouth closes, but also to prevent mouth closure.

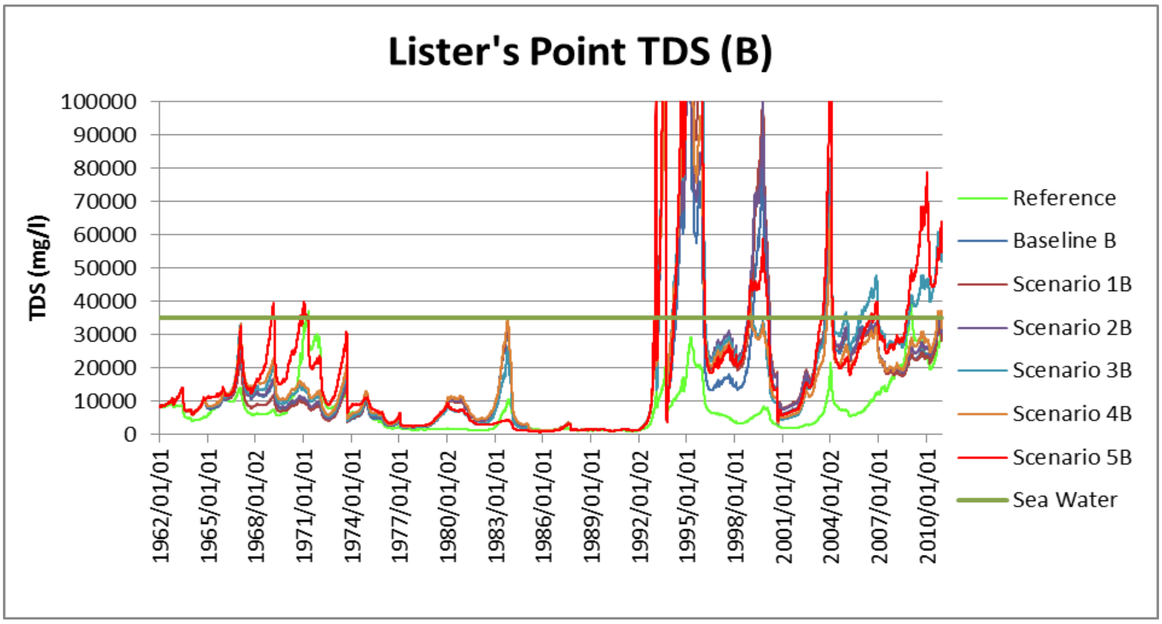

Figure 9.4 **Simulated TDS concentrations at Lister's Point (DWS, 2016).**

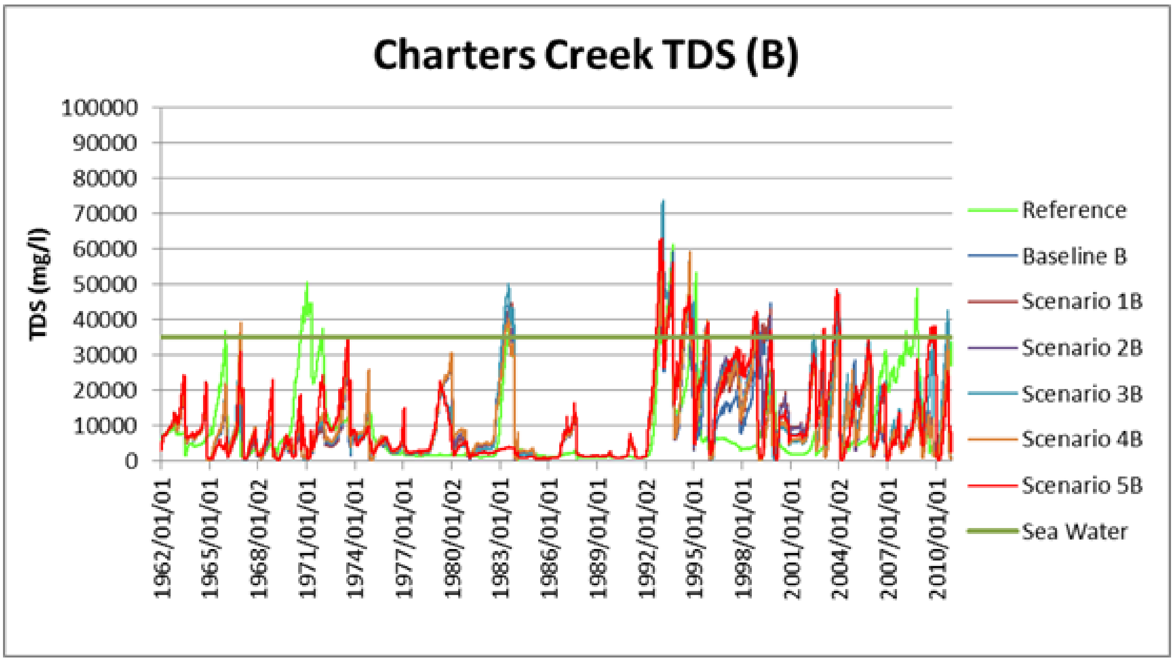

Figure 9.5 **Simulated TDS concentrations at Charters Creek (DWS, 2016).**

Simulated Present Day (with dredge spoil removed) daily water levels vs. TDS are shown in Figure 9.6-Figure 9.8, with the red line indicating a critical TDS of 2 x seawater concentration. Under Present Day conditions, results from the ecological model (DWS 2016) suggest that TDS levels would need to remain below 70000 mg/l at Lister's Point to improve the health of the system from a category "C" to a category "B", the Recommended Ecological Category for the St Lucia estuary. At Charter's Creek, the TDS is considerably better than at Lister's Point, but peaks are above 35000 mg/l are still expected.

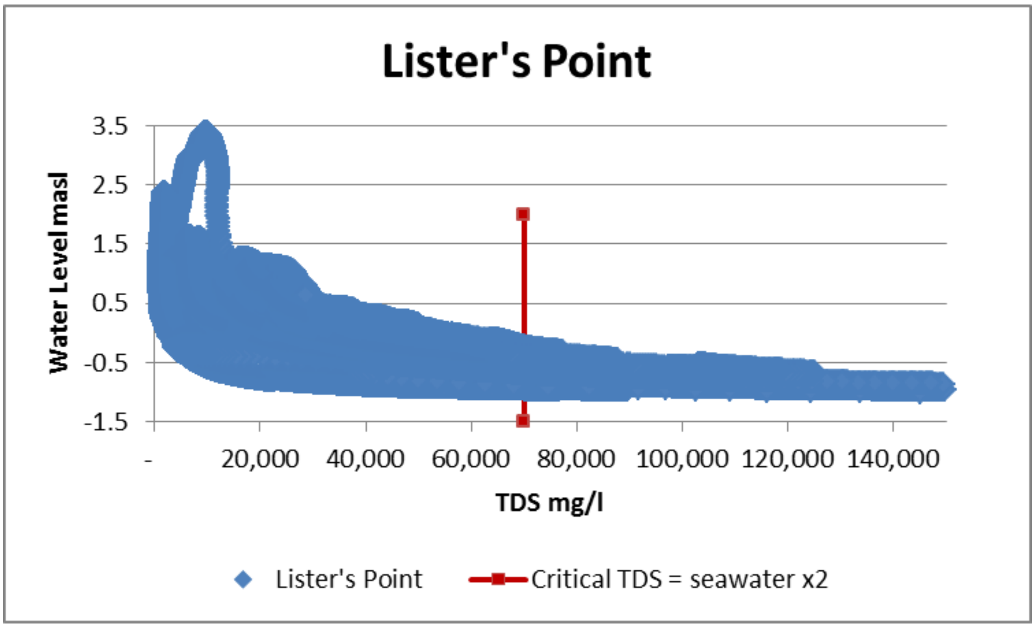

Figure 9.6 Simulated TDS vs water level relationship at Lister's Point for the Baseline scenario (1962to 2010 daily data);

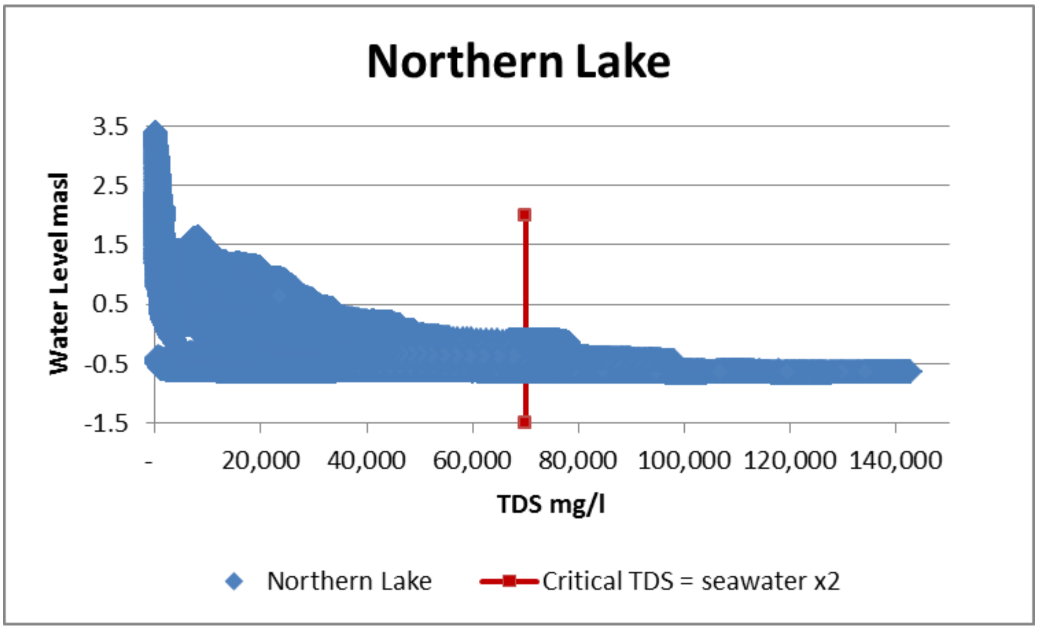

Figure 9.7 Simulated TDS vs water level relationship at Northern Lake for the Baseline scenario (1962to 2010 daily data).

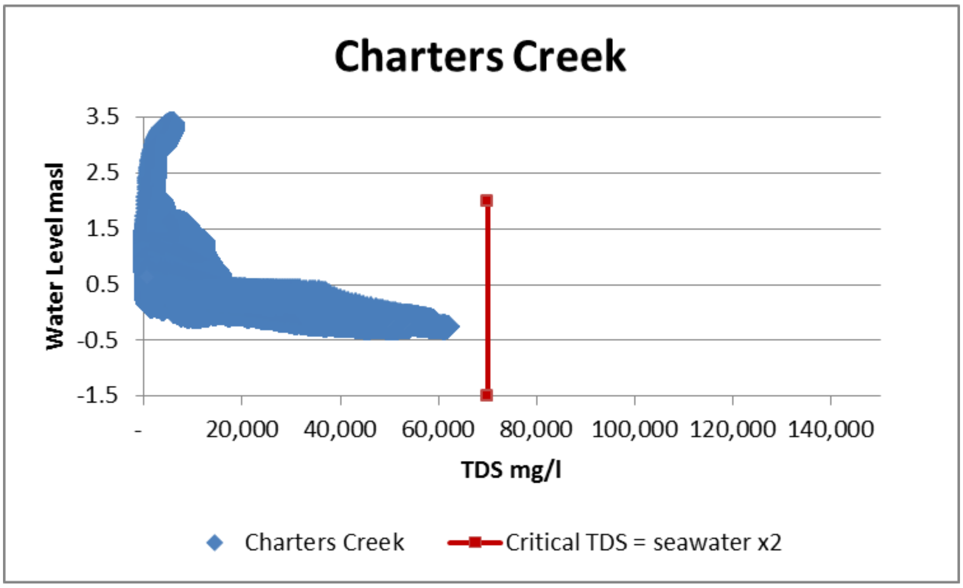

Figure 9.8 **Simulated TDS vs water level relationship at Charters Creek for the Baseline scenario (1962to 2010 daily data).**

9.2 How much flow is required to improve the Baseline Scenario from Category C to Category B?

Table 9.1 shows the boundary conditions as used in the hydrodynamic modelling of the DWS (2016) study for the Reference and Baseline conditions. The combined inflow reduction of the uMfolozi and uMsunduzi Rivers from Reference to Baseline is 41 million m3/a. Of all the rivers entering the Lake directly the total flow reduction is 80 million m3/a. The combined total flow reduction as MAR is 121 million m3/a (Baseline lower than Reference), which is equivalent to discharge of 3.9 m3/s on average. It is important, however, not only to evaluate the mean annual flows but also the low flows and drought flows, because these are disproportionately affected by land use and land degradation changes that have been implemented since 1920. Figure 9.9-Figure 9.11 show the low flow duration data based on daily data from 1962 to 2010.

Table 9.1 **River inflows (DWS, 2016)**

Scenario	uMfolozi	uMsunduzi	Nyalazi	Mzinene	Nsimane	uMkhuze	Eastern shores
	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a	million m^3/a
Reference	**695.1**	**142.2**	**50.1**	**32.2**	**29.3**	**180.5**	**36.6**
Present	662.8	133.2	35.0	31.3	12.0	125.6	44.6

The critical Lower uMfolozi River flow at which the mouth closes, based on historical data, varies between 1.5 to 3.0 m3/s. In the DWS (2016) study, a threshold of 1.5 m3/s was used in the modelling. However, due to uncertainties, especially in low flow measurement accuracy, a Baseline discharge > 3 m3/s is recommended as the minimum flow required to maintain an open mouth. Based on Figure 9.9 and Table 9.2, discharge of 3 m3/s in the uMfolozi River is exceeded 52% of the time under Present Day conditions, while the discharge for the same exceedance was 7.9 m3/s - under Reference conditions a reduction of 4.9 m3/s. If one takes drought flow conditions as to be 80% flow exceedance, then the reduction from Reference condition to Baseline is 2.3 to 0.4 m3/s, a difference of 1.9 m3/s. Under the latter Reference condition, the mouth will be open based on the 1.5 m3/s minimum flow rule of the DWS (2016) study, but closed under Present Day conditions, if the Lake level is also low.

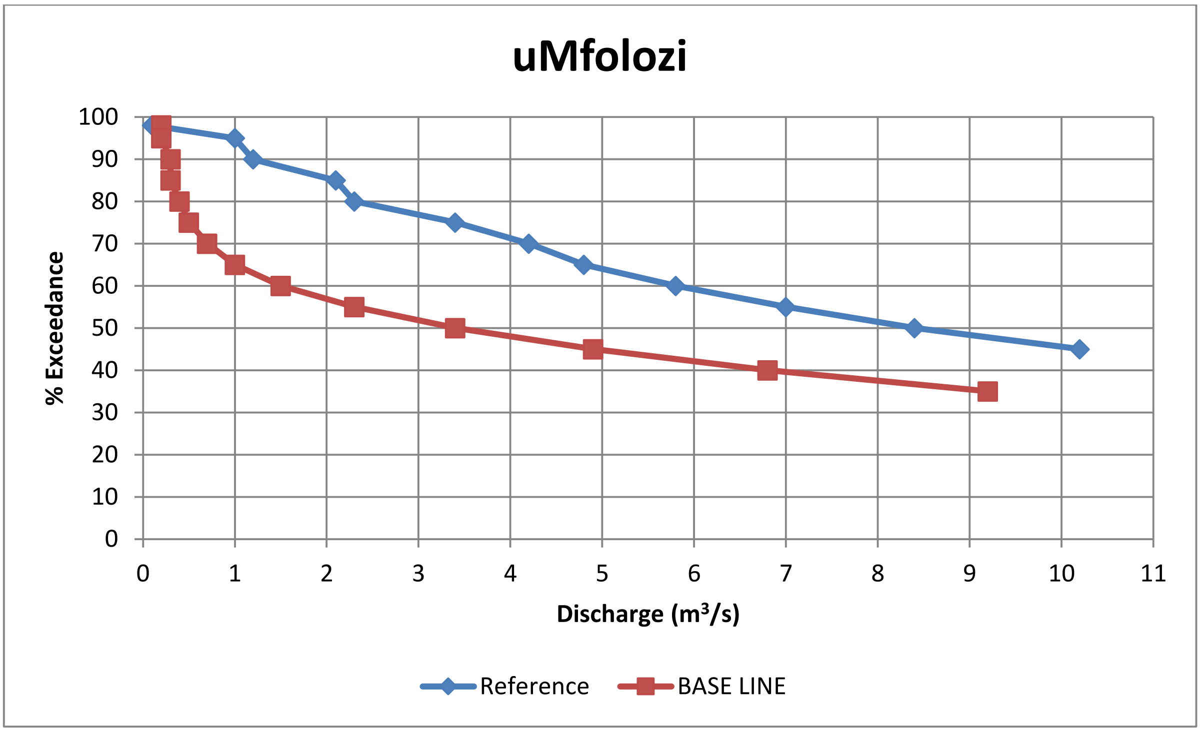

Figure 9.9 uMfolozi River downstream of the bifurcation flow duration graph (1962 to 2010 daily data).

Table 9.2 uMfolozi Flow Exceedance.

% Exceedance	Reference	BASE LINE
	m^3/s	m^3/s
98	0.1	0.2
95	1	0.2
90	1.2	0.3
85	2.1	0.3
80	**2.3**	**0.4**
75	3.4	0.5
70	4.2	0.7
65	4.8	1.0
60	**5.8**	**1.5**
55	7.0	2.3
50	**8.4**	**3.4**
45	10.2	4.9
40	12.2	6.8
35	14.6	9.2
30	17.4	12.3
25	21.2	16.5
20	26.5	22.4
15	34.0	31.6
10	45.5	47.4
5	73.1	88.1
1	225.4	283.3

Based on Figure 9.10 and Table 9.3, a 3 m3/s uMfolozi River and uMsunduzi discharge is exceeded 56% of the time under Present Day conditions, while under Reference conditions the discharge for the same exceedance was 8.1 m3/s - a decreased of 5.1 m3/s for current conditions. If one takes a drought flow conditions as 80% flow exceedance, then the reduction from Reference condition to Present is 3.5 to 0.6 m3/s, a difference of 2.9 m3/s. Under the latter Reference condition, the mouth will be open based on the 1.5 or even 3 m3/s minimum flow rule of the DWS (2016) study, but closed under Present Day conditions if the Lake level is also low.

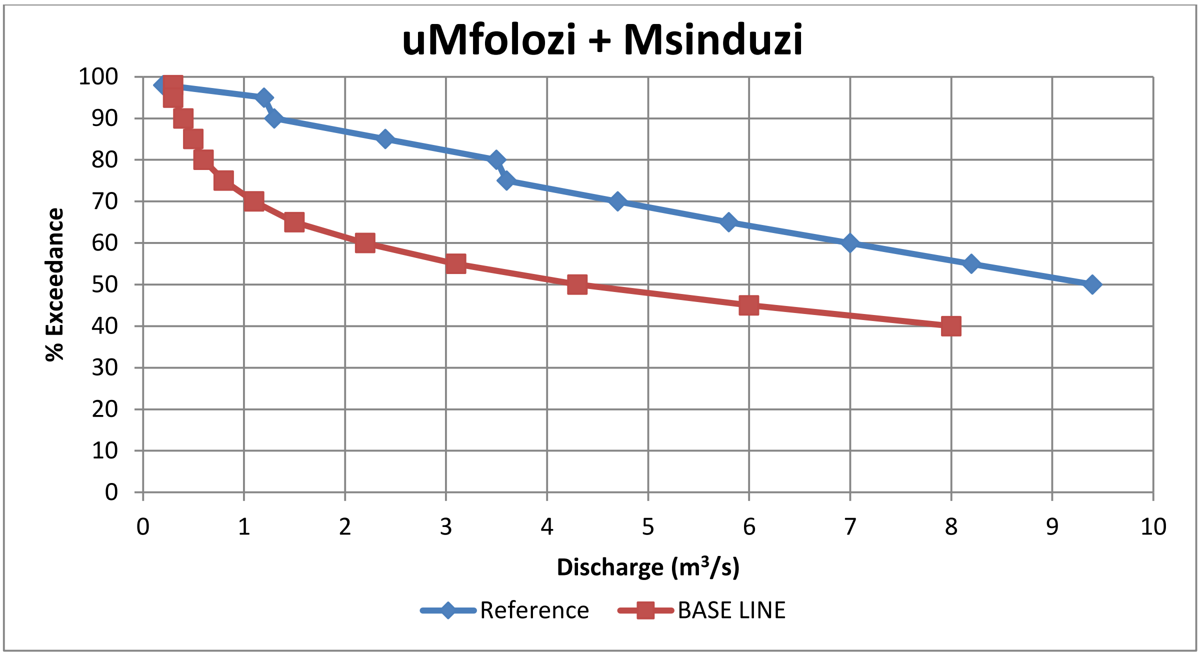

Figure 9.10 uMfolozi and uMsunduzi Rivers combined flow duration graph (1962 to 2010 daily data).

Table 9.3 uMfolozi + Msunduzi Flow Exceedance.

	Reference	BASE LINE
% Exceedance	**m^3/s**	**m^3/s**
98	0.2	0.3
95	1.2	0.3
90	1.3	0.4
85	2.4	0.5
80	**3.5**	**0.6**
75	3.6	0.8
70	4.7	1.1
65	5.8	1.5
60	7	2.2
55	**8.2**	**3.1**
50	9.4	4.3
45	11.7	6
40	14	8
35	16.4	10.7
30	18.8	14
25	23.4	18.5
20	28.1	24.7
15	36.3	34.4
10	50.3	51.41
5	78.4	92.655
1	243.3	305.3

Based on Figure 9.11 and Table 9.4, the total Lake inflow from rivers during drought periods typically decreases from 2.6 to 0.1 m3/s and from 1.5 to 0.05 m3/s, at the 80% and 90% exceedance levels for Reference and Baseline conditions, respectively, . Even under median conditions (50% exceedance) the Reference flow into the Lake was 6.2 m3/s, compared to only 0.7 m3/s under Baseline conditions. The decrease in flow from Reference to Baseline conditions for 50%, 80 % and 90% exceedance are thus 5.5, 2.4 and 1.4 m3/s, respectively.

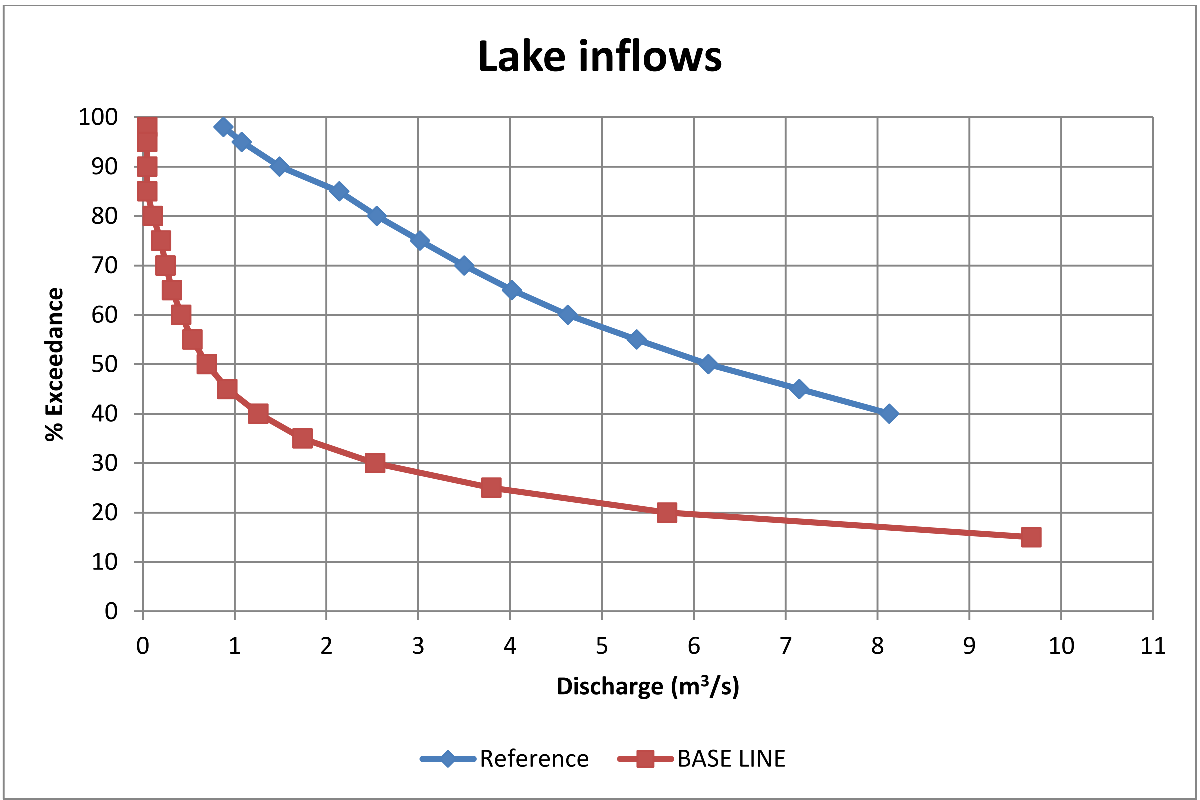

Figure 9.11 Combined direct Lake river freshwater inflows flow duration graph (1962 to 2010 daily data).

Table 9.4 Lake freshwater inflow - Flow Exceedance.

% Exceedance	Reference	BASE LINE
	m^3/s	m^3/s
98	0.88	0.05*
95	1.08	0.05
90	**1.49**	**0.05**
85	2.14	0.05
80	**2.55**	**0.11**
75	3.02	0.2
70	3.5	0.25
65	4.02	0.32
60	4.63	0.42
55	5.38	0.54
50	**6.16**	**0.7**
45	7.15	0.92
40	8.13	1.26
35	9.22	1.74
30	10.62	2.53
25	12.48	3.80
20	14.63	5.71
15	17.49	9.68
10	21.98	15.54
5	30.19	26.98
1	63.35	81.87

Note: Minimum from ACRU model is 0.05 m3/s

The combined critical low flow on the uMfolozi River has therefore decreased by 5.0 m3/s from Reference to Present, and the total Lake inflow from rivers has decreased by about 5.5 m3/s at the 50% exceedance level.

Table 9.5 indicates the additional water volume required to maintain the Lake level at a point where TDS concentrations at Lister's Point and the Northern Lake do not exceed an ecological critical TDS value of 70000 mg/l. (Note that based on the results of the ecological assessment (DWS 2016), it is anticipated that this would ensure that the health of the St Lucia system improves from a current category C to a category B). This estimate was obtained from the daily Lake volume difference calculations, but it is recommended thatthe effect of adding additional runoff in rivers should still be evaluated by hydrodynamic modelling. Under Present Day conditions, the Lake requires an additional 5.2 m3/s during drought periods. For possible future development scenarios, the Lake thus requires additional inflows of 5.5 to 6.6 m3/s during droughts.

The ratio of the direct Lake inflows to the Narrows inflows to the Lake plus the direct Lake inflows is 74%, for the mean of the Reference and Present Day. Based on the above, to improve the Present Day health of the estuary from a category C to B it is proposed that a total flow of **3.8 m^3/s** is added at the Mkuze River where it enters the Northern Lake, and **1.3 m^3/s** is added to the uMfolozi River flow constantly, to give the total additional flow requirement of 5.2 m^3/s . If it is not possible to increase the uMfolozi River low flows by 1.3 m^3/s because of existing lawful uses, it is recommended that no additional low flow water abstractions are permitted from the uMfolozi River, and that the total additional required **5.2 m^3/s** will need to be supplied from the Mkuze River.

The proposed additional freshwater inflows to the Lake and on the uMfolozi River should be tested by hydrodynamic model simulations of TDS to determine the final EWR.

Table 9.5 Additional river discharge for the Baseline and future scenarios (DWS, 2016) required during drought periods to maintain the TDS at Lister's and Northern Lake below 61114 mg/l at 1.46% exceedance *

Description	Reference*	Present	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Number of days additional flow from uMfolozi River required during droughts (days)	**0.0**	**519.0**	**689.0**	**655.0**	**615.0**	**493.0**	**806.0**
Total drought period with flow augmentation from uMfolozi required (years)	**0.0**	**1.4**	**1.9**	**1.8**	**1.7**	**1.3**	**2.2**
Additional uMfolozi total volume of flow augmentation required during droughts (MCM)	**0.0**	**231.7**	**355.4**	**372.6**	**321.2**	**241.7**	**386.4**
Additional uMfolozi/Mkuze discharge required during drought periods (million m^3/a)	**0**	**163**	**188**	**208**	**191**	**179**	**175**
Additional uMfolozi/Mkuze discharge required for TDS at Listers < 70000 mg/l during droughts (m^3/s)	**0.0**	**5.2**	**6.0**	**6.6**	**6.0**	**5.7**	**5.5**

Note: Under Reference conditions, the TDS is 31062 mg/l at 1.46 % exceedance for the period 1962 to 2010, while Present Day conditions the TDS is 91166 mg/l for the same exceedance percentage.

9.3 Where will the additional flow required come from for the Lake system classification to change from C to B?

Possible sources of additional flow to the Lake have been investigated in the GEF (2015) study. These could include:

a) When the uMfolozi flow drops below 1.5 m^3/s (or to be more conservative 3 m^3/s due to DWS flow measurement inaccuracy), and the Lake is below its critical level of 0.35 m MSL, the mouth is expected to close. Following closure, the mouth should not be breached artificially. If the mouth is allowed to breach when the water spills over the berm, this could inundate farmland, but breaching at a high water level ensures flushing of sediment and the creation of a relatively large mouth (width and depth) with more tidal flow. The berm crest level could typically build up to 2.5 m to 3.0 m MSL, and this will allow fresh water to flow up the Narrows to the Lake. During droughts the uMfolozi River is currently typically almost dry and is currently not a source of fresh water as was previously believed.

b) Alien vegetation should be removed from the eastern and western shores of the Lake, and along rivers and swamps/wetlands flowing into the Lake. Vegetation removal should be carefully managed to prevent tree/debris blockage as has happened in the past in the uMkhuze Swamp.

c) Increased fresh water inflow to the northern part of Lake St Lucia is possible by supplying current irrigators on the uMkhuze River with water pumped from Pongolapoort Dam, thereby allowing more water from the uMkhuze to flow through the swamp to the Northern Lake. The ACRU hydrological model (Görgens *et al*. 2014) indicated that the increased flow in the river upstream of the swamp would amount to **1.6 m^3/s**. Higher uMkhuze River inflows would also decrease the salinity at Lister's Point during droughts in future as discussed earlier. Currently, the Pongola River system has excess water available and this should be a feasible scenario. Figure 9.12 shows the existing uMkhuze River irrigation area which could possibly be supplied from Pongolapoort Dam instead of from the uMkhuze River. The hydrology report from the GEF study gives an indication of the irrigation area and water use from the uMkhuze River which could be made available for the St Lucia system.

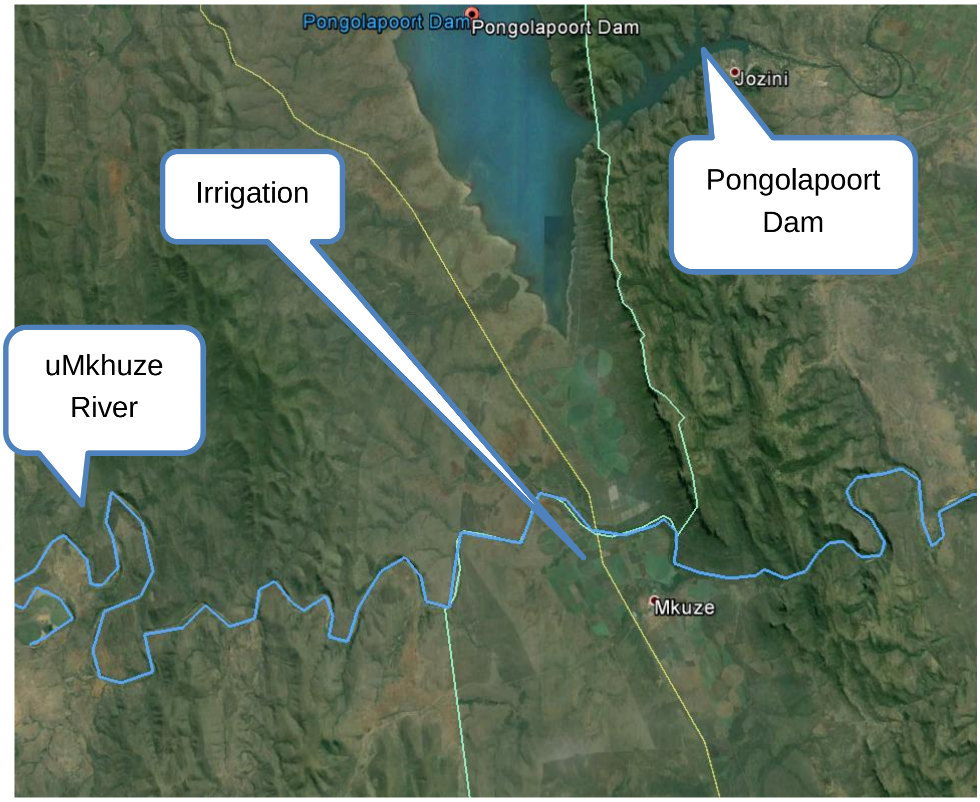

Figure 9.12 Existing irrigation at uMkhuze River.

d) No future additional water use for irrigation from the rivers flowing into Lake St Lucia should be allowed. The current forestry areas should also not be expanded in the catchments feeding the Lake, and deforestation of commercial forestry should rather be considered. Urbanization (formal or informal) in the Lake system catchments should be limited, especially if deforestation of natural forests is involved (Figure 9.13). The latter will increase flood peaks and sediment transport into the Lake, and decrease low flows needed during droughts.

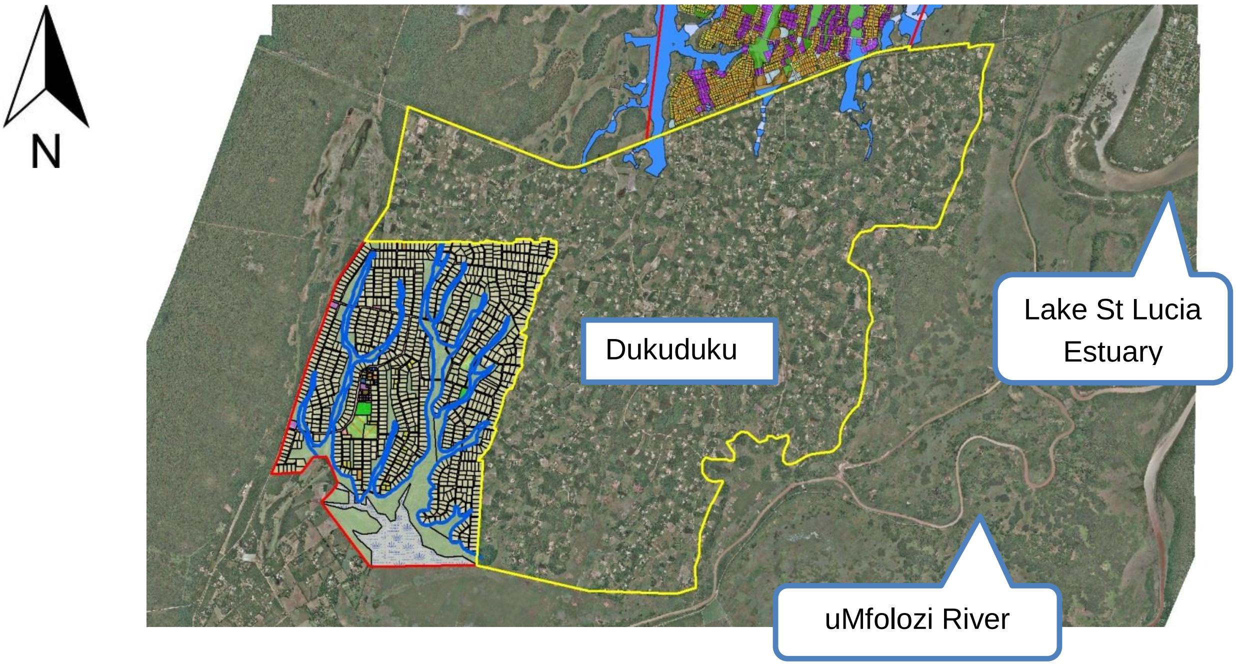

Figure 9.13 Dukuduku Deforestation urbanization area: inside yellow and red lines.

e) Proposed future water transfer scheme from Pongolapoort Dam by pipeline from the existing irrigation canal system. Pongolapoort Dam has always had an excess firm water yield. It should be possible to construct a pipeline from the existing irrigation canal downstream of the dam to convey water to the downstream end of the uMkhuze swamp, or to the Northern Lake (see Figure 9.14). The impact on the water levels and TDS of the Lake for various water transfers should be simulated. The required diversion transfer could probably be between **3.8 to 5.2** m^3/s required downstream of the swamp. This transfer should be in addition to the uMkuze irrigation water supplied from Pongolapoort Dam (1.6 m^3/s), and taking account of losses of around 25% in the swamp, would provide the additional inflow of 5.2 m^3/s, required by the Lake. The additional discharge should be constant because this is the critical drought flow requirement. It should not only be transferred during droughts because it is difficult to predict when a drought will occur.

f) The required pipeline length is 53 km. The pipeline is a gravity pipeline (no pumping). An open canal could be investigated but will be longer, with more evaporation losses and possible illegal abstractions. A shorter pipe of 6 km to the uMkhuze River upstream of the swamp is possible. There will be extra water losses in the swamp but it is important to maintain the swamp in a good condition to trap increased sediment loads in future. The 6 km transfer scheme under gravity is the preferred transfer from Pongolapoort Dam.

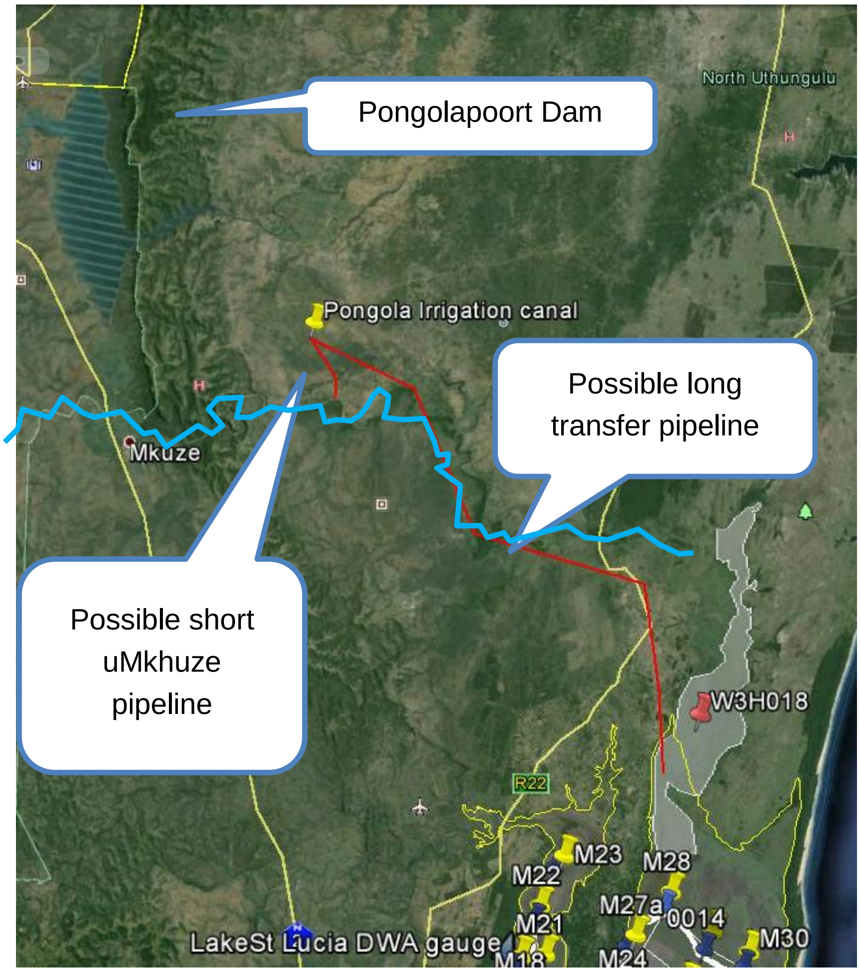

Figure 9.14 Proposed water transfer pipeline routes from the Pongola irrigation canal to the uMkhuze River.

g) In the uMfolozi River catchment land care practices should focus on the most critical sub-catchment areas to limit future erosion and land degradation. The minimum discharge on the uMfolozi River during droughts should be at least 3 m^3/s at about 65 to 75% exceedance, for the improved category B Baseline scenario, to ensure the mouth remains open.

h) The above possible water transfer schemes are subject to the uncertainties reported here that centre on differences between the ACRU modelled discharges and the mass balance requirements of the 1D model. Given these discrepancies, these scenarios likely need more attention in advance of the significant investments required.

9.4 Conclusions and Recommendations

To improve the Baseline scenario from a category C to category B, the following is recommended:

a) St Lucia should have a single mouth, with the dredged spoil dump removed (phased), and with no manipulation of the mouth (artificial breaching or closing).
b) When the mouth closes the uMfolozi River flow is a source of fresh water for the Lake, but under the current (Baseline scenario) conditions, the river is almost dry when the mouth close.
c) Remove alien vegetation around the Lake, estuaries and rivers
d) Limit further natural deforestation such as in the Dukuduku Forest
e) Prevent urbanization in the catchments feeding directly into the Lake and the Narrows
f) Reduce commercial forestation in the Lake catchments to increase low flows as much as possible
g) In the uMfolozi River catchment, land care practices should focus on the most critical sub-catchment areas to limit future erosion and land degradation which could further reduce low flows.
h) Illegal river abstractions on especially the Mkuze and uMfolozi Rivers must be eliminated.
i) The low flow discharge on the uMfolozi River during droughts should not drop below 3 m^3/s more than 65-75% of the time to ensure the mouth remains open. Therefore future development scenarios which abstract more of the base flows should not be allowed. Based on the flow duration data of the uMfolozi River, to improve the Baseline scenario, additional low flow of **1.4 m^3/s** should be added constantly to the uMfolozi River (downstream of the bifurcation). If this is not possible, then the additional uMkhuze River flow needed should be increased.
j) The uMkhuze River irrigators could be supplied directly from Pongolapoort Dam which would make **1.6 m^3/s** (MAR) available upstream of the Swamp.
k) The flow of the uMkhuze River could be augmented further by transfer from Pongolapoort Dam under gravity by pipeline from the end of the irrigation canal to upstream of the Swamp. The excess firm yield of Pongolapoort Dam could be used to transfer **3.8 m^3/s** (if uMfolozi River flow is increased by **1.4 m^3/s**), or the total Lake requirement of **5.2 m^3/s** should be transferred (if the Baseline low flows on the uMfolozi River cannot be improved by 1.4 m^3/s). This flow augmentation should be in addition to the uMkhuze irrigation flow of 1.6 m^3/s made available (see (j) above), to allow for losses through the uMkhuze Swamp.

Based on the above the total required additional discharge to improve the Baseline scenario to a category B is 1.4+1.6+3.8 = **6.8 m^3/s**. When the EWR is determined, the hydrodynamic model should be used to simulate the impacts of the increased/augmented flows on the salinity in the system. At this stage, no simulations have been carried out for a single mouth augmentation scenario in the GEF (2015) or the DWS (2016) study.