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Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

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

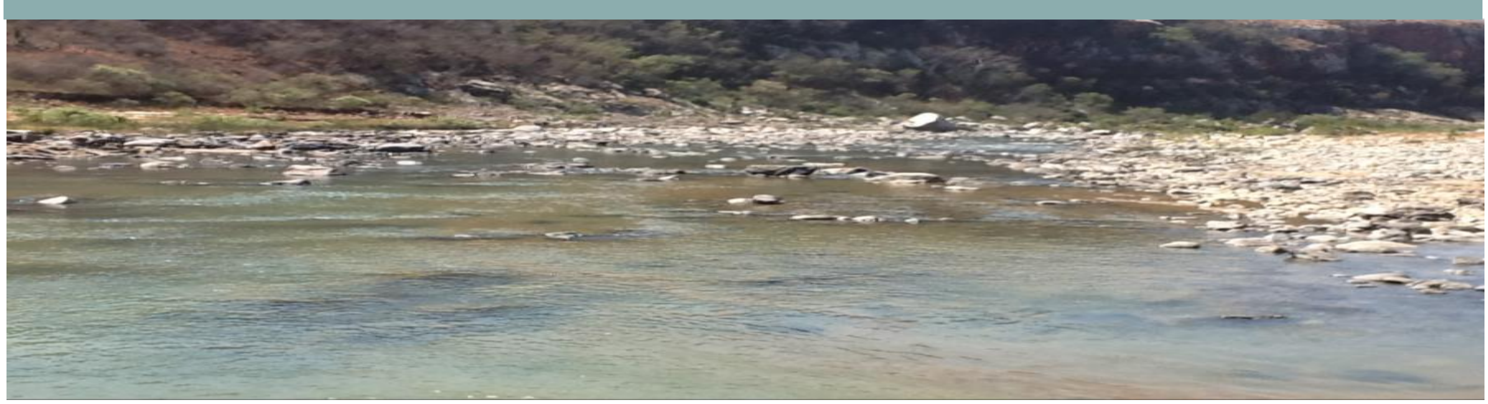
KOSI ESTUARY RAPID ECOLOGICAL WATER REQUIREMENTS DETERMINATION:

VOLUME 1 - EWR REPORT

FINAL

JULY 2016

Report No. RDM/WMA6/CON/COMP/2613



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DEPARTMENT OF WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS

CONTRACT NO. WP 10544

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EXECUTIVE SUMMARY

INTRODUCTION

The Kosi Estuarine Lake System (also referred to as Kosi Estuary) is located on the east coast of South Africa, approximately 2 km south of the Mozambique border. The estuary is sited on the edge of the flat northern KwaZulu-Natal coastal plain, about 75 km from the Lebombo Mountain range. Except for the mouth, the system is separated from the sea by a high vegetated barrier dune complex that reaches 130 m in height.

The Kosi system is a series of interconnected estuarine lakes. These lakes from north to south are called Makhawulani (Lake 1), Mpungwini (Lake 2), Nhlange (Lake 3) and Amanzimnyana (Lake 4). The estuary forms a broad channel (tidal flat) that opens to the Indian Ocean. Three rivers feed the system, KuKhalwe inlet into the estuary, the Sihadhla (Malangeni) River into Lake 4 and the Swamanzi (Gesiza) River into Lake 3.

For the purposes of this EWR study, the geographical boundaries of the Kosi Estuary are defined as follows:

Downstream boundary:	*Estuary mouth 26°53'41.25"S 32°52'48.43"E*
Upstream boundary:	*27° 4'7.60"S 32°48'5.15"E*
Lateral boundaries:	*5 m contour above Mean Sea Level (MSL) along each bank*

Geographical boundaries of the Kosi Estuary based on the Estuary Functional Zone.

PRESENT ECOLOGICAL STATUS

The Kosi Estuary in its Present State is estimated to be 91 % similar to the Natural Condition, which translates into a Present Ecological Status (PES) of an A/B Category. The reduction in state compared to Natural Condition is mostly attributed to the following factors:

- *Ground water abstraction;*
- *Over exploitation of fish resources (e.g. fish traps and poaching of fish);*
- *Harvesting of Mangroves and reeds;*
- *Invasive alien invertebrate Tarebia granifera (an aquatic snail) displacing indigenous species;*
- *Over exploitation of invertebrate resources (e.g. crab collection and bait collection);*
- *Muti trade of fish eagle fledglings and vegetation;*
- *Recreational activities at the mouth; and*
- *Agricultural activities in the Estuary Functional Zone causing loss of estuarine habitat.*

The overall current Estuarine Health Score as well as the score with non-flow related pressures removed is given below.

Estuarine Health Score for the Kosi Estuary.

Variable	Estuarine health score			
	Weight	Ecological condition	Excluding non-flow related pressures	Conf
Hydrology	25	90	90	Low
Hydrodynamics and mouth condition	25	100	100	Low
Water quality	25	94	94	Low/Medium
Physical habitat alteration	25	95	100	Medium
Habitat health score		**95**	96	
Microalgae	20	95	95	Medium
Macrophytes	20	90	100	Medium
Invertebrates	20	75	98	Low
Fish	20	80	87	Low/Medium
Birds	20	92	96	Medium
Biotic health score		**86**	95	
ESTUARY HEALTH SCORE		**91**	**95**	**Low**
PRESENT ECOLOGICAL STATUS (PES)		**A/B**	**A**	
OVERALL CONFIDENCE		**Low**	**Low**	

TRAJECTORY OF CHANGE

*The Kosi Estuary is on a **negative trajectory** of change that is contributed to the following:*

- *As the human population in the surrounding areas increase, groundwater use and direct abstraction is expected to increase, unless actively managed.*
- *Similarly, increased population densities will increase direct resource abstraction and use (e.g. fishing, mangrove harvesting, crab collection) of the system.*
- *The traditional artisanal fishery (fish traps) is in the process of switching to a commercial fishery, which will put additional pressure on the fish and bait resources of the system.*
- *The invasive alien invertebrate species Tarebia granifera is a relatively new introduction to the system and is still increasing in abundance (density).*
- *Current ground water usage (abstraction and forestry) has increased the probability of mouth closure, which will have severe consequences on the biodiversity of the system, e.g. die back of mangroves.*

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

Estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an increase in the health score from a PES of 91 to 95 (see table above), which would raise the health score to an A Category. This suggests that non-flow related impacts have played some role in the degradation of the estuary to an A/B, but that some flow-related impacts are also driving the current condition.

OVERALL CONFIDENCE

Confidence levels for two of the four abiotic components were rated as Low, with one component rated as Medium. Three of the five biotic components had enough data to yield Medium Confidence assessments. However, the overall confidence assessment for this study is LOW as the hydrology and hydrodynamics are of low confidence.

ESTUARY IMPORTANCE

The Kosi estuarine system is unique in South Africa as a series of connected estuarine lakes with very clear subtropical waters and salinities ranging from fresh (0 psu) to near seawater (35 psu). Kosi is also the only estuarine system of significant size that flows into an area of coastal sea where coral reefs occur, a reflection of its location on the warm Agulhas influenced coast of KwaZulu-Natal near the South Africa / Mozambique border.

The Estuary Importance Score (EIS) takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account. Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. Estuary Importance was rated at 97, indicating that the estuary is rated as "Highly Important".

Estuarine Importance of the Kosi Estuary.

Criterion	Weight	Score
Estuary Size	15	100
Zonal Rarity Type	10	70
Habitat Diversity	25	100
Biodiversity Importance	25	100
Functional Importance	25	100
Estuary Importance Score		**97**

The Functional Importance of the Estuary is VERY HIGH. It serves as a very important movement corridor for invertebrates (e.g. Varuna litterata) and fish (e.g. eels) breeding in the sea. The system also serves as an important waypoint for Kingfish and Barracuda that uses the reef in the estuary mouth. From an estuarine connectivity perspective, Kosi Estuary links St Lucia and Maputo Bay along a 300 km coastline.

RECOMMENDED ECOLOGICAL CATEGORY

The Recommended Ecological Category (REC) represents the level of protection assigned to an estuary. The Present Ecological State (PES) sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of importance and level of protection or desired protection of a particular estuary. The PES for the Kosi Estuary is an A/B and the estuary is rated as "Highly Important" from a biodiversity perspective.

In addition, the Kosi falls within the iSimangaliso Wetland Park, a UNESCO World Heritage Site. The system forms part of the core set of priority estuaries in need of protection to achieve biodiversity targets in the 2011 National Estuaries Biodiversity Plan defined as part of the National Biodiversity Assessment 2011 (NBA 2011) (Turpie et al., 2012c). The NBA 2011 (Van Niekerk and Turpie 2012) recommended that the minimum Category for the Kosi be an A, that the system is granted partial no-take protection, and that 75 % of the estuary margin be undeveloped.

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

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

* BAS = Best Attainable State

Taking into account the current conditions (PES = A/B), the reversibility of some impacts, the ecological impotence and the conservation requirements of the Kosi Estuary, the REC for the system is an A Category.

ECOLOGICAL CATEGORIES ASSOCIATED WITH SCENARIOS

A summary of a range of water resource development scenarios that could affect the Kosi Estuary is provided below:

Summary of the change in low flow conditions to the Kosi Estuary from the Reference Condition to the Present State and future scenarios.

Scenario Description	*Total Freshwater input (x 10^6 m^3)*	*% Similar*
Reference (natural conditions)	*69.09*	*100*
Present uses (all use)	*63.79*	*92.0*
1: Lawful use	*65.87*	*95.3*
2a: Artificial breaching to address mouth closure (assume double abstraction and plantations)	*58.49*	*84.7*
2b: Allow for extended mouth closure (assume double abstraction and plantations)	*58.49*	*84.7*

Scenario 1 represents a 3% increase in freshwater input (surface water and groundwater) to the system through the curbing of illegal use of freshwater resources in the catchment.

Of particular concern, is the short simulation period used in this EWR assessment. The very limited time series covered by the freshwater simulation dataset did not allow for a strong correlation with the critical period of 1965/66 when estuary mouth closed. The simulated period is relatively similar in inflow volumes and therefore do not provide the study with sensitivity to a reduction to freshwater input. An additional concern is that the various groundwater reports available for the region indicate different impacts on the average groundwater level. Lack of long-term monitoring data precluded any of the studies from achieving a high confidence in groundwater and surface water input.

Nevertheless, the study teamed observed a 5 to 7 m decline in the water table during the February 2016 field visit, which is not reflected in the freshwater inflow data supplied for this study. An analysis of rainfall data indicates that since 2003 rainfall has not been significantly below the average for the region. Drought experienced in the wider region of northern KwaZulu-Nata therefore appears not to have been as significant a factor in the Kosi area. This in combination with current high salinity measurements highlights the potential impact of forestry and abstraction on the system. The observed drawdown in the groundwater table would present an additional stress to the ecological system as it would remove/reduce the buffering effect the groundwater input provides to the riparian vegetation, i.e. reduce salinity in sediments. Therefore, to provide for some indication of the consequences of mouth closure on the Kosi Estuarine Lake System two additional scenarios were developed (current abstraction and forestry were doubled to provide some resolution in the simulation period):

- *Scenario 2a: Assumes that the relevant authorities will artificial breach the system within 3 to 6 months of closure to prevent die-back of the mangroves. As a result of this* *management intervention, salinity is expected to increase to above 10 psu in Lake 3 and 1 psu in Lake 4 as a result of the open mouth state under low freshwater input conditions.*

- *Scenario 2b: Assume that the mouth will be allowed to remain closed until the system fills to its breaching capacity. Closure will last months to years. Salinity will be less than 5 psu in Lake 3 and 1 psu in Lake 4. No connection will exist with the sea for the duration of the closed period.*

The individual EHI scores, as well as the corresponding ecological category under different scenarios are provided in the Table below.

EHI scores and corresponding Ecological Categories under the different runoff scenarios.

COMPONENT	Weight	Present	Scenario 1	Scenario 2	Scenario 3	Confidence
Hydrology	25	90	94	81	81	L
Hydrodynamics and mouth condition	25	100	100	95	90	L
Water quality	25	94	94	64	88	L
Physical habitat alteration	25	95	95	94	94	L
Habitat health score		**95**	**96**	**83**	**88**	
Microalgae	20	95	95	70	70	L
Macrophytes	20	90	90	70	50	L
Invertebrates	20	75	85	50	65	L
Fish	20	80	82	62	67	L
Birds	20	92	92	50	50	L
Biotic health score		**86**	**89**	**60**	**60**	
ESTUARY HEALTH SCORE		**91**	**92**	**72**	**74**	**L**
ECOLOGICAL CATEGORY		**A/B**	**A/B**	**C**	**C/B**	

None of the Future scenarios achieves the REC. Scenario 1 shows an improvement in condition from the present, but the system remains in an A/B category.

Under Scenario 2a (mouth closure mitigated with artificial breaching) all components with the exception of the physical habitat shows a sharp decline in health. The overall the ecological health of the system declines to a C Category, with important socio-economic component like the fish declining to a C/D Category and the invertebrates declining to a D Category. The motivation for this decline in health is related to the reduced freshwater input, that in combination with artificial breaching, elevates the salinity in Lake 3 to between 5 and 10 psu during droughts. This in turn causes major tropic shifts in Lake 3 and Lake 4.

Under Scenario 2b (mouth remains closed for months to years) the system fares marginally better with an overall ecological category of a C/B. Under this scenario, salinities do not elevate above 5 psu in Lake 3, but extended mouth closure causes die-back of the mangroves and related ecosystem impacts. However, the macrophyte, invertebrate, and fish components still show a marked decline in condition and productivity from the present.

Both Scenario 2a and 2b holds severe ecological and socio-economic consequences for the Kosi Estuarine Lake System. The headline message is that mouth closure cannot be mitigated through artificial breaching in the absence of surface and groundwater input. During periods of low flow (winter) and droughts, freshwater input is critical in maintaining the salinity regime and mouth status of the system. Without this critical driver, the system and the ecosystem services it provides will experience a severe decline.

However, it should be stressed that there is a risk of mouth closure occurring even at the present water resource utilisation levels. The February 2016 field visit showed that the present freshwater input to the Kosi System is very low, resulting in a very constricted mouth (inlet) at present. Therefore the system is at a very high risk of closure if high wave condition were to develop at sea during the low flow season.

RECOMMENDED EWR SCENARIO

Scenario 1 is the recommend scenario to achieve the REC of an A in conjunction with the following key management actions:

- *Cap the groundwater utilisation especially during drought conditions, i.e. reduce plantations that decrease the winter freshwater input.*
- *Maintain the traditional subsistence fishery using traditional methods to sustainable levels. Traditional methods refer to the back facing traps, but exclude gear such as diving masks and spear guns, augmented baskets (lined with nets) and gill nets.*
- *Control and monitoring the crab harvesting (at present uncontrolled and sold in Durban).*
- *Control resource utilisation of reeds, sedges, and mangroves through the introduction of rest areas.*
- *Control the burning of the flood plain, swamp forest and mangroves through for example an education programme.*
- *Control the clearing and draining of the peatlands for gardening.*
- *Control the usage of DDT, herbicides and pesticides in the catchment. There is a growing concern that the use of DDT and organic phosphates will have an increasing impact on the system because of their long resident time and vulnerability of the lake system.*

A key concern under the present and future scenarios is the impact that mouth closure would have on the system.

CONSEQUENCES OF MOUTH CLOSURE:

If the mouth of Kosi Estuarine Lake System were to close for an extended period the following impacts will be expected:

- Saline water will backflood into the surrounding landscape killing of some of the surrounding freshwater vegetation. The rising water table can also influence some shallow wells providing water to the surrounding communities. There will potentially also be a loss of surrounding subsistence agricultural land.
- Mouth closure will cause extensive die back of mangroves within a short time period (i.e. about 3 months).
- Loss of connectivity to the sea will cause loss of nursery function for important estuarine associated fish species.

Key findings of the study are summarised in the appendixes to the main report:

- **Appendix A Data available on the Kosi Estuary used for the study**
- **Appendix B Specialist report Abiotic Report**
- **Appendix C Specialist report Microalgae**

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ABBREVIATIONS AND ACRONYMS

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

GLOSSARY OF TERMS

Ecological Category	Defines the ecological condition of a river in terms of the deviation of biophysical components from the reference condition. There are six Ecological Categories that range from A (natural) to F (critically modified).
EcoClassification	The determination and categorisation of the Present Ecological Status or various biophysical attributes of rivers relative to the natural and/or reference condition.
EcoStatus	The totality of features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services.
Ecological Water Requirements	The pattern (magnitude, timing and duration) and quality of flow needed to maintain an aquatic ecosystem in a particular condition (Ecological Category).
Ecological Reserve	The quantity and quality of water required to satisfy basic human needs by securing a basic water supply and in order to ensure ecologically sustainable development and use of water resources, as prescribed in the NWA.
EcoSpecs	Clear and measurable specifications of ecological attributes (e.g. water quality, flow, biological integrity) that defines the Ecological Category.
Present Ecological Status	The degree to which ecological conditions have been modified from reference condition, based on water quality, biota and habitat information that is scored on a six point scale from A (natural) to F (critically modified).
Reference conditions	Natural ecological conditions prior to anthropogenic disturbance.

1 INTRODUCTION

1.1 Background to the Study

The Chief Directorate: Resource Directed Measures 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 Usutu 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 in the area affecting the availability of water.

Preliminary Reserve determinations are required to assist the Department of Water and Sanitation (DWA) in making informed decisions regarding the authorisations of future water use and the magnitude of the impacts of the proposed developments on the water resources in the WMA, and to provide the input data for Classification of the area's water resources, and eventual gazetting of the Reserve (DWAF 1999).

DWA appointed Tlou Consulting to undertake the project in July 2013.

1.2 Study objectives

The objectives of the study are to:

- determine the Ecological Reserve (DWAF 1999), at various levels of detail, for the Nyoni, Amatikulu, Mlalazi, Mhlatuze, Mfolozi, 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 St Lucia/Mfolozi, Estuary System;
- determine the Ecological Reserve, at a Rapid level for the Mlalazi Estuary;
- determine the Ecological Reserve, at a Rapid level for the Kosi 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 Usutu/Mhlatuze WMA;
- outline the socio-economic water use in the Usutu/Mhlatuze WMA;
- build the capacity of team members and stakeholders with respect to EWR determinations and the ecological Reserve.

1.3 This report

This report details the processes and outcomes of a Rapid Environmental Water Requirements (EWR) Determination for the Kosi Estuarine Lake System.

1.4 Ecological water requirement method for estuaries

Methods to determine the environmental flow requirement of estuaries were established soon after the promulgation of the NWA in 1998. The so-called "Preliminary Reserve Method" involves setting a Recommended Ecological Category (i.e. desired state), recommended Ecological Reserve (i.e. flow allocation to achieve the desired state) and recommended Resource Quality Objectives for a resource on the basis of its present health status and its ecological importance. The method follows a generic methodology that can be carried out at different levels of effort (e.g. rapid, intermediate or comprehensive). The official method for estuaries (Version 2) is documented in DWA (2008). In 2013, a Version 3 of the method was published as part of a Water Research Commission study (Turpie *et al*. 2012a). At the start of this project it was decided that Version 2 would be used in the study (DWAF 2008).

The generic steps of the official "Ecological Reserve Method" for estuaries were applied as follows:

Step 1: Initiate study defining the study area, project team and level of study (confirmed in the **inception report** of this study)

Step 2: Delineate the geographical boundaries of the resource units (confirmed in the **delineation report** of this study)

Step 3a: Determine the **Present Ecological Status** (PES) of resource health (water quantity, water quality, habitat and biota) assessed in terms of the degree of similarity to the reference condition (referring to natural, unimpacted characteristics of a water resource, and must represent a stable baseline based on expert judgement in conjunction with local knowledge and historical data). An Estuarine Health Index (EHI) is used to evaluate the current condition of the estuary (Table 1.1).

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

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

Table 1.1 Estuarine Health Index (EHI) scoring system.

VARIABLE	SCORE	WEIGHT	WEIGHTED SCORE
Hydrology	…	25	…
Hydrodynamics and mouth condition	…	25	…
Water quality	…	25	…
Physical habitat alteration	…	25	…
Habitat health score			**…**
Microalgae	…	20	…
Macrophytes	78	20	…
Invertebrates	…	20	…
Fish	…	20	…
Birds	…	20	…
Biotic health score			**…**
Estuary Health Score Mean (Habitat health, Biological health)			**…**

Table 1.2 Translation of EHI scores into ecological classes.

EHI SCORE	PES	GENERAL DESCRIPTION
91 – 100	A	Unmodified, or approximates natural condition; the natural abiotic template should not be modified. The characteristics of the resource should be determined by 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
76 – 90	B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged. Only a small risk of 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.
61 – 75	C	Moderately modified. A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the wellbeing and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least partly be mitigated by the presence of sufficient refuge areas.
41 – 60	D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred. Large risk of modifying the abiotic template and exceeding the resource base may be allowed. Risk to the well-being and survival of intolerant biota depending on (the nature of the disturbance) may be allowed to generally increase substantially with resulting low abundances and frequency of occurrence, and a reduction of resilience and adaptability at a large number of localities. However, the associated increase in the abundance of tolerant species must not be allowed to assume pest proportions. The impact of local and acute disturbances must at least to some extent be mitigated by refuge areas.
21 – 40	E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive
0 – 20	F	Critically modified. Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible

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

Table 1.3 Estuary Importance scoring system.

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

Table 1.4 Estuarine Importance rating system.

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

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

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

Protection Status and Importance	REC	Policy basis
Protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area (based on complementarity)		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category
Important	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D category

* BAS = Best Attainable State

An estuary cannot be allocated an REC below a category "D". Therefore, systems with a PES in categories "E" or "F" need to be managed towards achieving at least a REC of "D".

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

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

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

1.5 Definition of confidence levels

The level of available historical data in combination with the level of effort expended during the assessment determines the level of confidence of the study (see Appendix A). Three levels of study have been recognised in the past in terms of the effort expended during the assessment – rapid, intermediate and comprehensive.

The brief for the current study was to undertake a Rapid Assessment of the Kosi Estuary. One reconnaissance level field trip was undertaken during February 2016 for the study team to familiarise themselves with the system. Apart from the invertebrates and fish, almost no historical data was available. No long-term river inflow or ground water data was available to be able to benchmark abiotic processes.

As a result, the confidence of the study is LOW. This can only be remedied with some comprehensive and long-term data collection on the system. Criteria for the confidence limits attached to statements in this study are:

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

1.6 Assumptions and limitations for this study

The following assumptions and limitations should be taken into account:

- The accuracy and confidence of an Estuarine Ecological Water Requirements study is strongly dependent on the quality of the hydrology. The overall confidence in the hydrology supplied to the estuarine study team is of a LOW Level (<40%). Lack of monitoring data prevented the groundwater specialist from calibrating the groundwater and surface water assumptions.

- Of particular concern is the very short simulation period used in this study. The very limited period covered by the simulation did not allow for a strong correlation with the critical period of 1965/66 when mouth closure occurred.
- An additional concern is that the various groundwater reports available for the region indicate different impacts on the average groundwater table. Lack of long-term monitoring data precluded any of the studies from achieving a high confidence. This concern is exacerbated by the fact that the study teamed observed a 5 to 7 m decline in the water table during the February 2016 field visit which was not reflected in the freshwater inflow data supplied for this study.

1.7 Structure of this report

The report is structured as follows:

Chapter 1 Provides an overview of EWR methods and confidence of the study.

Chapter 2 Summarises important background information related to the hydrological characteristics, catchment characteristics and land-use, as well as human pressures affecting the estuary.

Chapter 3 Defines the geographical boundaries of the study area, as well as the zoning and typical abiotic states adopted for this estuary.

Chapter 4 Provides a baseline ecological and health assessment of the estuary. It describes each of the abiotic and biotic aspects of the estuary, from hydrology to birds, describing an understanding of the present situation and estimation of the reference condition. The health state of each component is computed using the Estuary Health Index (EHI).

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

Chapter 6 Combines the EHI score with the Estuarine Importance Score (EIS) for the system to determine the Recommended Ecological Category.

Chapter 7 Describes the ecological consequences of various future flow scenarios, and determines the Ecological Category for each of these using the EHI.

Chapter 8 Concludes with the recommendations on the ecological water requirements for the estuary, as well as recommended resource quality objectives (ecological specifications). Finally, monitoring requirements to improve the confidence of the EWR assessment is recommended.

2 BACKGROUND INFORMATION

2.1 Catchment characteristics

The Kosi Catchment covers the surface and groundwater catchments of the Kosi Lakes system as shown in Figure 2.1. The area lies along the northern extreme part of the Zululand coastal plain of South Africa.

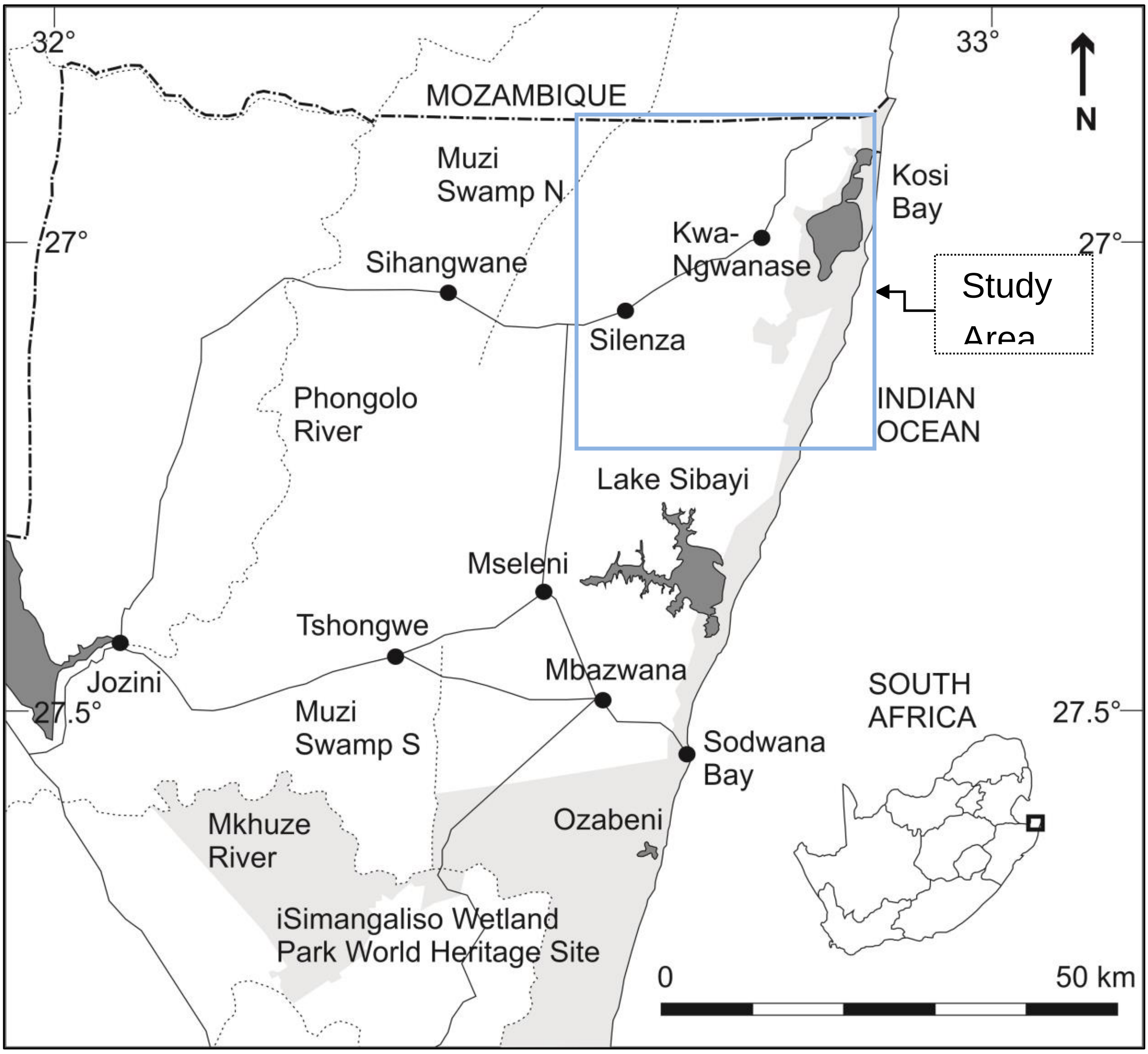


Figure 2.1 Location map of the study area in north-eastern South Africa

The Kosi Lakes System is located within the Usutu to Mhlathuze Water Management Area (WMA), specifically within the north-eastern corner of Quaternary catchment W70A. It is bounded in the west by the Pongola River drainage system, in the north by the Mozambique-South African Boundary, in the east by the Indian Ocean and in the south by the Lake Sibayi catchment. Due to the flat nature of the topography, the study area is characterised by an ill-defined drainage system. Two perennial rivers, the Sihadhla and Gesiza (Swamanzi), drain into Lake Amanzimnyana and Lake Nhlange, respectively (Figure 2.2). The semi-perennial KuKhalwe stream(s) drains into the estuary from the northwest. The permeable nature of the cover sands, the relatively flat topography and shallow water table situations have resulted in a close relationship between surface waters (i.e. lakes, streams, and wetlands) and the groundwater.

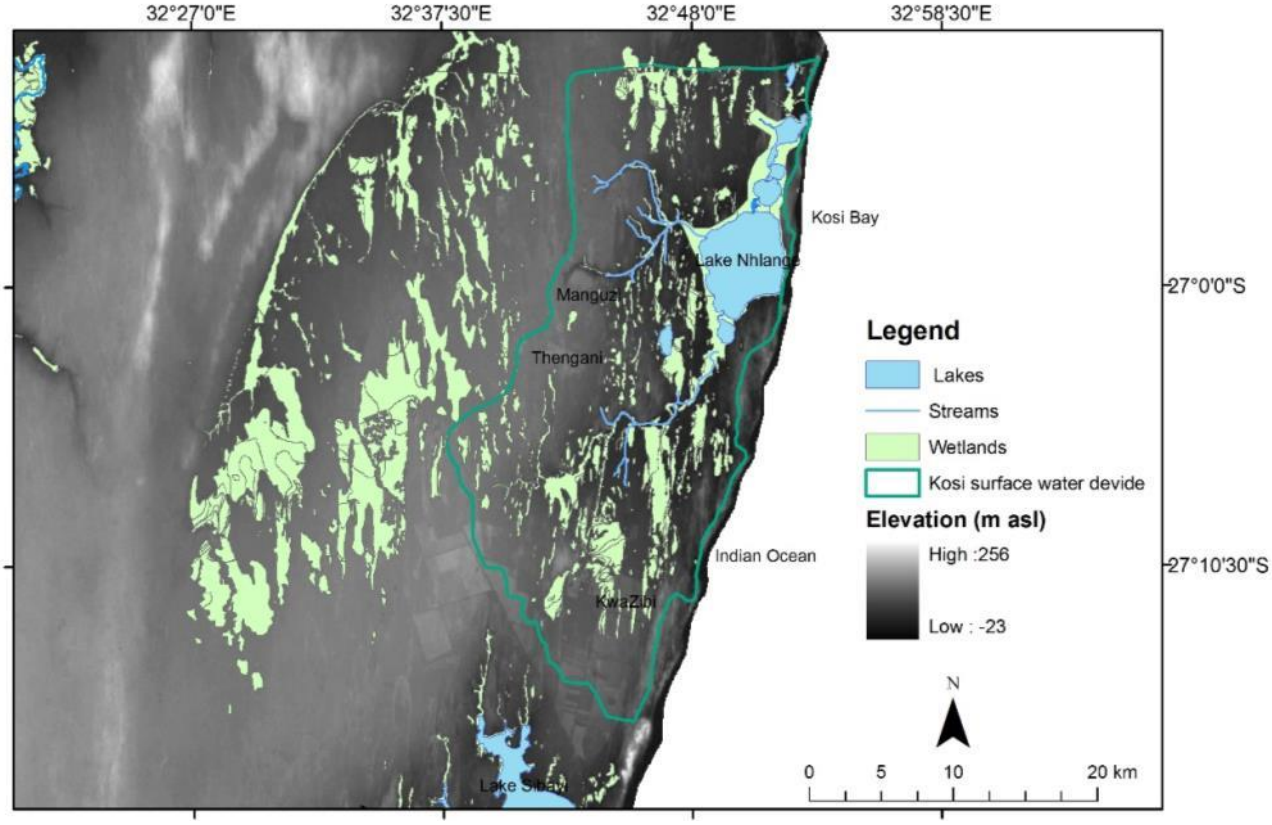


Figure 2.2 Drainage map of the Kosi lakes system.

2.2 Climate

The climate of the study area is humid sub-tropical, with warm to hot summers and mild winters. A strong seasonal precipitation pattern is observed in the region with most of the rainfall occurring during the summer months, mainly from January to March (Figure 2.3). There is a strong precipitation gradient to the west or an increase in precipitation in an easterly direction over the study area. Precipitation is found to increase from approximately 700 mm/a along the western margin of the study area to approximately 1 000 mm/a along the coast. Pitman and Hutchison (1975) reported precipitation distribution for the Lake Sibayi catchment which ranged from 700 mm/a in the southwest of the catchment to 1 200 mm/a in the east.

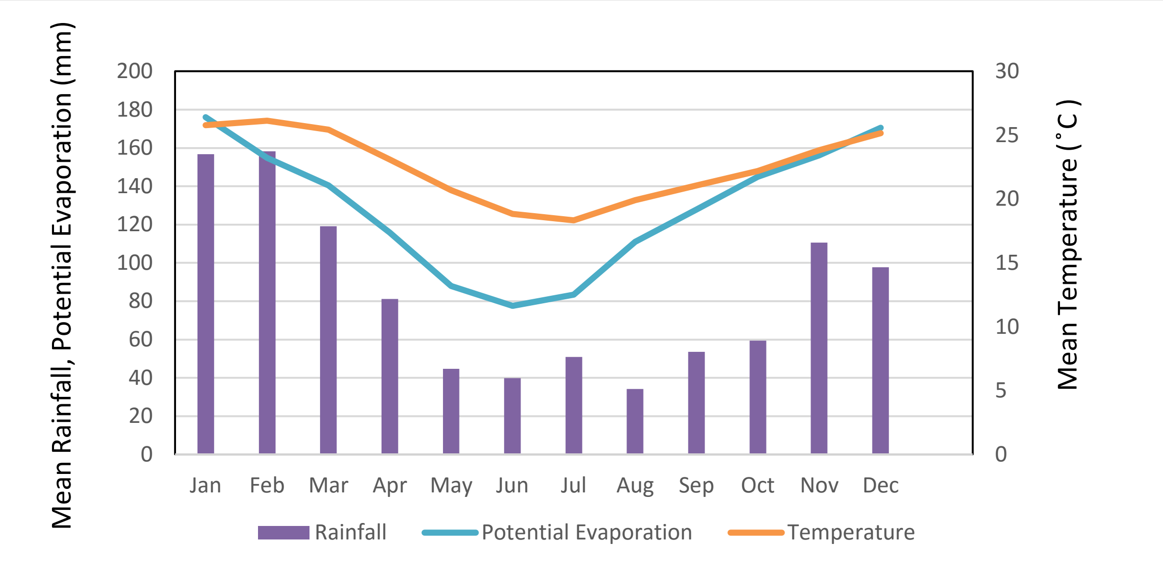


Figure 2.3 Mean monthly rainfall data from Ingwavuma Kosi station, mean monthly temperature data from Mbazwana airfield station and pan evaporation data at W7E004 (Demlie, 2015).

2.3 Land-cover

The area is characterised by a chain of barrier lakes, lagoons and swamps, situated behind high vegetated dunes.

The natural vegetation of the area consists of a mosaic of coastal thicket, Licuati sand forest, woodlands, woody edaphic grassland and patches of hygrophilous grassland, reed swamps and swamp forests (Matthews et al., 2001). Commercial plantations cover a substantial part of the southern Kosi Bay catchment (about 67km^2) (Figure 2.4). The area is characterized by soil cover that is associated with the Maputaland Group dune sands including the dune cordon. Thus, the broad soil patterns can be described as deep, grey, structure-less and mainly non-calcareous sandy soils, which are excessively drained.

2.4 Hydrogeology of the Kosi Bay Lakes System

The Zululand coastal plain which is underlain by unconsolidated to semi-consolidated sediments hosts the most extensive and the largest primary aquifer in South Africa. The majority of the sedimentary succession above the Cretaceous floor rocks can all be treated as potential aquifer units. The Quaternary sediments that cover the coastal plain are highly permeable, promote rapid recharge to the aquifer and have strong interactions with wetland and other surface water bodies, including lakes in the region. Borehole data have indicated that the entire succession is generally fully saturated from the interface with the Cretaceous formations up to a generally shallow groundwater level.

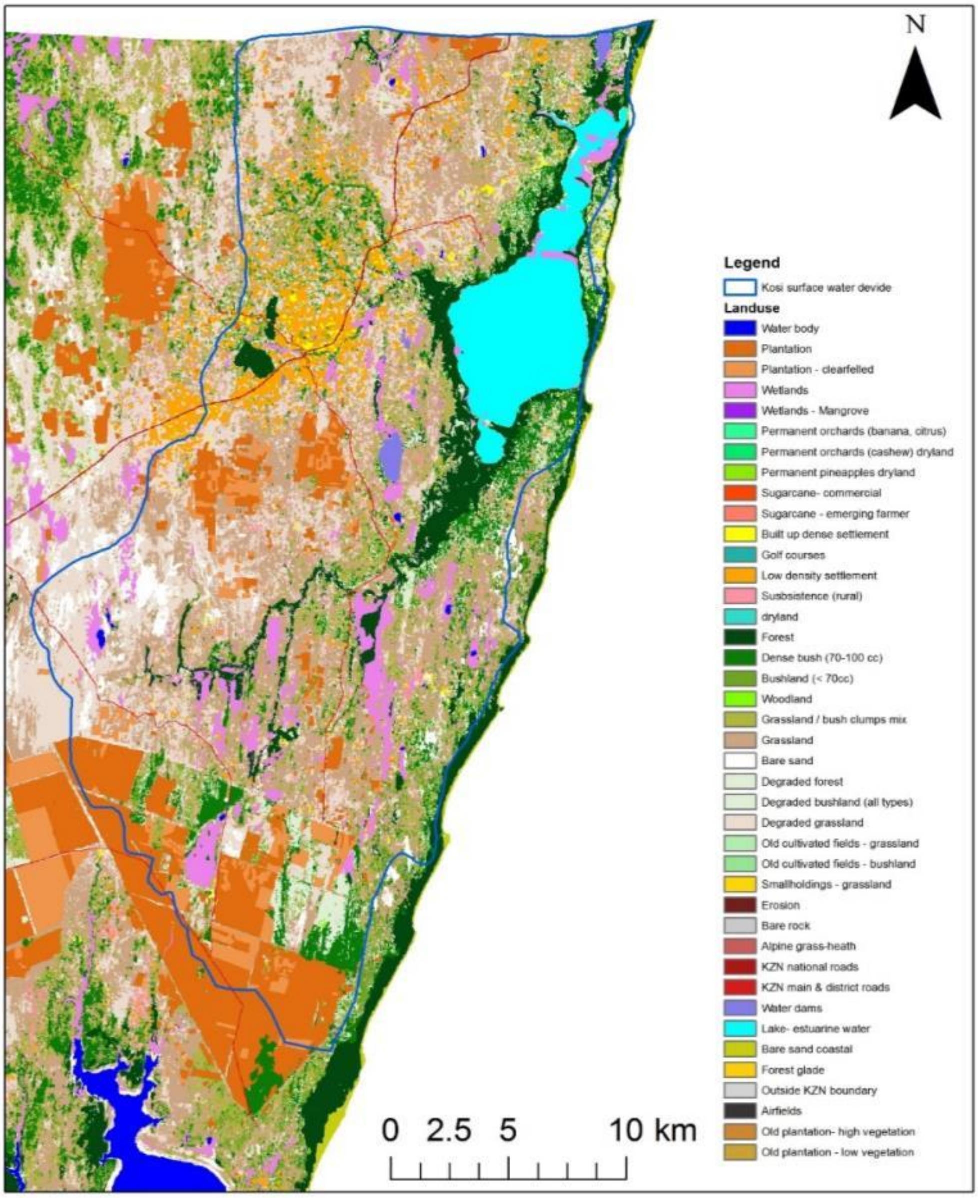


Figure 2.4 Land use and land cover map of the North Eastern KZN (modified from Ezemvelo KZN spatial datasets, 2008) (Demlie, 2015).

The coastal plain can be characterised by two major aquifers and an aquitard, while the regional Cretaceous basement acts as an aquiclude. The two most productive aquifer systems are the shallow Pleistocene KwaMbonambi Formation and the deep Mio-Pliocene Port Durnford and Uloa/ Umkwelane Formations. Due to the low transmissivity and high adhesive forces of the overlying Kosi Bay Formation, it acts as an aquitard, creating a leaky confined aquifer underlying it. Moreover, the large storage capacity afforded by the Kosi Bay Formation makes it a storage reservoir for the underlying Port Durnford and Uloa Formations.

The Uloa Formation is overlain by a thick succession of relatively low-yielding silty sands and silts, of the Late Pleistocene Kosi Bay Formation (Demlie, 2015). However, the Kosi Bay Formation could also potentially be a good aquifer, effectively connecting the overlying unconfined unit to the lower aquifer. The hydraulic conductivity of this unit ranges from 4 m/d to 5 m/d (Demlie, 2015). The uppermost KwaMbonambi Formation extends to variable depths and is frequently exploited by the local community through shallow wells and hand-dug wells indicated sustainable yields of between 190 m^3/d and 1 700 m^3/d and average transmissivity of 1 490 m^2/d.

2.5 Groundwater levels and groundwater flow direction

The groundwater level contour map for the catchment (Figure 2.5) indicates that there appears to be a close relationship between water levels and surface topography and groundwater flows from west (along the western boundary of the lakes catchment) towards the lakes. Because of the presence of numerous wetlands and pans, the regional flow pattern is somewhat distorted with flow lines directed towards the wetlands and pans and eventually to the lakes. Near the western catchment boundaries of the lakes, the groundwater elevation is around 70-80 m amsl (well above the stage of the Kosi Bay Lakes) from where it drops towards the coast to the altitude of the surface of the lakes. Groundwater levels and flow patterns are affected by the presence of the various wetlands and lakes. The surface water divide and groundwater divide do not coincide. The groundwater contributing area to the Lakes is approximately 331 km^2, which is much lower than the 609 km^2 surface water catchment of the lakes.

Environmental isotope measurements in and around the study area show that the aquifers are recharged from rainfall. Most of this recharge is abstracted for various purposes and that that remains is stored within the aquifers and discharges into the lakes, wetlands and the sea. Recharge is estimated at 13% of the mean annual precipitation (MAP). Groundwater gradients (Figure 2.5) indicate that flow direction towards the lakes and the Indian Ocean.

Groundwater in the area is discharged in the form of abstraction for domestic and agricultural use, natural evapotranspiration, forestry and natural outflow to the lake and ocean. Groundwater use within the Kosi catchment is limited to rural water supply, small-scale irrigation and water use by commercial forestry. The registered groundwater uses for the study area account for 1 645 204 m^3/a, located mainly around the town of Manguzi. However, a brief hydrocensus undertaken in 2013 indicates many unregistered wells, indicating higher levels of groundwater abstraction, mainly from shallow and intermediate depth wells (Demlie, 2015). These wells are scattered throughout the region. Moreover, the total registered water use by forestry up until April 2010 was about 6.5 x10^6 m^3/a (Table 2.1). However, a minimum of 65 km^2 area of the catchment of the lakes is covered by commercial plantations which might use more than the registered groundwater use. The balance of the annual groundwater recharge that is left after groundwater abstraction is expected to be discharged into streams, wetlands, lakes and to the sea.

Table 2.1 Groundwater use by various sectors within the Kosi lakes catchment.

GROUNDWATER USE				
WARMS (Boreholes for domestic use) (Mm^3/a)	WARMS (only for Forestry) (Mm^3/a)	Hydrocensus (estimated domestic use) (Mm^3/a)	Irrigation (Mm^3/a)	Total (Mm^3/a)
1.62	6.5	2.75	1	11.75

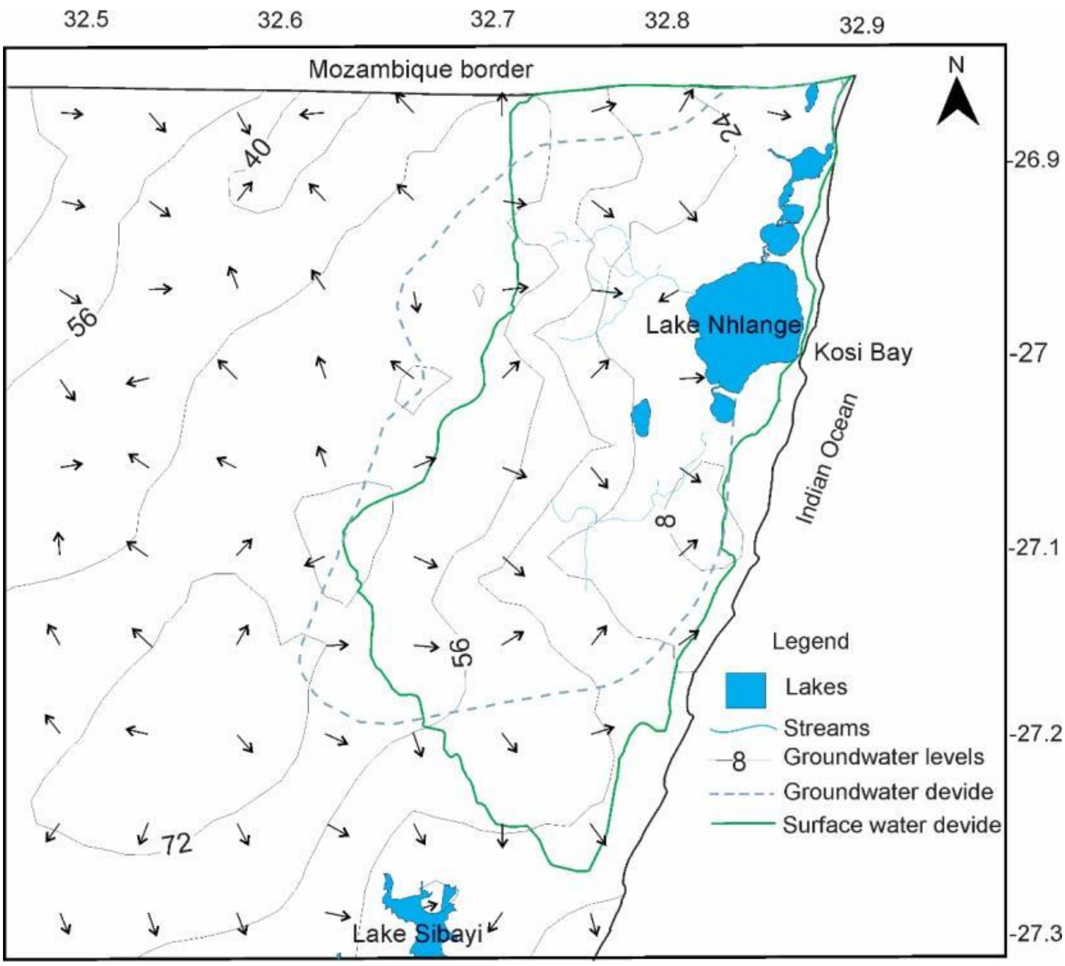


Figure 2.5 Groundwater level contour map and groundwater flow conditions for the Kosi catchment.

2.6 Human activities affecting the estuary (Pressures)

Table 2.2 provides a summary of significant flow related pressures on the Kosi Estuary, while Table 2.3 summarises key non-flow related pressures.

Table 2.2 Pressures related to flow modification.

ACTIVITY	PRESENT	DESCRIPTION OF IMPACT
Water abstraction and dams (including farm dams)	✓	Abstraction for domestic and agricultural use, natural evapotranspiration, forestry.
Infestation by invasive alien plants	✓	There are some alien invasive plants in the catchment that leads to flow reduction.

Table 2.3 Pressures, other than modification of river inflow presently affecting estuary.

ACTIVITY	PRESENT	DESCRIPTION OF IMPACT
Agricultural and pastoral run-off containing fertilisers, pesticides and herbicides		
Municipal WWTW		
Bridge(s)		
Artificial breaching	✓	Once in 1966 after the mouth was closed for 5 months, before Cyclone Claude.
Low-lying developments	✓	Some wells are in the estuarine functional zone.
Recreational fishing	✓	Limited. Mostly in Lake 1 and Lake 2, and to a lesser degree in Lake 3.
Subsistence fishing (e.g. fishtrap fishery)	✓	Very high as a result of the fish traps, and other means of harvesting fishes.
Illegal fishing (Poaching)	✓	Yes, significant high levels using in appropriate gear.
Bait collection	✓	Mostly in Lake 1 and Lake 2.
Harvesting of reeds, sedges and mangroves	✓	Extensive harvesting.
Grazing and trampling of riparian vegetation	✓	Cattle feed on the surrounding vegetation and some areas are burnt to provide grazing
Translocated or alien fauna and flora	✓	Invasive alien invertebrate *Tarebia granifera* displacing indigenous species
Recreational disturbance of waterbirds	✓	In the lower reaches of the system.

3 DELINEATION OF ESTUARY

3.1 Geographical boundaries

The Kosi Estuary is located on the east coast of South Africa, approximately 2 km south of the Mozambique border. The estuary is sited on the edge of the flat northern KwaZulu-Natal coastal plain, about 75 km from the Lebombo Mountain range. Except for the mouth, the system is separated from the sea by a high, vegetated barrier dune complex that reaches 130 m in height.

The Kosi system is a series of interconnected estuarine lakes. These lakes from north to south are called Makhawulani (Lake 1), Mpungwini (Lake 2), Nhlange (Lake 3) and Amanzimnyana (Lake 4). The estuary forms a broad channel (tidal flat) that opens to the Indian Ocean. Three rivers feed the system, KuKhalwe inlet into the estuary, the Sihadhla River into Lake 4 and the Swamanzi River into Lake 3.

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

Downstream boundary:	Estuary mouth 26°53'41.25"S 32°52'48.43"E
Upstream boundary:	27° 4'7.60"S 32°48'5.15"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

Figure 3.1 Geographical boundaries of the Kosi Estuary based on the Estuary Functional Zone.

3.2 Zonation of the Kosi Estuary

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

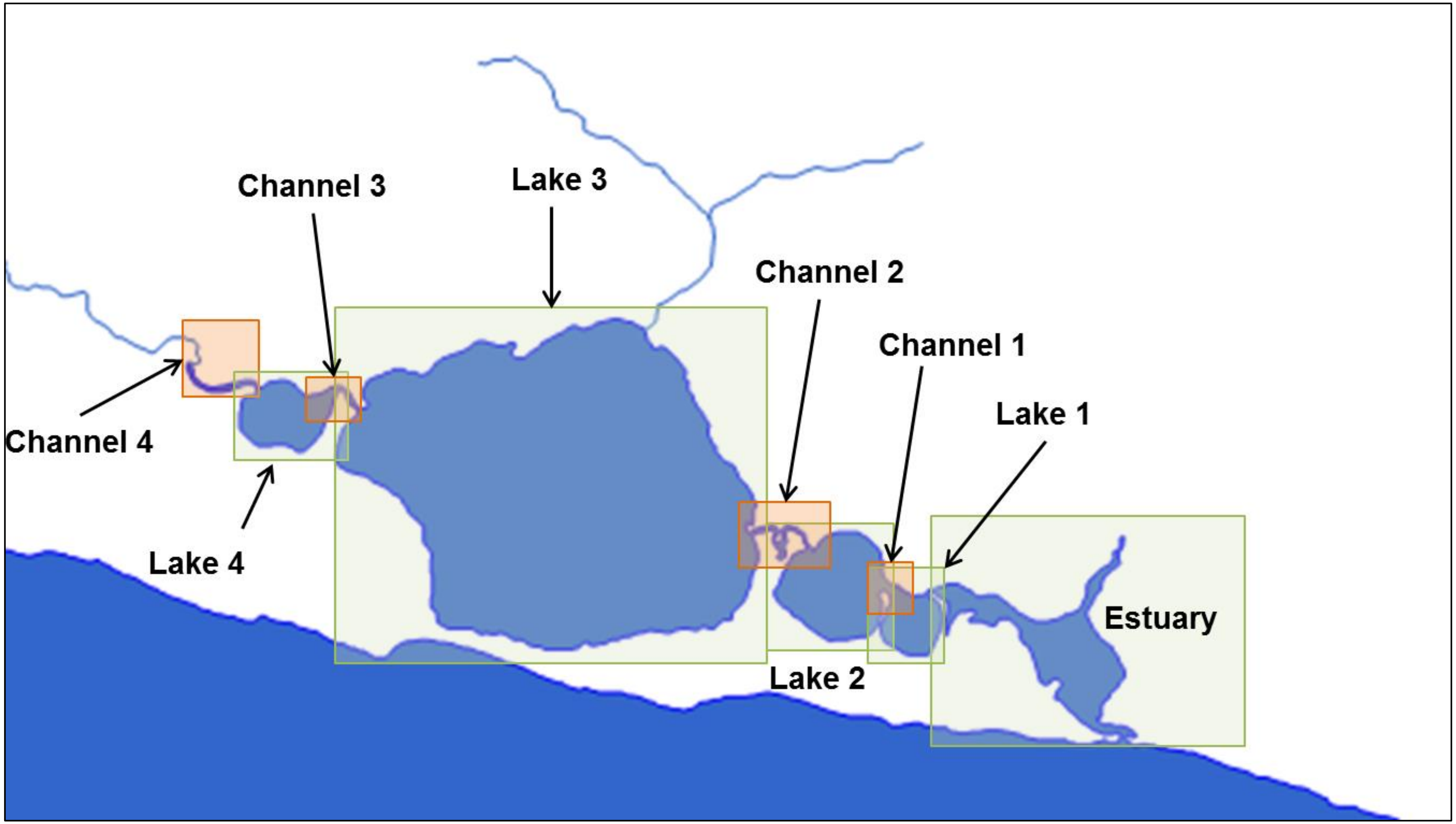


Figure 3.2 Zonation of the Kosi Estuary.

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

Table 3.1 Key features of the Kosi Estuary zonation.

Parameter	Zone								
	Estuary	**Lake 1**	**Channel 1**	**Lake 2**	**Channel 2**	**Lake 3**	**Channel 3**	**Lake 4**	**Channel 4**
Code	Est	L1	C1	L2	C2	L3	C3	L4	C4
Common name		Makhawulani	Channel between Lakes 1 and 2	Mpungwini	Mthando channel	Nhlange	Ntolweni Channel	Amanzimnyana	Sihadhla riverine section
Surface area (km^2)	3.1	1.0	<0.1	2.8	<0.1	37.7	<0.1	1.5	<0.1
Relative weighting (%) derived from area/volume estimates	5	5	1	10	2	70	1	5	1
Depth (m)	1.0 -1.5	8 m (max)		20 (max) 8 (mean)	1-2 (max)	32 (max) 7 (mean)		2 (max)	1.5-3.0
Mixing process	Tides	Wind and tides	Neap-spring cycle	Wind and tides	Neap-spring cycle	Wind	Neap-spring cycle	Wind	River inflow
Organics on bottom	Very little	Yes, in deeper area	Some	Yes, in deeper area	Some	Yes, in deeper area	Some	Significant	Significant
Unique vegetation	Seagrass Mangroves	Mangroves	Mangroves	Mangroves		Diversity submerged macrophytes and algal mats at depth		Diversity submerged macrophytes	

Note that Lake Zilondo is not tidal or saline. It was therefore not included as part of the system in the Rapid Kosi Estuary EWR assessment, but dealt with as a feeder system (similar to a river). However, as it is connected to the larger system, higher confidence level studies in future may require a more detailed assessment to achieve the desired level of confidence in the overall results.

3.3 Typical abiotic states

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

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

State	Description
State 1: Open, fresh	A weak marine influence is confined to Lakes 1 and 2. Strong statification develops in Lakes 1 and 2, with surface salinity fresh to brackish. Lake levels are elevated above sea level with a strong netto outflow.
State 2: Open, saline	The strong marine influence is confined to Lakes 1 and 2, with seasonal elavation in salinity. Lake levels similiar to that of sea level. Strong tidal flows observed.
State 3: Open, very saline	The system shows a strong marine influence due to reduced freshwater inflow over long period. Marine influence detected in all lakes. Lake levels at sea level or slightly below.
State 4: Closed	The estuary mouth is closed for weeks to months. System shows a strong marine influence. Lake levels rise to above that of sea level as a result of back flooding.

The transition between the different states will not be instantaneous, but will take place gradually. To assess the occurrence and duration of the different abiotic states selected for the estuary during the different scenarios colour coding (indicated above) was used to highlight visually the occurrence of the various abiotic states between different scenarios. A summary of the typical physical and water quality characteristics of different abiotic states in the Kosi is provided in Chapter 4.

4 ECOLOGICAL BASELINE AND HEALTH ASSESSMENT

4.1 Hydrology

4.1.1 Baseline description

According to the hydrological data provided for this study, the present day freshwater inflow into the Kosi Estuary is 63.7 Million m^3. This is a decrease of 8% compared to the natural freshwater inflow of 69.1 Million m^3. The mean monthly surface and groundwater contributions for the Present State and Reference Condition, derived from the 25-year simulated data set, are provided in Table 4.1 to Table 4.3.

Table 4.1 A summary of the monthly surface water volume (in $10^6 m^3$) distribution under the Reference and Present State.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1997	10.66	1.93	4.86	2.44	2.27	2.05	1.88	2.87	2.12	2.58	12.26	3.78	49.69
1998	4.59	5.97	2.67	1.41	0.39	1.19	1.22	0.13	0.96	2.66	1.17	3.69	26.05
1999	6.32	13.17	4.13	1.89	0.49	0.03	1.15	1.88	2.59	3.14	6.73	2.87	44.38
2000	7.74	9.82	13.04	1.94	1.85	0.58	1.73	0.15	4.95	3.23	11.01	3.09	59.12
2001	4.35	8.53	2.95	1.55	0.72	1.48	1.15	0.07	1.21	1.89	3.40	4.03	31.32
2002	1.15	0.78	1.21	2.53	0.05	1.53	1.81	0.59	0.42	0.87	1.29	2.69	14.91
2003	0.68	4.24	0.99	0.74	1.75	1.19	2.11	0.20	1.04	0.94	3.04	1.94	18.85
2004	5.52	4.55	5.13	4.12	0.45	0.38	1.68	0.82	1.16	0.89	4.65	1.81	31.17
2005	6.00	1.89	5.66	2.52	1.60	0.17	1.30	0.07	1.05	0.58	5.80	1.38	28.01
2006	2.47	3.12	2.10	4.19	0.70	1.97	0.04	2.77	0.64	0.91	3.82	6.87	29.60
2007	1.19	1.38	2.88	6.98	0.12	2.94	2.79	0.55	1.37	1.34	6.49	5.90	33.93
2008	1.19	1.88	2.27	2.87	0.38	6.28	1.18	0.93	1.05	0.15	1.41	2.36	21.96
2009	6.77	4.10	1.87	1.11	1.89	1.39	0.04	0.21	0.45	1.82	2.58	2.54	24.78
2010	5.66	2.49	2.90	4.58	1.12	1.09	4.57	0.62	0.16	3.34	5.32	3.79	35.64
2011	8.37	2.12	0.09	1.73	1.05	1.51	5.78	1.39	0.26	2.70	1.98	1.99	28.97
2012	1.67	3.08	10.06	1.03	0.05	0.06	0.68	0.79	9.20	1.71	1.90	1.45	31.69
2013	5.31	0.58	1.35	2.47	0.18	0.61	1.55	2.51	0.48	2.79	2.47	5.46	25.76
2014	2.36	3.81	13.01	0.70	0.32	0.18	1.55	0.27	0.11	1.30	2.26	1.35	27.23
2015	3.95	2.79	2.79	0.69	0.09	0.64	0.77	0.13					
												Total surface water inflow	31.28

Table 4.2 A summary of the ground water monthly volume (in 10^6m^3) distribution under the Reference Condition.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1997								4.04	2.99	3.65	17.31	5.33	
1998	6.48	8.43	3.77	0.00	0.00	1.68	1.72	0.00	0.00	3.76	0.00	5.21	31.05
1999	8.92	18.59	5.83	2.67	0.00	0.00	1.62	2.65	3.66	4.43	9.51	4.05	61.91
2000	10.92	13.87	18.41	2.74	2.62	0.00	2.44	0.00	6.98	4.56	15.54	4.36	82.43
2001	6.14	12.04	4.16	2.18	0.00	2.08	1.63	0.00	0.00	2.67	4.80	5.69	41.39
2002	0.00	0.00	0.00	3.57	0.00	2.16	2.56	0.00	0.00	0.00	0.00	3.80	12.09
2003	0.00	5.99	0.00	0.00	2.47	1.68	2.98	0.00	0.00	0.00	4.29	0.00	17.41
2004	7.79	6.42	7.24	5.81	0.00	0.00	2.38	0.00	0.00	0.00	6.57	0.00	36.20
2005	8.48	2.66	7.99	3.55	2.25	0.00	1.84	0.00	0.00	0.00	8.18	0.00	34.96
2006	3.48	4.40	2.97	5.92	0.00	2.78	0.00	3.92	0.00	0.00	5.39	9.70	38.55
2007	0.00	0.00	4.06	9.85	0.00	4.15	3.94	0.00	1.94	0.00	9.16	8.33	41.43
2008	0.00	2.65	3.21	4.06	0.00	8.87	1.67	0.00	0.00	0.00	0.00	3.33	23.79
2009	9.56	5.79	2.64	0.00	2.67	1.97	0.00	0.00	0.00	2.57	3.65	3.59	32.44
2010	7.99	3.52	4.09	6.47	1.58	1.53	6.45	0.00	0.00	4.72	7.51	5.36	49.21
2011	11.82	2.99	0.00	2.44	0.00	2.13	8.15	1.97	0.00	3.81	2.80	2.81	38.92
2012	0.00	4.35	14.20	0.00	0.00	0.00	0.00	0.00	12.99	2.41	2.68	0.00	36.62
2013	7.50	0.00	0.00	3.48	0.00	0.00	2.19	3.55	0.00	3.93	3.49	7.70	31.84
2014	3.33	5.38	18.37	0.00	0.00	0.00	2.19	0.00	0.00	0.00	3.18	0.00	32.46
2015	5.58	3.94	3.94	0.00	0.00	0.00	0.00	0.00					
	Annual ground water inflow												37.81

Table 4.3 A summary of the ground water monthly volume (in 10^6m^3) distribution under the Present State.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1997								3.71	1.98	2.36	16.89	4.52	
1998	6.18	8.15	2.24	0.00	0.00	0.86	0.72	0.00	0.00	2.60	0.00	4.35	25.09
1999	8.64	18.31	5.58	1.48	0.00	0.00	0.60	1.56	2.53	3.38	9.09	2.75	53.92
2000	10.64	13.59	18.22	1.81	1.78	0.00	2.03	0.00	6.56	4.14	15.12	3.04	76.94
2001	5.60	11.76	3.22	0.99	0.00	1.71	0.82	0.00	0.00	1.22	4.15	4.97	34.44
2002	0.00	0.00	0.00	2.67	0.00	1.76	2.20	0.00	0.00	0.00	0.00	2.34	8.97
2003	0.00	5.61	0.00	0.00	1.46	1.16	2.76	0.00	0.00	0.00	3.12	0.00	14.12
2004	7.51	6.14	7.05	5.63	0.00	0.00	1.90	0.00	0.00	0.00	6.15	0.00	34.37
2005	8.20	0.88	7.80	2.94	1.15	0.00	1.08	0.00	0.00	0.00	7.76	0.00	29.81
2006	1.81	3.38	1.36	5.73	0.00	2.59	0.00	3.46	0.00	0.00	4.77	9.42	32.53
2007	0.00	0.00	2.93	9.67	0.00	3.96	3.75	0.00	0.49	0.00	8.74	8.05	37.59
2008	0.00	1.12	2.18	3.87	0.00	8.69	1.11	0.00	0.00	0.00	0.00	1.79	18.76
2009	9.28	5.51	1.23	0.00	2.26	1.56	0.00	0.00	0.00	1.18	2.59	2.17	25.78
2010	7.71	2.46	3.44	6.29	0.61	0.82	6.26	0.00	0.00	4.22	7.09	4.74	43.64
2011	11.54	1.49	0.00	1.27	0.00	1.70	7.97	0.89	0.00	2.79	1.09	0.98	29.72
2012	0.00	3.40	14.01	0.00	0.00	0.00	0.00	0.00	12.57	0.81	0.98	0.00	31.77
2013	7.22	0.00	0.00	2.84	0.00	0.00	1.70	2.98	0.00	2.85	2.05	7.42	27.05
2014	1.86	4.97	18.18	0.00	0.00	0.00	1.46	0.00	0.00	0.00	1.70	0.00	28.18
2015	5.30	2.87	2.90	0.00	0.00	0.00	0.00	0.00					
	Annual ground water inflow												32.51

4.1.2 Total inflow

As indicated above, the Kosi Estuarine Lake System receives freshwater from surface and ground water sources (Table 4.4), thereby maintaining open mouth conditions and controlling the ingress of salinity into the Lake 3 and Lake 4. Under the Present State the total freshwater input to the Kosi System has been reduced from 69.1 x10^6 m^3 to 63.7 x10^6 m^3 (92 %).

Table 4.4 Summary of the change in low flow conditions to the Kosi Estuary from the Reference Condition to the Present State.

Scenario	Mean Annual Runoff (x10 ^{6} m^3)	% Similarity
Natural	69.086 766	100
Present	63.790 466	92.03

In addition to contributing to the total freshwater inflow into the Kosi Estuarine Lake System, ground water also maintains the water table in the estuary functional zone. This in turn supports the development of the riparian and micro- habitats along the lake margins and banks. A key concern is therefore the degree to which abstraction has reduced the groundwater inflow during the low flow periods (Table 4.5).

Table 4.5 Summary of the groundwater abstraction as a percentage of the total groundwater inflow.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Groundwater (10^6 m^3)	5.44	5.61	5.60	2.93	0.64	1.61	2.32	0.85	1.59	2.03	5.78	3.85
Abstraction (10^6 m^3)	0.28	0.28	0.19	0.19	0.19	0.19	0.19	0.34	0.42	0.42	0.42	0.28
Relative	5.5	5.6	3.7	7.4	46.2	13.5	9.8	68.0	32.2	30.8	9.6	9.1

Confidence: Low

4.1.3 Hydrological health

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

Table 4.6 Calculation of the hydrological health score.

Variable	Summary of change	Score	Conf
a. % Similarity in total freshwater input	A reduction in groundwater inflow to the estuary resulting from 3.37 x10^6 m^3 abstraction and up to 11.685 X10^6 m^3 forest evapotranspiration losses.	92	L
b. % Similarity in groundwater	Groundwater component (proxy for water table)	86	L
Hydrology score		**92**	**L**

$Weight\ score\ to\ reflect\ importance\ of\ groundwater = \frac{(a * 0.67)+(b * 0.33)}{2}$

4.2 Hydrodynamics

4.2.1 Baseline description

4.2.1.1 Mouth dynamics

While littoral drift is predominantly towards the north, the sandbar at the mouth has a south and north extending component, resulting in highly mobile beach spit (Begg 1978). The Uguma rocks immediately south of the mouth protect it to a certain extent from the prevailing swell direction, assisting with maintaining an open mouth state under low inflow conditions.

The Kosi mouth is nearly always open and subjected to regular and strong tidal movements, though at times the connection is maintained with difficulty. The mouth varies in size with every tide, particularly during the spring tides. Generally, it is between 20 to 50 m wide and about 3 m deep, but can vary in width between 5 to 100 m.

On August 1965, the mouth closed, and remained closed until opened artificially on 4 January 1966. During the closed period a gradual rise in water levels (0.3 m) was followed by a dramatic water level rise of 1.6 m after Cyclone Claude, post mouth breaching.

4.2.1.2 Mixing processes and currents

Lake 4: The shallow bathymetry of Lake 4 ensures that it is dominated by wind generated wave action. The wave action in turn reworks the sands and provides an environment around the shore that is too energetic for the settling of any fine matter (gyttja). A delta forming at the end of the Channel 3 where it discharges into Lake 3 indicates that very little sand is transported into the Lake 3 due to low flow velocities.

Lake 3: Due to it large size, this lake has a large fetch and is consequently dominated by wind-induced wave action. The typical southerly and north-easterly bi-modal wind pattern sets up local currents that have modified the lake in a process called segmentation. The waves also flatten large areas in terraces. Both raised and submerged terraces indicate past lake levels. The lack of a delta forming where Channel 2 (Mtando) joins the lake indicates that the (inflowing) tidal currents do not have enough energy to transport sandy sediment into Lake 3.

Channel 2: The Mtando channel is a narrow (4 m wide) meandering channel that connects Lake 2 and 3. It is the only route that boats may use to gain access to the lower lakes. Due to its narrow width and steep margins it is extremely susceptible to bank erosion by boat wakes undercutting the top peat horizon (Wright et al. 1997).

Lake 2: Deltas have formed where the channels enter Lake 2 from both Lake 1 and Lake 3 (i.e. Channels 1 and 2 respectively). This indicates high tidal flows. On rare occasions, a combination of equinox spring tides can result in significant bottom water renewal. When combined with strong winds this causes the toxic bottom waters rich in hydrogen sulphide and depleted in dissolved oxygen to be brought to the surface in Lake 2.

Lake 1: A large tidal delta has formed on the tidal-flat side of the lake (where estuarine water flows into the system) indicating strong tidal currents active 5.5 km upstream of the mouth.

Estuary: The tidal flats of the estuary are dominated by both ebb and flood orientated sedimentary structures, indicating very strong tidal currents. In general, flood features are found in the wide shallow areas, while ebb features are mostly confined to the deeper channels.

4.2.1.3 Water levels and tidal variation

On 17 August 1965 the estuary mouth closed and over a period of 140 days water level in the system rose gradually (increased by 0.3 m). In early January 1966 the area was subjected to 640 mm of rain in three days during Cyclone Claude, and water levels rose rapidly (increase by 1.6 m).

Tidal effects are noticeable in Lake 3 particularly in winter (low water periods). Tidal asymmetry is recorded in the system with the low water levels being lower at neap tides than during spring tides. This is because more water enters the system on a spring tide than can leave it before the next high tide starts.

Outflow to the sea is greater during the summer, with water movement mostly contributed to tidal effects during the winter.

The tidal variation in the Kosi Estuary is strongly dependant on the mouth configuration and state of the mouth. Analyses of the 1942, 1959, 1976, 1984, 2010 and 2013 photographs and satellite imagery shows that the mouth configuration has generally been stable (Figure 4.1 to 4.6), but with variations in the position and size of the mobile sand bodies and tidal channels.

Deep channels are normally located seaward of the flood-tidal delta but occasionally a channel is formed against the estuary bank opposite the inlet.

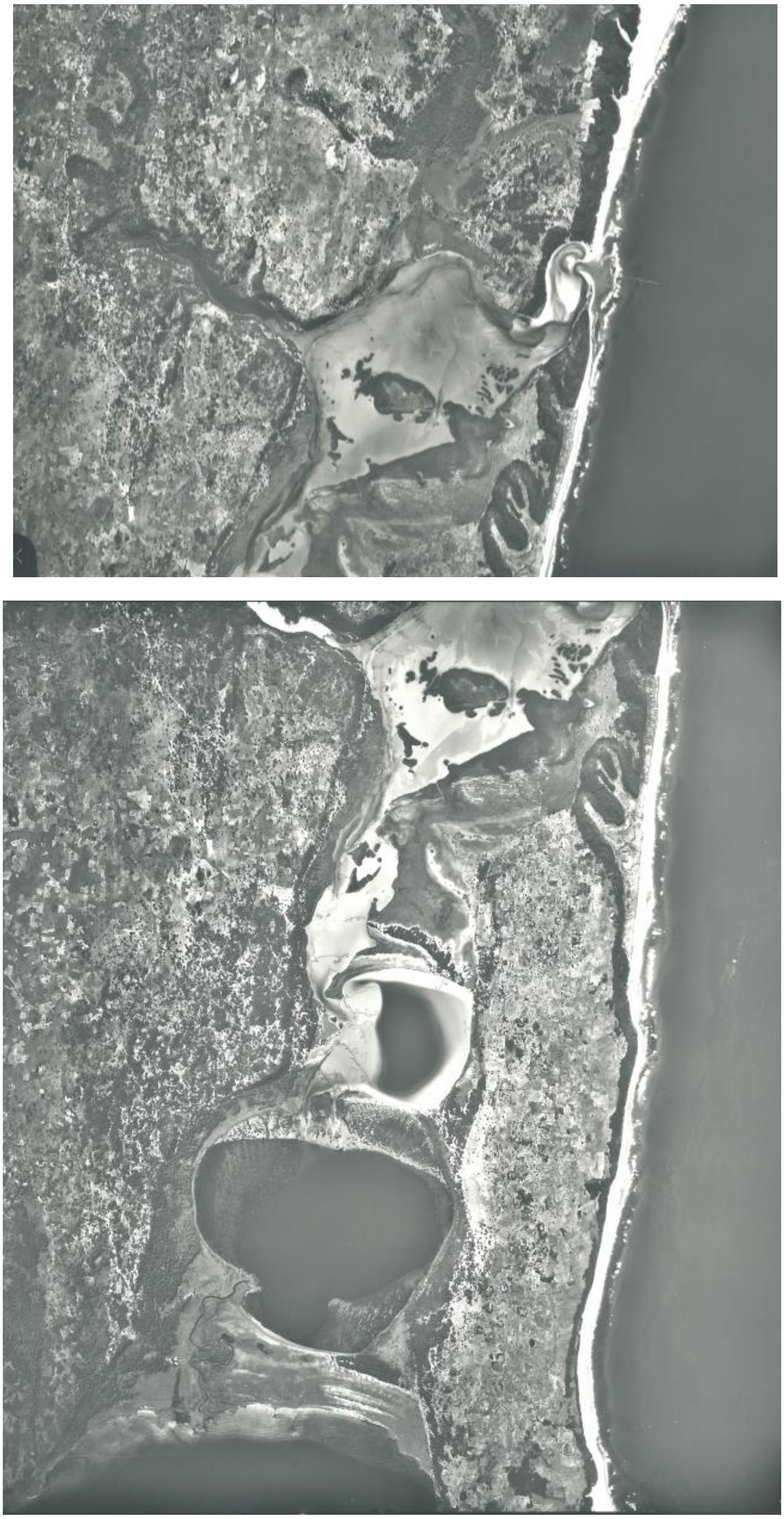


Figure 4.1 Historical image of the Kosi Estuarine Lake System – 1959.

Figure 4.2 Historical image of the Kosi Estuarine Lake System – 1969.

Figure 4.3 Historical image of the Kosi Estuarine Lake System – 1969.

Figure 4.4 Historical image of the Kosi Estuarine Lake System – 1986.

Figure 4.5 Satellite image of the Kosi Estuarine Lake System - 13 Augustus 2010 (Google Earth).

Figure 4.6 Satellite image of the Kosi Estuarine Lake System - 2013 (Google Earth).

4.2.2 Water Balance model

To estimate changes in the freshwater input to the Kosi System a water balance model was developed that incorporates the following key assumptions (Table 4.7 and 4.8):

- Kosi Lakes surface area: 42.6 km^2
- Catchment surface area: 609 km^2
- Surface water runoff rate: 5% of precipitation
- Groundwater catchment area: 331 km^2
- Groundwater recharge rate: 13% of precipitation
- Groundwater inflow into lakes: 30 $x10^6$ m^3/year
- Direct precipitation on lakes surfaces: 40 x 10^6 m^3/year
- Evaporation losses from lakes surface: 56 x 10^6 m^3/year
- Evapotranspiration rate for study area: 15 $x10^6$ m^3/year
- State 1: Resultant freshwater input/losses more than 3 $x10^6$ m^3
- State 3: Resultant freshwater input/losses below -3 $x10^6$ m^3 for more than 6 months in a year (indicative of the years where Lake 3 will have higher salinity developing)
- State 4: The occurrence of State 3 increases the probability of mouth closure. Assume one out of three occurrences of State 3 can lead to mouth closure
- State 2: Remaining months was taken as the resultant of 100 - State 1, 3 and 4.

Table 4.7 Water Balance of the resultant freshwater input/losses to the Kosi System ($x10^6$ m^3) under the Reference Condition.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	No. months resultant input/losses less than -3 x 10^6 m^3
1997								3.4	0.4	0.6	38.0	4.6		
1998	7.6	13.7	0.4	-5.7	-8.1	-1.7	-2.8	-7.4	-6.6	1.3	-6.8	4.7	-2.3	5
1999	15.1	42.1	7.1	-0.7	-6.7	-6.4	-2.8	-0.2	1.0	2.7	16.5	2.4	70.2	2
2000	21.0	29.6	41.3	-0.2	-0.6	-4.7	0.5	-6.6	10.3	3.8	33.0	2.3	129.7	2
2001	7.6	24.7	2.7	-2.0	-6.2	-0.1	-2.4	-7.0	-5.3	-1.5	4.5	5.7	20.8	3
2002	-7.5	-7.2	-7.2	0.5	-9.2	-0.4	0.4	-5.8	-6.6	-8.0	-6.8	0.7	-57.1	8
2003	-7.7	7.8	-6.7	-6.5	-1.5	-1.6	1.1	-8.2	-5.9	-7.1	2.2	-5.6	-39.6	7
2004	11.7	8.9	10.6	7.3	-7.2	-5.2	-0.3	-5.2	-5.8	-7.5	8.5	-5.1	10.6	6
2005	14.0	-0.7	13.1	1.7	-1.7	-5.9	-1.7	-7.8	-5.9	-7.9	12.4	-6.2	3.6	5
2006	0.2	3.7	-0.8	7.7	-6.5	1.7	-6.8	2.6	-6.7	-6.8	5.6	17.1	11.1	4
2007	-5.7	-4.4	2.7	19.0	-7.3	5.1	4.3	-5.5	-1.2	-3.7	17.7	15.4	36.5	5
2008	-4.1	0.9	2.1	5.0	-5.0	18.2	-1.3	-4.5	-4.5	-6.9	-3.8	1.5	-2.5	6
2009	18.3	9.6	0.5	-3.6	0.8	-0.8	-6.4	-6.0	-5.5	0.0	3.3	3.0	13.1	4
2010	15.3	3.9	4.9	11.6	-1.7	-1.9	11.3	-4.7	-6.0	6.1	13.4	7.5	59.7	2
2011	23.9	0.9	-7.6	-0.5	-4.5	-0.1	15.6	-1.6	-5.8	3.2	0.4	0.2	24.1	3
2012	-3.7	4.7	31.0	-4.1	-6.4	-5.8	-4.8	-4.8	27.9	-0.6	0.0	-3.9	29.6	7
2013	12.6	-5.4	-4.0	2.8	-6.1	-4.6	-0.2	2.5	-6.0	3.0	1.9	13.4	10.0	5
2014	2.7	8.9	43.4	-4.3	-5.6	-5.7	-0.6	-5.8	-6.5	-3.6	2.2	-3.2	22.0	7
2015	8.8	4.8	4.1	-4.3	-6.2	-4.5	-4.8	-6.3						Total= 81

Table 4.8 Water Balance of the total freshwater input and losses to the Kosi Estuarine Lake System (x10^6 m^3) under the Present State.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	No. months resultant input/losses less than -3 x 10^6 m^3
1997								3.1	-0.6	-0.7	37.6	3.8		
1998	7.3	13.4	**-1.1**	-5.7	-8.1	-2.5	-3.8	-7.4	-6.6	0.1	-6.8	3.8	-3.2	6
1999	14.9	41.8	6.9	-1.8	-6.7	-6.4	-3.8	-1.3	-0.1	1.6	16.1	1.1	62.2	3
2000	20.7	29.3	41.1	-1.1	-1.5	-4.7	0.1	-6.6	9.8	3.4	32.5	1.0	124.2	2
2001	7.1	24.4	1.8	-3.2	-6.2	-0.4	-3.2	-7.0	-5.3	-3.0	3.8	5.0	13.9	5
2002	-7.5	-7.2	-7.2	-0.4	-9.2	-0.8	0.1	-5.8	-6.6	-8.0	-6.8	-0.8	-60.2	8
2003	-7.7	7.4	-6.7	-6.5	-2.5	-2.1	0.9	-8.2	-5.9	-7.1	1.0	-5.6	-42.9	7
2004	11.4	8.6	10.4	7.1	-7.2	-5.2	-0.8	-5.2	-5.8	-7.5	8.1	-5.1	8.8	6
2005	13.8	**-2.5**	12.9	1.1	-2.8	-5.9	-2.4	-7.8	-5.9	-7.9	12.0	-6.2	-1.6	5
2006	-1.5	2.7	-2.4	7.5	-6.5	1.6	-6.8	2.2	-6.7	-6.8	4.9	16.8	5.1	4
2007	-5.7	-4.4	1.6	18.8	-7.3	4.9	4.1	-5.5	-2.6	-3.7	17.3	15.1	32.6	5
2008	-4.1	-0.7	1.0	4.8	-5.0	18.0	-1.8	-4.5	-4.5	-6.9	-3.8	0.0	-7.5	6
2009	18.0	9.3	-0.9	-3.6	0.4	-1.2	-6.4	-6.0	-5.5	-1.4	2.2	1.5	6.4	4
2010	15.0	2.8	4.2	11.4	-2.6	-2.6	11.2	-4.7	-6.0	5.6	13.0	6.9	54.2	2
2011	23.6	-0.6	-7.6	-1.6	-4.5	-0.5	15.4	-2.7	-5.8	2.1	-1.3	-1.6	14.9	3
2012	-3.7	3.8	30.8	-4.1	-6.4	-5.8	-4.8	-4.8	27.5	-2.2	-1.6	-3.9	24.8	7
2013	12.3	-5.4	-4.0	2.1	-6.1	-4.6	-0.7	1.9	-6.0	1.9	0.5	13.1	5.2	5
2014	1.2	8.5	43.2	-4.3	-5.6	-5.7	-1.4	-5.8	-6.5	-3.6	0.7	-3.2	17.7	7
2015	8.5	3.7	3.1	-4.3	-6.2	-4.5	-4.8	-6.3						Total = 85

Table 4.9 provides a summary of the hydrodynamics characteristics associated the typical abiotic states occurring in the Kosi Estuarine Lake System.

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

PARAMETER	Mouth State	Water level	Inundation
State 1: Open, fresh	Open	> 0.8	Yes, during cyclones
State 2: Open, Saline	Open	0.8 - 0.55	N/A
State 3: Open, Very Saline	Open	< 0.55	N/A
State 4: Closed	Closed	1.5 – 2.5 (can reach ~3.5 m MSL if closed for extended periods)	Yes, back flooding during closed state

4.2.3 Hydrodynamic health

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

Table 4.10 Calculation of the hydrodynamics score.

Variable	Summary of change	Score	Conf
Hydrodynamics and mouth conditions score	Mouth closure occurs for less than 1% of the time under the Present State, similar to the Reference Condition. However reduction in freshwater input to the system has potentially resulted in more constricted mouth configuration under the present state.	99	L
Hydrodynamic score		**99**	**L**

4.3 Water quality

4.3.1 Baseline description

A summary of the water quality characteristics typical of the system in various abiotic states (see above, and Table 4.11) in each of the zones is presented in Table 4.12 and 4.13. This summary was derived from available information on the estuary as presented in the Abiotic Summary Report (Appendix B).

Salinity characteristics in the system are largely influenced by freshwater inputs, evaporation and tidal exchange. While these processes also have some influence on the other water quality characteristics (i.e. inorganic nutrients, turbidity and dissolved oxygen), *in situ* processes such as wind mixing and remineralisation also have a strong influence, at times greater than the character of freshwater inputs and tidal exchange. It is not expected for the water quality characteristics in the various zones to have changes between reference and present, or future scenarios except for toxic substances where spraying of DDT and plastic pollution are introduced in the present and future scenarios. Also extensive die-back of submerged marcophytes in Lake 3 (when salinity in this lake increases to 10) will affected nutrients, turbidity and dissolved oxygen in the lake and adjacent channels. A summary of the average water quality conditions in each of the zones, under Reference and Present State is presented in Table 4.12 and Table 4.13.

Table 4.11 Summary of the abiotic states distribution.

PARAMETER	Reference % occurrence	Present % occurrence
State 1: Open, fresh	30.0	27.6
State 2: Open, Saline	56.7	59.0
State 3: Open, Very Saline	13.4	13.4
State 4: Closed	0	0

4.3.2 Water quality health

The similarity in each parameter (e.g. salinity, dissolved oxygen) to reference condition was scored as follows:

- Define zones along the length of the estuary (Z) (i.e. EST, L1, C1, L2, C2, L3, C3, L4, C4).
- Weighted fraction of each zone (V) (5, 5, 1, 10, 2, 70, 1, 5, 1).
- Define abiotic states (S) (i.e. States 1 to 4).
- Define the flow scenarios (i.e. Reference, Present, Future scenarios).
- Determine the % occurrence of abiotic states for each scenario.
- Define WQ concentration range (C) (e.g. 6 mg/l; 4 mg/l; 2 mg/l).

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

Table 4.12 Summary of water quality characteristics of different abiotic states in the Kosi Estuarine Lake system (differences in concentrations between reference condition and present state are indicated were relevant for some parameters).

Parameter	State	EST	L1	C1	L2	C2	L3	C3	L4	C4
Salinity (psu)	1	20	15	15 (springs) 10 (neaps)	10	5 (springs) 0 (neaps)	0	0	0	0
	2	30	25	25 (springs) 20 (neaps)	20	20 (springs) 0 (neaps)	0	0	0	0
	3	35	30	30 (springs) 25 (neaps)	25	25 (springs) 5 (neaps)	5	5 (springs) <1 (neaps)	1	0.5
	4	30	25	25	20	10	5	3	1	0.5
DIN (µg/ℓ)	1	80	80	150	100	100	50	100	100	100
	2	80	80	150	100	100	50	100	80	200
	3	80	80	150	100	100	50	100	80	200
	4	100	100	200	150	150	50	100	80	200
DIP (µg/ℓ)	1	10	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	15	10	10
	3	10	10	10	10	10	10	15	10	10
	4	15	15	15	10	10	10	15	10	10
Turbidity (NTU)	1	2	2	2	2	2	2	10	15	15
	2	2	2	2	2	2	2	5	10	10
	3	2	2	2	2	2	2	5	10	10
	4	2	2	2	2	2	2	5	10	10
DO (µg/ℓ)	1	7	7 2	7	7 0	7	7	7	8	6
	2	7	7 2	7	7 5	7	7	7	8	4
	3	7	7 2	7	7 5	7	7	7	8	2
	4	6	7 2	6	7 5	7	7	7	8	2

NOTE: For the purposes of this assessment the estuary was sub-divided into nine zones representing from left to right: Estuary (Est), Lake 1 (L1), Channel 1 (C1), Lake 2 (L2), Channel 2 (C2), Lake 3 (L3), Channel 3 (C3), Lake 4 (L4) and Channel 4 (C4) (Figure 3.1).

Table 4.13 Summary of average changes in water quality from Reference Condition to Present State within each of the various zones.

Parameter	Summary of change	Scenario	EST	L1	C1	L2	C2	L3	C3	L4	C4
Salinity (psu)	Due to decrease in the surface and ground water inflow to the system	**Reference**	28	23	20	18	8	1	0	0	0
		Present	28	23	20	18	9	1	0	0	0
DIN (µg/ℓ)	No marked difference	**Reference**	80	80	150	100	100	50	100	101	170
		Present	80	80	150	100	100	50	100	99	172
DIP (µg/ℓ)	No marked difference	**Reference**	10	10	10	10	10	10	14	10	10
		Present	10	10	10	10	10	10	14	10	10
Turbidity (NTU)	No marked difference	**Reference**	2	2	2	2	2	2	7	12	12
		Present	2	2	2	2	2	2	6	11	11
DO (µg/ℓ)	No marked difference	**Reference**	7	7 2	7	7 4	7	7	7	7	5
		Present	7	7 2	7	7 4	7	7	7	7	5
Toxic substances	Some DDT contamination & plastics in littoral zones	90% similar throughout									

A summary of the water quality characteristics and scores under reference and present are provided for each zone in Table 4.14.

Table 4.14 Summary of changes and calculation of the Water Quality health score for the overall system.

	Variable	Summary of change	Score	Conf
1	**Salinity**			
	Similarity in salinity	Slight increase in salinity in Lake 3 and Lake 4	99	L/M
2	**General water quality in estuary**			
a	DIN and DIP concentrations	No marked difference	100	L/M
b	Turbidity (transparency)	No marked difference	100	L/M
c	Dissolved oxygen (mg/l)	No marked difference	100	L/M
d	Toxic substances	Some DDT contamination & plastics in littoral zones	90	L
Water quality health score[1]				
% of impact non-flow related				
Adjusted score				

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

4.4 Physical habitat

4.4.1 Baseline description

Sediments enter the Kosi system from a number of sources, including: 1) marine sand entering through the estuary mouth on the flood tide, 2) catchment sediment being brought down by floods, 3) detrital sediment being deposited within the system by biological activities, and 4) localised bank erosion (Wright et al 1997). At present aeolian transport within the present system is negligible due to the thick subtropical vegetation that fringes the system.

Unlike most Natal estuaries, the nature of the bottom material in the Kosi system is clean, white sands, particularly in the estuary where the marine influence is most marked (Begg, 1978). This sandy substrate occurs throughout the Kosi system. Profiles across Lakes 1, 2 and 3 are noticeably terraced; i.e. the littoral shelf of each lake extends to varying degrees, but then delves suddenly to a series of lower platforms (Begg 1978). The only silt in the system is found in deeper waters, or as a thin layer overlying sand in certain shallow areas. The sandy substrate is characterised by a lack of fine particles and low nutrient content. This is attributed to the finer mud fractions being removed from the shallower areas in the system by wind induced wave action. Typically the sand from Kosi catchment has a fine to medium grain size, a well sorted nature and comprises almost entirely of quartz indicating extreme maturity (i.e. reworked a number of times since its departure from its source).

The only coarse grained sand found within the system is a small wedge entering the estuary mouth from the littoral zone within the flood-tidal channel (Wright et al 19997) (Figure 4.3). The remainder of the system is covered by either medium- or fine-grained sand. The fine-grained sand tends to occupy the deeper parts of Lakes 1 and 2 and to a lesser extent Lake 3. It is associated with a finer mud fraction. Very fine-grained sand is absent from the whole system. Gravel (>2 mm) is only present in the system as a bioclastic component (from intact and broken bivalves).

The vast majority of sand in Lakes 1 to 3 is well sorted indicating a possible aeolian origin in geological time. Isolated areas around the margins of Lakes 3 and 4 are very well sorted, indicating reworking from wind-induced waves attacking the shallow margins, or erosion of the very-well sorted aeolian sediment from the dunes that mantle the lakes (Wright et al 1997).

By contrast, the bottom material in the deeper areas is unconsolidated organic debris, which is characterised by low dry weight, and high volatile and nutrient values. It can be of considerable thickness, black and hydrogen bearing. These materials originate in the marshes and swamps alongside the system, and then naturally gravitate towards the deeper areas. The reserves of fragmented plant material in Lake 4 and the Sihadhla River are considered important sources of organic debris for Lake 3. The shallow, freshwater Lake 4 has a high suspended gyttja (mud that takes the form of a sapropelic ooze) fraction. Surveys of Lake 3 also indicate that the gyttja occurs in the deeper areas away from the wave interference and where salinities below 5 facilitate it remaining in suspension. The organic and clay depleted nature of the catchment ensures that the mud is not flocculated in these two lakes. The gyttja in Lake 2 forms a harder, more defined bottom due to its flocculated state, caused by higher salinities.

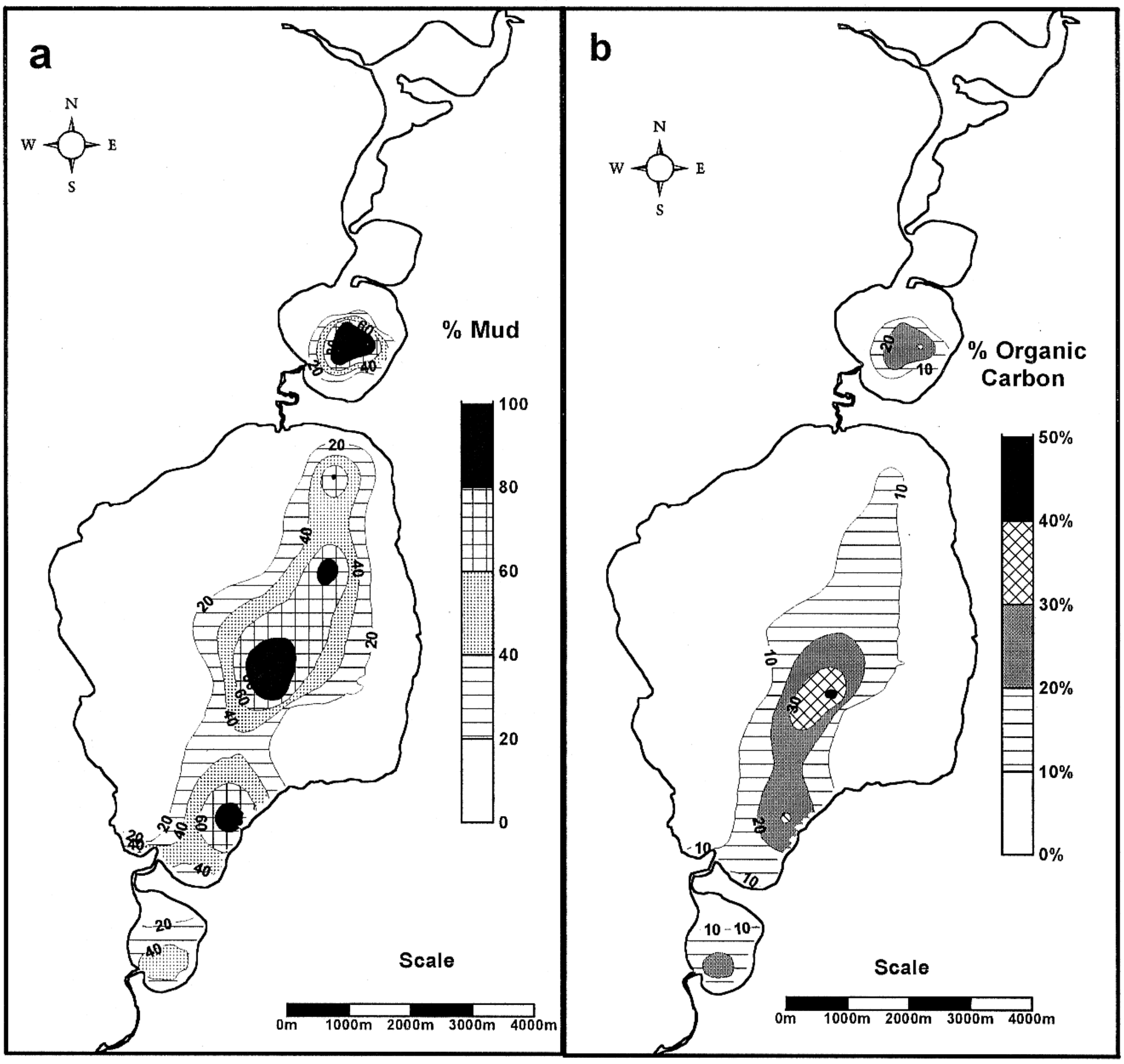


Figure 4.2 a) Percent mud (<63 micron) distribution showing mud accumulating within the deeper areas of the system. b) Percent organic carbon distribution showing a direct correlation with the mud distribution (Wright et al 1997).

Almost all the gyttja is found within the deeper sections of Lakes 2, 3 and 4 where tranquil conditions below the wavebase influence allows the fine material to settle. Wind induced waves and tidal currents prevent gyttja accumulating in the intertidal sand flats and mouth area. Whereas mangroves in general, tend to trap muds, there is a distinct lack of terrigenous mud within the mangroves, indicating a catchment severely depleted in clay material.

The organic carbon distribution is very similar to the mud distribution indicating a direct correlation between the two. The high values indicate that the fine muddy material comprises gyttja. The organic material comprises a breakdown of the macrophytes occurring along the lake margin.

The rise and fall of the water levels in the system may cause periodic die-back of vegetation, which in turn is further broken down by wave action and moved to the deeper regions, where it sinks to the bottom and is finally broken down by bacteria.

Under the Reference Condition there would have been slightly less sediments coming from the catchment. Poor land-use practises in the present day are possibly leading to slightly more sediment, especially finer fractions, entering the system.

4.4.2 Physical habitat health

Table 4.15 provides a summary of the physical habitat health of the Kosi Estuary.

Table 4.15 Calculation of the physical habitat score and adjusted score (net of non-flow impacts).

Variable		Score	Motivation	Conf
1. Resemblance of intertidal sediment structure and distribution to Reference condition				
1a	% Similarity in intertidal area exposed	95	Sedimentation processes are very similar to the Reference conditions, but there is some loss of intertidal habitat due to subsistence agricultural activities along lake riparian areas.	M
1b	% Similarity in sand fraction relative to total sand and mud	95	Very similar to reference. While there is large scale land transformation in the catchment this do not translate into a significant shift in sediment composition as there is very little clay and muds in the catchment.	M
2	% Similarity in subtidal components: depth, bed or channel morphology	95	Very similar to reference, but assume some some deepening of the channels due to boat action under low water levels conditions. Limited localised impact on sediment movement around fish traps.	M
	Physical habitat score	**95**		**M**

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

Anthropogenic influence:			
Percentage of overall change in intertidal and supratidal habitat caused by **anthropogenic** activity as opposed to modifications to water flow into estuary	100	Poor agricultural practises and developments in the catchment are causing degradation and changes sediment availability.	M

Percentage of overall change in subtidal habitat caused by **anthropogenic** modifications (e.g. bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary	100	Poor agricultural practises and developments in the catchment are causing degradation and changes sediment availability.	M

4.5 Microalgae

4.5.1 Overview

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

i) Main grouping and baseline description.

There is little historical microalgal data available for the Kosi estuarine lake. The data collected during the field visit in 2016 is presented in the Appendix D and summarised here (Table 4.16). In February 2016 average phytoplankton chlorophyll *a* showed a distinct increase with distance from the estuary mouth, ranging from 1.24 ± 0.44 $\mu g.l^{-1}$ at the estuary to 10.29 ± 0.82 $\mu g.l^{-1}$ at Lake 4. Phytoplankton chlorophyll *a* was usually highest near the surface with only the depth profile in Lake 3 indicating oligotrophic to mesotrophic conditions (<10 $\mu g.l^{-1}$) throughout the water column. The large Lake 3 had similar biomass for the different sites with an average around 6 $\mu g.l^{-1}$ which is low. Interestingly, sites with fast flowing water had no chlorophyll-*a* in the water, i.e. at the mouth, in the channel linking the estuary with Lake 1, and in Sihadhla River. Overall phytoplankton biomass is low and indicative of oligo-/mesotrophic conditions (< 20 $\mu g.l^{-1}$) (Lemley et al., 2015).

Cyanophyceae (blue-green algae), and to a lesser degree Chlorophyceae, were dominant in the fresh Lake 3 and Lake 4. The co-occurrence of these two algal classes is indicative of freshwater environments. Flagellates and Bacillariophyceae (diatoms) were dominant in the brackish/marine Lake 1, Lake 2 and the estuary. Dominant cyanophyte species present in Lake 3 and 4 included *Merismopedia* sp., *Microcystis* spp., *Aphanothece* sp., and *Chroococcus* sp.; whilst *Oocystis* sp. and *Dictyosphaerium* sp. were the dominant chlorophytes present in Kosi Bay. *Nitzschia longissima* was the dominant marine diatom in the Kosi Estuary.

Benthic microalgal biomass also showed a distinct pattern with highest values in Lake 4 (441.13 ± 94.43 mg m^{-2}) decreasing to Lake 1 (51.14 ± 14.45 mg m^{-2}); while the average benthic chlorophyll *a* for all sites was 130.1 ± 22.88 mg m^{-2}. Sediment type is important with regards to 'regulating' MPB biomass, with sheltered, fine cohesive sediments (i.e. mud) generally supporting elevated levels compared to exposed, non-cohesive sands and silts. For the Kosi system, the sediments with high organic content had the highest benthic chlorophyll *a*. Sheltered areas at Sites 2 and 3, in Lake 4, had high benthic microalgal biomass compared with exposed sandy sites of Lake 3. Lake 2 also had low values except for the west bank (Site 19, Appendix D) which was characterised by high organic content and the west bank of Lake 1 (Site 18, Appendix D). It is significant that these are freshwater seepage sites and that on the west bank of Lake 2 had almost the exactly same biomass values as the other westerly sites. The sheltered characteristics of some of the sites in Lake 3 resulted in an even higher benthic microalgal biomass.

Table 4.16 Main phytoplankton microalgae groupings and their defining features and typical/dominant species.

Main groupings	Defining features and typical/dominant species
Flagellates	The flagellate components of the microalgal community are able to maintain themselves in the water column using their flagellae and they are usually numerically dominant when counts are made. They are made up of both autotrophic and heterotrophic organisms, the latter being consumers rather than photosynthetically productive. Despite this, they are still components that are ingested and are therefore part of the food available to larger consumers and especially fish.
Bacillariophyceae	Being relatively large by comparison with other microalgal groups, diatoms are sometimes the most important group in an estuary even though they may not be numerically dominant. They have relatively large cells and can be present in the water column or on the bottom. Under very low flow conditions the diatom community is mostly on the sediment surface but under disturbed or high flow conditions they become suspended in the water column. The marine diatom *Nitzschia longissima* was dominant in the saline areas of Kosi Estuarine Lake.
Dinophyceae	Dinoflagellates like flagellates are able to maintain their position in the water column. They prefer stable, stratified conditions with warmer temperatures and high nutrient concentrations (but low Silica concentrations). *Peridinium* sp. was abundant in the fresher lakes in summer 2016.
Cyanophyceae	The cyanophytes (blue-green microalgae) are a group of non-flagellated photosynthetic bacteria that can make up a large component of both the planktonic and benthic microalgal community. They can be important in that under certain conditions (including anaerobic) because they can utilise gasses such as hydrogen sulphide in order to grow. Some species are able to fix nitrogen and can become important under conditions where the water column is oligotrophic. Certain species of cyanophytes can produce toxins which are able to be harmful if present in high concentration. Cyanophytes were abundant in the fresh Lake 3 and 4. Prominent species were: *Merismopedia* sp., *Microcystis* spp., *Aphanothece* sp. and *Chroococcus* sp.
Chlorophyceae	The green microalgae are a very diverse group that can be present in estuary waters in fairly high proportions. They are included mostly in the flagellated group and because of the flagellum they are able to maintain their presence within the water column rather than sink to the sediment surface as do the diatoms. *Oocystis* sp. and *Dictyosphaerium* sp. were the dominant Chlorophytes recorded in 2016.

ii) Description of factors influencing microalgae.

Details of the effect of abiotic characteristics and process on the various groupings are listed in Table 4.17 and Table 4.18.

Table 4.17 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on the various groupings of Microalgae.

Variable	Grouping	
	Phytoplankton	**Microphytobenthos (MPB)**
Open water area	Proportional reduction of microalgal biomass with loss of open water area	Proportional reduction of microalgal biomass with loss of open water area
Salinity	Very little effect when > 5. When < 5 there can be a few freshwater species present.	Very little salinity effect with estuary MPB. There are a range of freshwater, brackish and saline species.
Mouth condition	Mouth open - Biomass maximum at ~15. This area is known as the REI (river estuary interface) as is found in systems with vertical and longitudinal salinity gradients.	MPB biomass can be regulated by tidal flows with diatoms moving off the sediment.
Water flow rate	Under high water flow rates most of the microalgae are suspended in the water column.	Many diatoms that are commonly benthic (epipelic) are found in the water column. This is especially the case where the fine sediment fraction is suspended due to turbulence.
Water retention time	Phytoplankton biomass elevated when there is water retention.	MPB biomass elevated when water retention time is longer.
Floods	Only temporary reduction in phytoplankton biomass as a result of flooding.	Only temporary reduction in MPB biomass as a result of flooding.
Turbidity	Because high turbidity occurs at the time of flooding there is very little effect on phytoplankton. They can function at very low light.	Possible small reduction in MPB productivity if water flow is slow and water very turbid.
Water quality	Low nutrient content - maximum species diversity with low biomass. Diversity decreases at high nutrient levels.	No evidence of a species change at high nutrient levels. Likely that benthic diatoms use recycled nutrients from the sediment.
Toxins	Literature indicates that there is an unspecified adverse effect with certain toxins	No information
Macrophyte community structure	Diatom phytoplankton exchange onto and off submerged and emergent macrophyte surfaces. Epiphytic when diatoms are attached to macrophytes.	MPB biomass high with high density of rooted aquatic macrophytes. Food availability to juvenile fauna increases - also security.
Oxygen levels	No effect on phytoplankton.	No effect on MPB.

Table 4.18 Summary of Microalgae responses to different abiotic states.

State	Response
State 1: Open, fresh	Biomass would be dependent on flows at the time. Freshwater phytoplankton groups including the green algae (Chlorophyceae) and blue-green algae (Cyanophycease) will increase in abundance.
State 2: Open, saline	High biomass and diversity would characterise this state if it is represented by a salinity gradient across the estuary into the lakes.
State 3: Open, very saline	Loss of some salt intolerant species but no changes in biomass expected.
State 4: Closed	There would be an increase in biomass for both phytoplankton and benthic microalgae due to an increase in water retention. Freshwater phytoplankton groups including the green algae (Chlorophyceae) and blue-green algae (Cyanophycease) will increase in abundance in response to a decrease in salinity.

iii) Reference condition

Table 4.19 lists the relative changes in the Microalgae from the Reference Condition to the Present State.

Changes that may have occurred or that are potential future threats are an increase in nutrients (e.g. fertilisers and sewage inputs) in the catchment and localised eutrophication. This would be of particular concern in the Lake 3 and 4, where numerous, potentially toxic, Cyanophyceae species currently dominate (but presently at low biomass levels) the phytoplankton. Domestic sewerage has not been a problem but with increasing human habitation in the catchment and several domestic water supply schemes this may soon change. Activities along the banks such as clearing, paths, cattle grazing and trampling would have resulted in some changes in the benthic microalgal habitat.

Table 4.19 Summary of relative changes in Microalgae from Reference Condition to Present State.

Key drivers	Change
Groundwater inflow	Localized decreases in benthic microalgal biomass where there has been reduced groundwater inflow
Intertidal and subtidal habitat	Small changes in the intertidal and subtidal habitat would mean loss of available habitat for benthic microalgae
Salinity	Small change in salinity would decrease species richness. Currently the phytoplankton groups clearly show the differences between Lakes 3-4 and Lakes 1-2.
Nutrients	Overall there has been no change in the estuary; however there would be site specific changes where cattle and people have disturbed the riparian zone. At nutrient rich sites there would be an increase in benthic microalgal biomass.
TOTAL CHANGE	**Overall small loss of habitat for benthic microalgae and small decrease in species richness, but no changes expected for the phytoplankton.**

4.5.2 Microalgae health

Table 4.20 provides details of the health score for the Microalgae. There is a small change for the benthic microalgae but the phytoplankton remains the same.

Table 4.20 Microalgae component health score.

Variable	Summary of change	Score	Conf
1. Species richness	Decrease in groundwater inflow and changes in salinity would lead to some loss of microalgal species in both the phytoplankton and benthos.	95	M
2. Abundance	Loss of benthic microalgal habitat due to disturbance of the riparian zone by cattle and people would decrease biomass.	95	M
3. Community composition	No changes expected	100	M
Biotic component health score		**95**	
% of impact non-flow related		50%	
Adjusted score		**98**	

4.6 Macrophytes

4.6.1 Overview

i) Main grouping and baseline description

The Kosi Estuarine Lake supports a nationally important area of swamp forest and mangrove habitat in South Africa (Table 4.21 and Figure 4.4). It is the only estuary in the country to support six tree species of mangroves: white mangrove *Avicennia marina*, black mangrove *Bruguiera gymnorrhiza*, red mangrove *Rhizophora mucronata*, Tonga mangrove *Lumnitzera racemosa*, Indian mangrove *Ceriops tagal* and cannonball mangrove *Xylocarpus granatum* of which the last two are at the southernmost limit of their distribution. The Kosi Lakes are of considerable botanical importance due to the presence of several Red Data species including the southernmost distribution of the giant palm *Raphia australis*. Extensive floating and submerged aquatic macrophytes also form an important component of the system. Aquatic macrophytes form the major portion of the primary energy source for the food webs of lakes (Howard-Williams 1980). They also stabilise sediments, protect against bank erosion, increase habitat diversity and provide shelter and breeding areas for benthic invertebrates, fish and birds. Macrophytes play an important role in sieving and trapping allochthonous and autochthonous matter. The fringing vegetation in Kosi Estuarine Lake is thus important as it reduces nutrient inputs to the lake.

The Kosi Estuary was visited in February 2016 to document the distribution and species composition of the macrophyte habitats in relation to the controlling environmental factors. The appendix data contain a description of the sites and an assessment of changes over time. A vegetation map for present conditions was produced from the field survey (Figure 4.3). The distribution and area covered by different macrophyte habitats was compared with the earliest aerial photographs available for 1942. These changes would then provide input to the assessment of the present ecological status of the estuary. The delineation of the estuary boundary is difficult because of the ill-defined drainage system consisting of the many swamps, pans and marshes surrounding it; the system is a complex set of interconnected wetlands. For this study the lateral estuary boundary was that represented by the 5 m contour line (bgis.sanbi.org).

Lake 4 consisted of a fringe of emergent reeds and sedges (*Phragmites australis, Schoenoplectus scirpoides* and *Typha capensis)* with fringing *Hibiscus tiliaceus* behind. Large swamp forest areas were present on the west bank with *Raphia australis* stands. Salinity at the shore sites was 3 and the dominant submerged macrophytes were *Ceratophyllum demersum*, *Potamogeton sweinfurthii* and *Najas marina. S*wamp forest and reed and sedge areas indicated seepage sites. Characteristic of Lake 3 was the expansive and clear waters with a diversity of submerged macrophytes. *Ceratophyllum demersum* and *Najas marina* were dominant.

Unique to this lake was the algae mats dominant in the deeper waters consisting of *Chara globularis* and green algae. *Potamogeton sweinfurthii* is known to prefer clear water. *Ceratophyllum demersum* is indicative of eutrophic and brackish water. The macroalgae *Spirogyra* sp. was abundant in Lake 3 and 4. *Spirogyra* is widespread in all freshwater habitats where it is common in standing water. Under favourable conditions it forms floating green filamentous mats (Janse van Vuuren et al. 2006).

Lumnitzera racemosa is a dominant mangrove in the lakes first appearing in the Mtando channel and then Lake 2. *Bruguiera gymnnorhiza* was also found on the south side of Lake 2 indicative of more saline conditions. Salinity at this site was 24 and the vegetation on the east bank consisted of a distinctive row of reeds, the mangrove *Lumnitzera racemosa* and then *Hibiscus tilieaceus* representative of swamp forest. The west bank had similar vegetation with a large expanse of swamp forest. The mangrove fern *Acrostichum aureum* occurred from Site 2 (Lake 4) all the way to the mouth. Other abundant plants were common reed *Phragmites australis* and the sedge *Schoenoplectus scirpoides. Hibiscus tilieaceus* was also widespread occurring throughout the system.

Resource utilisation was pronounced in all zones of the estuary with evidence of burning, cattle grazing and harvesting of mangroves, reeds, sedges and palms. Mangrove brushwood is used for the construction and maintenance of fish traps. Invasive plant species in the system were minimal.

Table 4.21 Macrophyte habitats and functional groups recorded in the estuary (spp. examples in italics).

Habitat type	Distribution	Area ha (2016)
Open surface water area	Serves as a possible habitat for phytoplankton.	3367 (+652 ha from submerged)
Intertidal sand and mudflats	Intertidal zone occurs in the estuary and lower lakes whereas Lakes 3 and 4 have extensive areas of shallow water habitat for microphytobenthos colonisation.	23
Macroalgae	*Chara globularis* and green algae formed mats offshore in Lake 3. In the other shallow water areas macroalgae were epiphytic on the emergent plants.	-
Floating macrophytes	Floating leaved aquatics included *Nymphaea nouchali* and *Nymphaea lotus* in Lake 4 with some in the channel linking Lake 4 and 3.	-
Submerged macrophytes	*Ceratophyllum demersum, Najas horrida* (can tolerate brackish water), *Najas marina, Potamogeton sweinfurthii* and *Urticularia* sp. were found in Lakes 3 and 4. Other species appeared as the salinity increased for example *Stuckenia pectinata* (grows best salinity < 20) was only observed in Lake 3, *Ruppia cirrhosa* in Lake 1 and the seagrasses *Zostera capensis* and *Halodule universis* in the estuary.	652
Reeds and sedges	Common reed *Phragmites australis* and the sedge *Schoenoplectus scirpoides* are abundant fringing the banks of the system. *Juncus kraussii* replaces *Schoenoplectus scirpoides* in more saline areas. Extensive areas of reeds, sedges, grasses and shrubs occur in lower lying areas (often fresh water seepages) and between the lakes. Common species present included *Cyperus natalensis, Cyperus textilis, Cyperus prolifer* and *Cyperus thunbergii. Cladium moriscus, Typha capensis* and *Pycreus nitidus* occurred in the freshwater lakes and channels.	127
Salt marsh	*Juncus kraussi* was abundant in low-lying areas surrounding Lake 1 and 2. *Triglochin striata* and *Sporobolus virginicus* were also present in this habitat. This habitat was interspersed between saline grasslands and fringing the banks in some places.	58
Saline grasslands (grasses, herbs and sedges	Saline grasslands of *Paspalum vaginatum, Stenotaphrum secundatum, S.dimidiatum* and some herbaceous species occurred on the penisulas between the lakes. In some areas the palm *Phoenix reclinata* and the fern *Acrostichum aureum* interspersed this habitat.	229
Swamp forest	Extensive swamp forest occurs alongside the streams, channels and banks of the Kosi lakes. *Hibiscus tiliaceus* is abundant fringing the open water and interspersed between mangroves. *H. tiliaceus* is well adapted to grow in the coastal environment as it tolerates salt and waterlogging. *Raphia australis* was more prominent surrounding the freshwater lakes and channels and *Phoenix reclinata* increased towards the mouth of the system often interspersed amongst forest habitat or grassland matrix. Ferns such as *Cyclosorus interruptus, Stenochlaena tenuifolia* and *Lygodium microphyllum* were prevalent in the undergrowth of this habitat. Climbers and creepers were conspicuous in this habitat with common species including *Derris trifoliata, Mikania natalensis, Smilax anceps* and *Ipomoea* spp.	869
Mangroves	The greatest concentrations of mangroves occur on the islands and south- eastern shore of the tidal basin where all 5 species are represented. *Lumnitzera racemosa* and *Bruguiera gymnorrhiza* are more tolerant of prolonged basal inundation by water and low salinities and thus extend further from the mouth than any of the other mangrove species. Only a single mature *Xylocarpus granatum* is known in the system. The mangrove fern, *Acrostichum aureum* clearly has wide tolerance ranges as it occurred from Lake 4 to the estuary. It is known to grow in brackish water but the spores germinate best in freshwater. Ward and Steinke (1982) reported 59 ha of mangrove habitat, updated by Pillay (CSIR, unpublished) to be 60.7 ha.	71
Coastal forest and grassland	Trees and shrubs occuring on the higher elevations surrounding the Kosi Estuarine Lake. Common species include Umdoni *Syzygium cordatum, Ficus trichopoda*, *Bridelia cathartica*, *Rapanea melanophleos,* and *Morella serrata*.	721
Disturbed habitat	Areas that have been developed, cultivated or cleared or disturbed for access to the lakes (e.g. roads, cleared areas for maintenance of fish traps). From the aerial photographs some areas appear to have been previously cultivated. The 2016 field surveys found these areas to be grasslands, however this habitat was still included as disturbed.	119

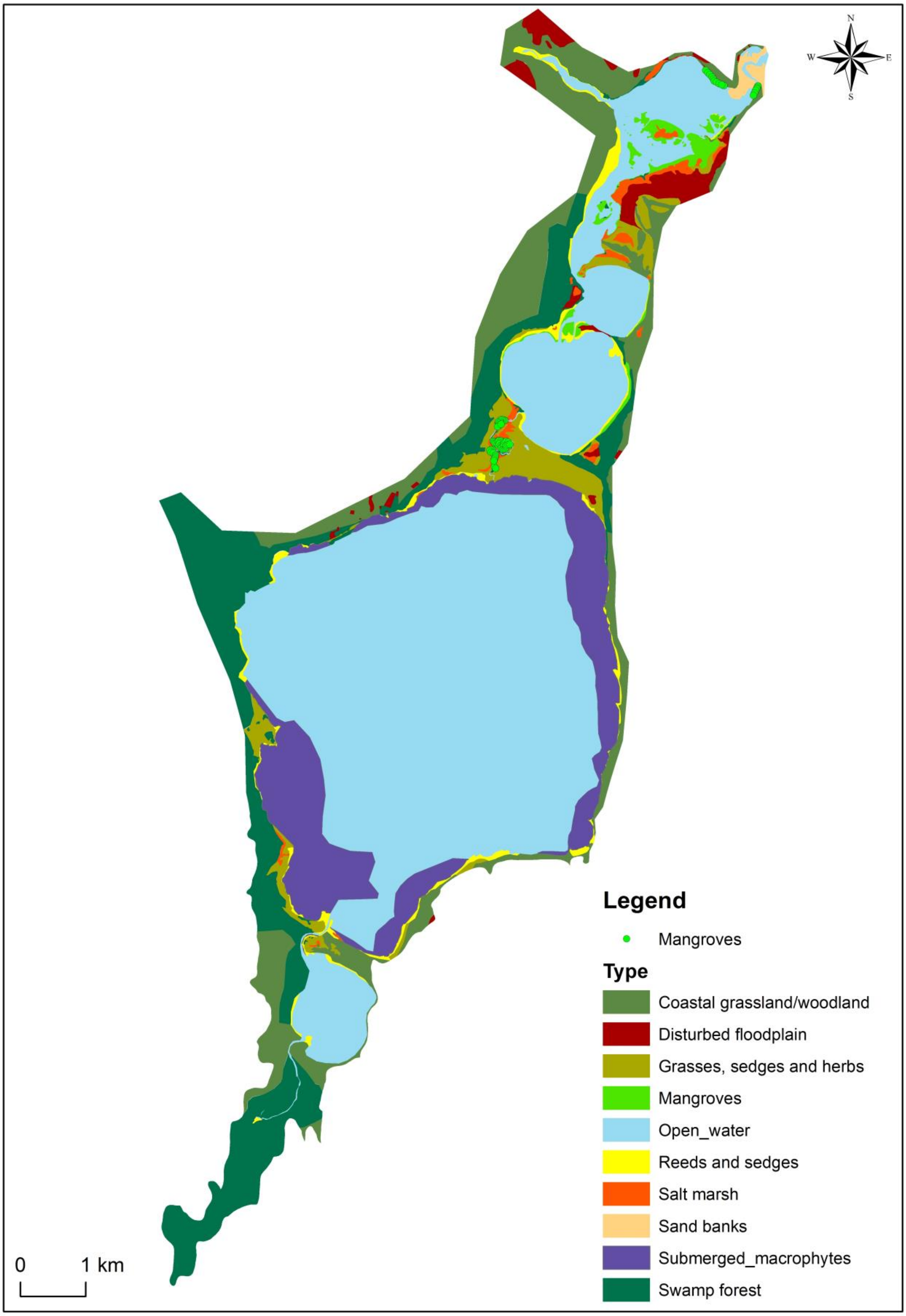


Figure 4.3 Distribution of macrophyte habitats at the Kosi Estuary based on 2013 aerial images.

ii) Description of factors influencing macrophytes

Table 4.22 Description of the factors influencing macrophytes

Variable	Grouping
Mouth conditions	Mass mortality of mangroves occurred in 1965/66 following a five month period of mouth closure, which resulted in flooding and prolonged inundation.
Retention times of water masses	Calm water results in extensive beds of submerged macrophytes.
Flow velocities (e.g. tidal velocities or river inflow velocities)	Strong flows in the channels between the lakes prevent the establishment of submerged macrophytes. These are however extensive in the shallows of Lakes 3 and 4.
Total volume and/or estimated volume of different salinity ranges	Salinity gradient results in a diversity of macrophyte habitats.
Water level fluctuations	Lakeshores are ecotones (a transitional zone between terrestrial and aquatic habitats) characterized by fluctuating water levels. Any rapid changes in water level will result in vegetation changes. Stable water levels can also cause an expansion of macrophytes such as reeds and sedges. Mangroves and swamp forest are sensitive to flooding, standing water and anoxic conditions and will not survive prolonged inundation (months).
Wave action	The edges of the estuarine lake are defined by distinct zones of emergent macrophytes, which act as a wave barrier for submerged macrophytes that grow in the shelter of these plants.
Floods	Floods would increase turbidity resulting in some loss of submerged macrophytes.
Salinity	A diversity of macrophytes is distributed along the salinity gradient; these are important indicators of changes in salinity. Groundwater inflow and seepage results in lower salinity in the root zone. Each species has a specific salinity tolerance range; particularly the submerged macrophytes in the Kosi system: *Zostera capensis* and *Ruppia cirrhosa* = 15 to 45, *Stuckenia pectinata* = <15, *Ceratophyllum demersum* = < 5 psu. *Lumnitzera racemosa* and *Bruguierra gymnorrhiza* are more tolerant of prolonged basal inundation by water and low salinity than the other mangrove species and thus extend further from the mouth than any of the other mangrove species.
Turbidity	The system is clear resulting in a proliferation of submerged macrophytes particularly in Lakes 3 and 4.
Dissolved oxygen	The extensive submerged and emergent macrophyte stands influence in situ oxygen concentrations particularly in the littoral zone.
Nutrients	The biggest threat to Kosi is deterioration in water quality. An increase in nutrients could change the system from the clear water macrophyte state to a eutrophic turbid system. Aquatic weeds such as *Azolla pinnata* subsp. *africana* (water fern) and water lettuce, *Pistia stratiotes* would proliferate.
Sediment characteristics (including sedimentation)	Groundwater input will be particularly important for the vegetation in large sandy areas.
Groundwater seepage	Seepage shorelines where swamp forest and reeds and sedges occur will be sensitive to changes in groundwater input.
Other biotic components	In a status assessment of the mangroves of South Africa, Rajkaran and Adams (2011) found that the height of adult trees at Kosi Bay were significantly shorter than at other northern KwaZulu-Natal forests. This was attributed to a lack of nutrients, particularly phosphorus, in the system. However it could also be due to intense resource harvesting.

Table 4.23 Summary of Macrophyte responses to different abiotic states.

State	Response
State 1: Open, fresh	Possible loss of some of the more salt loving species. Flooding can introduce silt and increase turbidity resulting in loss of submerged macrophytes.
State 2: Open, saline	Possible loss of some of the more freshwater species, however this represents the present state where a diversity of macrophytes was found.
State 3: Open, very saline	Loss of some salt intolerant species but no changes in biomass expected.
State 4: Closed	When the mouth closes the water level rises, resulting in inundation and die-back of all emergent vegetation particularly the more sensitive mangrove and swamp forest stands. Flooding of peripheral vegetation could encourage plants with a short lifespan/rapid recolonisation (reeds and bullrushes) rather than trees (swamp forest and raphia palms). Changes in salinity to a fresher system will decrease diversity.

iii) Reference condition

Comparison of aerial photographs (earliest: 1942 and most recent: 2013, Table 4.24) and field surveys of the Kosi Estuary in February 2016 showed little change in the distribution of macrophyte habitats. Forest and floodplain habitat previously cleared for agriculture in the 1942 aerial photographs has regrown. Over time there has been a small increase in the area of mangrove habitat in the Kosi Estuary with some of the islands in the tidal basin merging. Although the overall area of mangroves has increased there is intense harvesting of the trees particularly for brushwood to continually maintain the fish traps. Reed and sedge habitat has increased in cover where the Sihadhla River enters Lake 4 and an area north of Lake 2. However, the poor resolution of the old aerial photographs prevents precise calculations of changes over time.

Although few changes are evident from aerial photographs the effects of resource utilisation on the vegetation is extensive throughout the lakes and estuary as observed during the 2016 site visit. Harvesting of mangroves, reeds, palms, sedges and grasses was evident throughout the estuary. Burning of surrounding floodplain and forest habitat is also problematic and previous studies have emphasised the susceptibility of mangroves to fires (Ward et al. 1986).

Table 4.24 Summary of relative changes in Macrophytes from Reference Condition to Present state.

Habitat (within 5 m contour line)		**Key drivers for changes in area cover from reference**
Submerged macrophytes	~	Area cover is dynamic fluctuating in response to water level, turbidity and other disturbances.
Swamp forest	~	Agriculture and slash& burn, Recovery from previous cleared areas visible in 1942 back to similar area to reference
Mangroves	↑	Natural succession, sedimentation and growth from fish traps
Reeds & sedges	↑	Expansion, possible increase in nutrients in some littoral areas encourages growth as well as stable water levels
Floodplain	↓	Due to slash and burn, agriculture, grazing, trampling, access paths
Overall 10% loss of habitat		

4.6.2 Macrophyte health

The full system, in all its various zones, still retains habitat for all the species. We do not know of any loss in species when comparing present to reference states. Table 4.25 provides a summary of the Macrophyte components health scores.

Table 4.25 Macrophyte component health score.

Variable	Summary of change	Score	Conf
1. Species richness	Disturbance of the floodplain has possibly led to a loss of species	95	M
2. Abundance	Loss of habitat due to slash and burn, agriculture, grazing, trampling and access paths. Intense harvesting of reeds, sedges and mangroves would have decreased biomass and density.	90	M
3. Community composition	Burning results in loss of swamp forest, mangroves, reeds and sedge areas to disturbed floodplain, grasses and shrubs.	90	M
Biotic component health score		**90**	
% of impact non-flow related (due to N and P enrichment and aliens)		100	
Adjusted score		**100**	

4.7 Invertebrates

4.7.1 Overview

i) Main grouping and baseline description

Fauna that reside in the sediments (benthic macroinvertebrates), on or near the substrate (crustaceans, molluscs and annelid worms) and non-vertebrate planktonic organisms are collectively aquatic invertebrates. Invertebrates are secondary producers and many are primary consumers, constituting an important component of estuarine ecosystems, linking phytoplankton production and higher trophic levels.

The spatial and temporal heterogeneity of estuarine invertebrate distributions is determined primarily by longitudinal salinity gradients, but also sediment composition for invertebrates living on, or in substrates. These two parameters, in concert with a complex suite of other biotic and abiotic variables overall, structure an estuary's invertebrate community.

Although Kosi has been relatively well studied (Whitfield & Baliwe 2013), focussed studies on the invertebrate component have been sparse and in some cases, have not been done in over 40 years. Table 4.26 includes a summary of the studies excluding the most comprehensive to date, a seasonal study from 2002-2003 and winter 2006 on the macrobenthos from the Estuary to Lake 4.

Table 4.26 Summary of Kosi invertebrate studies prior to 2002.

	Habitat	Zooplankton	Macrocrustacea	Macrobenthos	Other	Comments	Date of study	Ref.
Estuary		Descrip.		Descrip.			Aug-71	4
		Descrip.		Descrip.			Aug-76	7
	Depth unspec.		Sp. List	Sp. List			Oct-Sept 78/9 & 79/80	5
		Descrip.	Descrip.	Descrip.			88 (updated 95)	10
			P/A	P/A	P/A		11-19 Jul-49	2
	Littoral	Sp. list					1958	15
			Fisheries, Sp. list				1999-2000	14
	Shallow (<3m)		P/A	P/A	P/A		11-19 Jul-49	2
		Abund..		Abund..	Abund.		10-12 Aug-71	8
	Deep (>3m)		P/A	P/A	P/A		11-19 Jul-49	2
Lake 1			P/A	P/A			11-19 Jul-49	2
		Descrip.		Descrip.			Aug-76	7
	Depth unspec.			Sp. List			Oct-Sept 78/9 and 79/80	5
		Descrip.	Descrip.	Descrip.			1988 (updated 95)	10
		Sp. list, Descrip.					2002-2003	9
		Abund..		Abund..	Abund.		10-12 Aug-71	8
	Shallow (<3m)		P/A			*Calichirus kraussi*		6
		Descrip.		Descrip.			Aug-71	4
				Abund..			10-12 Aug-71	8
	Deep (>3m)		P/A			*Calichirus kraussi*		6
		Descrip.		Descrip.			Aug-76	7
Lake 2			P/A	P/A			11-19 Jul-49	2
		Descrip.		Descrip.			Aug-76	7
	Depth unspec.		P/A	P/A			Oct-Sept 78/9 and 79/80	5
		Descrip.	Descrip.	Descrip.			1988 (updated 95)	10
		Sp. list, Descrip.					2002-2003	9
	Littoral		P/A	P/A	P/A		10-12 Aug-71	8
		Abund..		Abund..			10-12 Aug-71	8
	Shallow (<3m)		P/A			*Calichirus kraussi*		6
		Descrip.		Descrip.			Aug-71	4
	Deep (>3m)		P/A			*Calichirus kraussi*		6
		Descrip.		Descrip.			Aug-76	7
Mtando ch.	Shallow (<3m)	Abund..		Abund..	Abund.		10-12 Aug-71	8
	Littoral		P/A	P/A	P/A		10-12 Aug-71	8
Lake 3			P/A	P/A	P/A		11-19 Jul-49	2
			Sp. List	Sp. List	Sp. List			1
	Depth unspec.	Descrip.		Descrip.			Aug-76	7
				P/A	P/A		Oct-Sept 78/9 and 79/80	5
		Sp. list, Descrip.					2002-2003	9
	Littoral		P/A	P/A	P/A		10-12 Aug-71	8
		Descrip.		Descrip.			Aug-71	4
		Abund..		Abund..	Abund.		10-12 Aug-71	8
	Shallow (<3m)			Feeding ecol.		*Tarebia granifera*	Nov-08	11
				Pop. dynamics		*Tarebia granifera*	Nov-09 & 10	12
				Density		*Tarebia granifera*	Nov-08	13
	Deep (>3m)	Abund..		Abund..	Abund.		10-12 Aug-71	8
Lake 4	Depth unspec.	Descrip.		Descrip.			Aug-76	7
		Sp. list, Descrip.					02-03	9
	Littoral							
	Shallow (<3m)			Abund..			10-12 Aug-71	8
	Deep (>3m)							
Malangeni R.	Littoral		P/A	P/A	P/A		10-12 Aug-71	8

P/A Presence/Absence

References

1 Boltt & Allanson (1975)
2 Broekhuysen & Taylor (1959)
3 Champion (1971)
4 Cloete & Oliff (1976)
5 Cyrus & Blaber (1984)
6 Forbes (1979)
7 Gardner et al. (1983)
8 Hemens et al. (1971)
9 Jerling & Weerts (2006)
10 Kyle (1995)
11 Miranda et al. (2011a)
12 Miranda et al. (2011b)
13 Miranda & Perissinotto (2012)
14 Pederson et al. (2003)
15 Tinley (1976)

Without taking into account abundance, overall invertebrate assemblages are more species rich in the Estuary (where typically marine species are also able to reside) and least speciose in the freshwaters of Lake 4 (Figure 4.4). Crustaceans (Decapoda and Copepoda) and Gastropoda are the highest contributors to the list of different taxa found, primarily in the estuary, where Polychaeta are also more numerous. Note for comparative purposes, species names as per original literature are retained. The following species names have changed as per the World Register of Marine Species (WoRMS 2016): *Apseudes digitalis* (to *Halmrapseudes cooperi*), *Callianassa kraussi* (to *Callichirus kraussi*) *Ceratonereis keiskama* (to *Ceratonereis Composetia keiskama*), *Corophium triaenonyx* (to *Americorophium triaenonyx*), *Matuta lunaris* (to *Ashtoret lunaris*), *Rhyncoplax bovis* (to *Neorhyncoplax bovis*) and *Tanais philetaerus* (to *Sinelobas standfordi*).

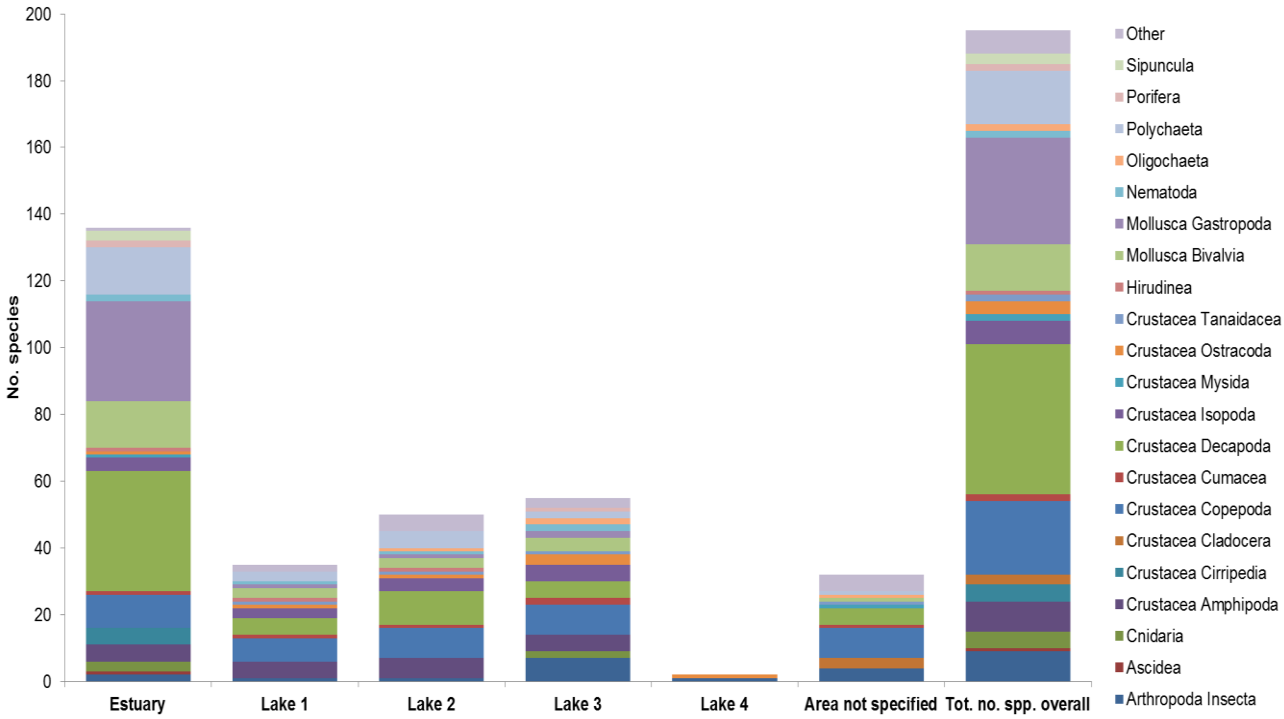


Figure 4.4 Distribution of different species across the Kosi estuarine lake system, based on all historical invertebrate surveys until 2003.

Zooplankton: Estuaries characteristically support a wide variety of marine, estuarine and freshwater holoplanktonic (complete life cycles within the plankton) and meroplanktonic animals (spending part of their lives in the plankton before progressing to the nekton or benthos) because of their links with freshwater and marine environments. The dominance of any of these components depends on individual estuary characteristics. These abiotic attributes link to environmental fluctuations that are short term e.g. tidal cycles, medium term related to seasonal cycles, or longer-term events such as decadal wet and dry cycles.

Kosi estuarine lakes are neither diverse nor abundant in zooplankton. This was the consensus of the very few studies done to date. The last documented study of Connell et al. (1976), did not sample the whole system, but did *ad hoc* collections in three lakes during daylight hours only. More recently, to address the data gap and understanding of zooplankton of the Kosi system, the Coastal Research Unit, University of Zululand embarked on a seasonal survey of the mesozooplankton of the four lakes from 2002-2003 (CRUZ unpublished data, Jerling and Weerts 2006). Mesozooplankton (size range 0.2-20 mm) is an important food source for larval and planktivorous fish and an energetic link between primary producers and secondary consumers (Neumann -Lleitao et al. 1999). Then, samples were collected after dark at one station at each of the four lakes using a double plankton net (mouth diameters 300mm, 2m net lengths, 200µm mesh size). The net was towed 1.5m below the surface for 3 minutes at each site. Salinity had a large influence on mesozooplankton distribution and composition. Lakes 3 and 4 supported a largely freshwater community while estuarine/marine species were present in Lakes 1 and 2. Lake 4 (Amanzimnyama) was consistently below 0.5 psu and the zooplankton assemblage was different from the other lakes as was the community within Lake 3 (Nhlange) with salinity ranging from 1.1 to 1.4 psu. Lake 2 (Mpungwini, salinity 7.4 - 15.5 psu) and Lake 1 (Makhawulani, salinity 9.9 - 22.3 psu) supported a comparable community and species complement. Overall, the zooplankton was neither diverse nor abundant (29 taxa reported overall), more individuals and species being found with higher salinity in Lakes 1 and 2 (Jerling and Weerts 2006), with species *Acartia natalensis*, *Pseudodiaptomus stuhlmanni* (calanoid Copepoda) and *Mesopodopsis africana* (Mysidacea) dominating Lakes 1 and 2. Freshwater cyclopoid copepods *Mesocyclops* sp. and *Thermocyclops* sp. and mites were limited to Lakes 3 and 4. No evidence of seasonality was found in the zooplankton. The findings were similar to a study conducted under drought conditions in nearby St Lucia where mesozooplankton was dominated by copepods during all sampling sessions, especially by the estuarine calanoids *P.stuhlmanni* and *A.natalensis (*Jerling et al. 2010*).* A notable difference comparing the studies of Connell et al. (1976) and Jerling (2002/3) is the disappearance of *P.hessei* from Kosi. During the earlier surveys, *P.hessei* was notably abundant as was the congeneric *P.stuhlmanni* (Oliff et al. 1977). The occurrence of both at that time extended the known distribution of these species, northwards (Gardner et al. 1983). Like many other estuarine zooplankton species, both copepods show a wide salinity tolerance from 0 to 80 psu (Jerling et al. 2010). Kyle (1995) also noted that marine zooplankton extends into the mesohaline reaches of Lakes 1 and 2. In addition, maximum densities in the system were from the eastern shores of Lake 1, postulated because of the higher water residence time there. Kyle's (1995) notes on the zooplankton further state that the system was dominated by *P.hessei*, being one of the few 50 taxa reported at sparse density, likely due to the oligotrophy of the system. It is not clear where the data for the description were sourced, but are likely from an August 1971 survey in the tidal basin and into Lake Mpungwini (Lake 2). Then, >50 taxa were found amongst the 3500 zooplankters obtained during a 50m haul (net diameter 25cm, mesh 80 microns), this was considered sparse relative to other systems and attributed to nutrient poor conditions (Hemens et al. 1971).

Macrobenthos: As with the other invertebrate components, few data exist on the macrobenthos of Kosi and none considers the entire system in one study. In 2002, the Coastal Research Unit of Zululand, University of Zululand (unpublished data) commenced data collection across the system to ascertain the baseline conditions of infauna from the mouth to Lake 4. Samples taken during successive sampling periods during austral summer (February), autumn (April), winter (August) and spring (October/November)from 2002-2004 and 2006 at 18 pre-selected sites. Sampling was limited to depths of <3m around the lake margins because the deeper areas are anoxic due to the bathymetry of the system (Allanson and Van Wyk 1969). Quantitative samples were collected using a Zabalocki-type Ekman grab for uniform substratum samples with a surface area of

0.0236m^2 to a depth of 4.5cm, with accompanying sediment distribution information and water physicochemistry.

Results showed the system to be rich and abundant and elements of the fauna were comparable to other KZN estuaries, the remainder being different in that they have preferences for clear, sandy, saline conditions more akin to nearshore marine environments rather than the turbid, muddy estuarine affiliated fauna of KZN. Over 200 taxa were found over the study, but 10 were good indicators of salinity states in that the assemblages showed a degree of zone fidelity. The majority of zone specific taxa were limited to polyhaline/euhaline zone in the lower reaches (Lake 1 and the estuary). Six of the zone fidelity taxa occur in other estuaries on the coast but there they are limited to the mesohaline zone. Estuarine resident species and direct developers/brooders (without a larval phase) *Ceratonereis keiskama*, *Corophium triaenonyx* and *Iphinoe truncata* were distributed across three different zones (polyhaline-oligohaline). Typical marine zone species were Nemertea spp. (12 taxa) and the fossorial amphipod *Urothoe pinnata*. The latter are common in nearshore marine samples (*F. MacKay ACEP Natal Bight data*). The estuarine mussel *Brachidontes virgiliae*, *Corophium triaenonyx* and *Grandidierella bonnieroides* were highly abundant in the REI region of Lake 2. *Ceratonereis keiskama* was ubiquitous at all stations in Lake 3. Lake 4 supported the largest abundance of Oligochaeta and Chironomidae larvae. Salinity and coarse sand were the primary in-system abiotic influences of the macrobenthos.

Overall abundance (indiv.m^{-2}) was highest in the REI reaches of Lakes 1 and 2 (Figure 4.5), but showed high variability particularly at stations 5-7 and 9-11. The estuary was comparatively depauperate in biomass as was the freshwater reaches of Lake 4. This was in contrast to the numbers of different species encountered, where the highest numbers were at the mouth and declined exponentially up the system into Lake 4 (Figure 4.6). The estuary showed the highest variability in species occurrences (Site 2), presumably due to ingressions of marine species via the mouth. Notable changes from previous studies were that there was a notable reduction in the 37 mollusc species present in 1949 (Broekhuysen and Taylor 1959) with only three species reported after 1965 (until 2002/2003) (Hemens et al. 1971). *Brachidontes virgiliae* appeared after 1966 (Kyle 1995) and remains abundant (seen from visual census in February 2016).

This most recent visual survey also indicated exceptionally high numbers of Assimineidae gastropods from sediment cores collected along the littoral margins of Lakes 1-3. Assimineidae are also now prolific in St Lucia that has undergone a prolonged deficit of freshwater (>decade). The species may be indicative of natural, cyclical change in estuarine coastal lakes. Lastly, detritus feeding *Melita zeylanica* and the taniad *Tanais philetaerus* were prolific in 1971 (Hemens et al. 1971), but neither have been recorded since. Overall, there has been relatively little change in the species composition of the benthos identified by Broekhuysen and Taylor (1959), Hemens et al. (1971) Boltt and Allanson (1975) and Oliff et al. (1977). Table 4.27 provides an overview of Invertebrate groupings and their defining features and typical/dominant species.

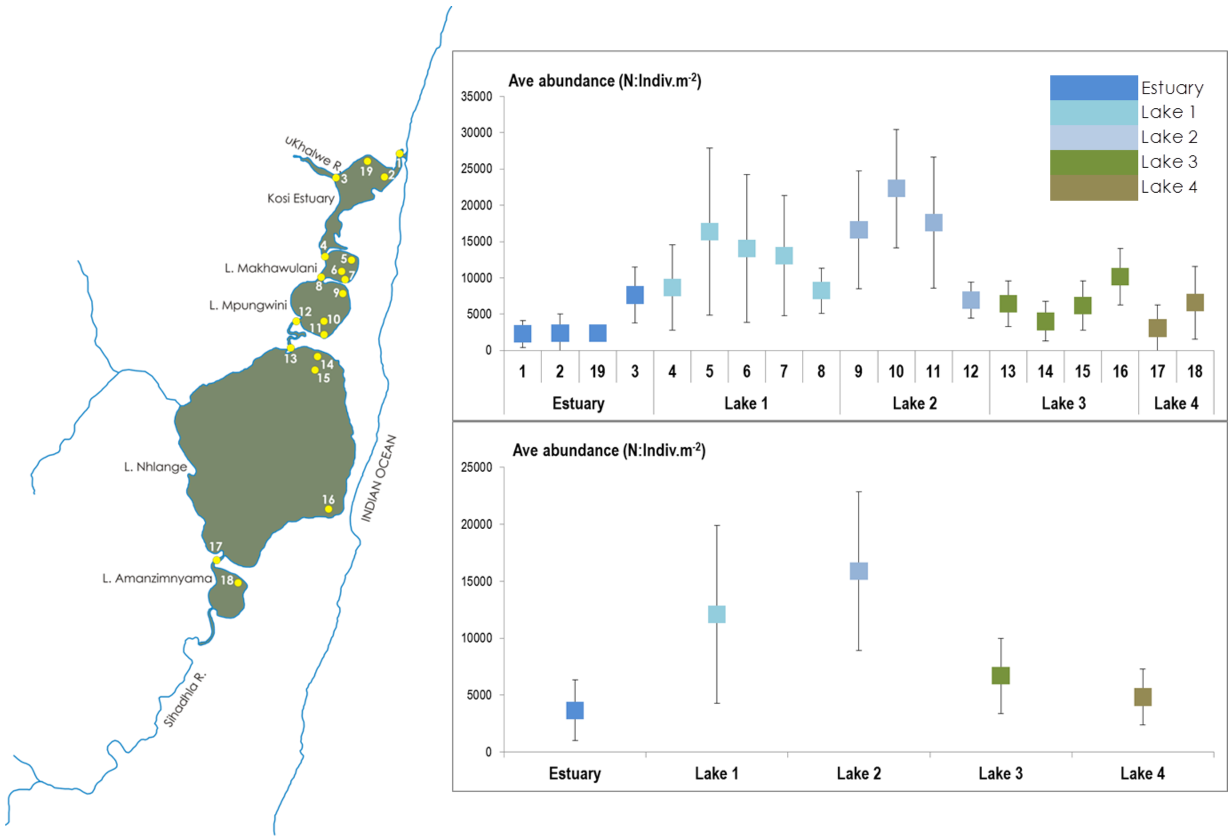


Figure 4.5 Abundance distribution (indiv.m^{-2}) of macrobenthos across the Kosi estuarine lake system, based on surveys until 2002-2004, 2006.

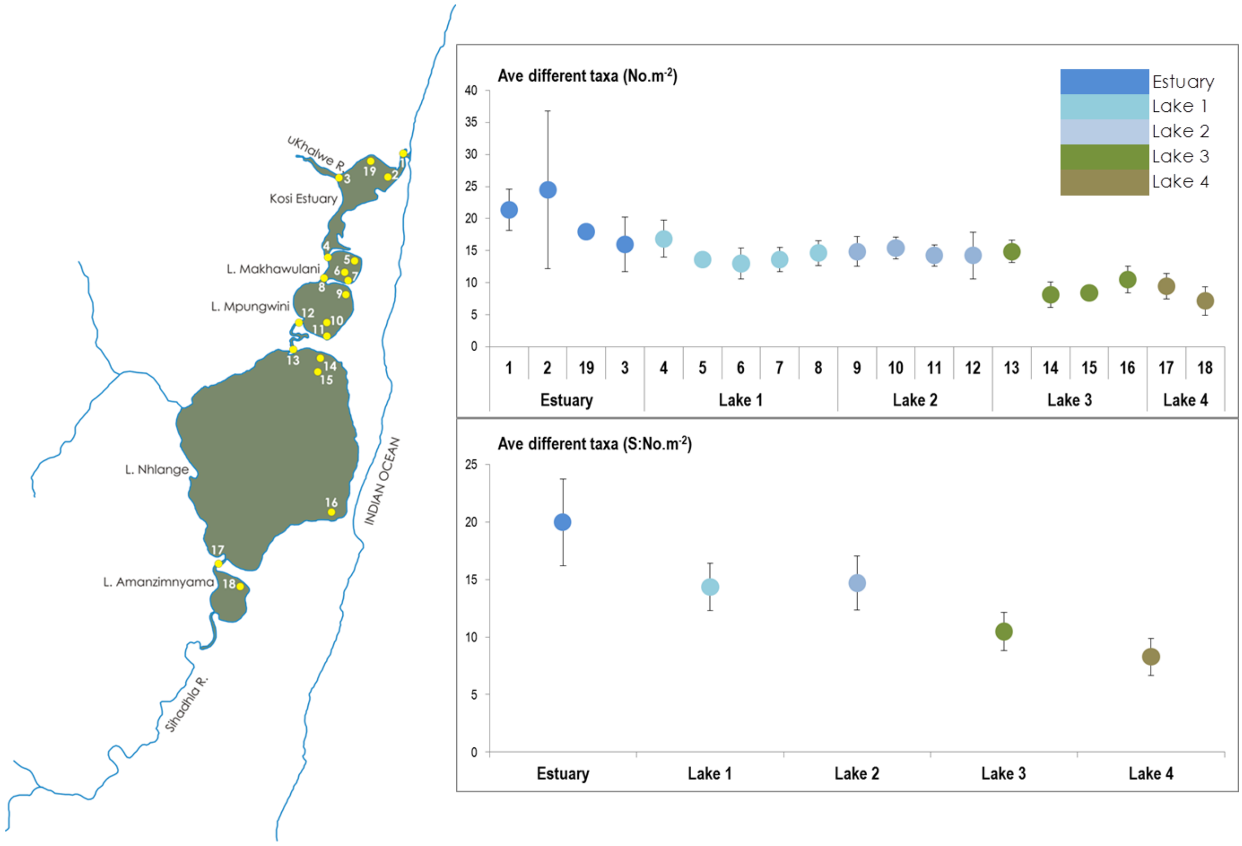


Figure 4.6 Distribution of numbers of different macrobenthos taxa (No.m^{-2}) across the Kosi estuarine lake system, based on surveys until 2002-2004, 2006.

Macrocrustaceans: No recent studies have addressed the macrocrustacea component of invertebrates in the Kosi system. Past studies were typically of single species, concerned with the biology of the fauna or were fisheries related. The most notable feature of the system's macrocrustaceans is the paucity of penaeid prawns (Champion 1971). The reason lies in the physical characteristics of the estuary where unlike St Lucia to the south that is a critical nursery to prawns, Kosi is silt free, nutrient deficient and has substrates that are comparatively coarse and clean sands. The lack of appeal as a settling habit was emphasised by Forbes and Cyrus (1991) who sampled penaeid postlarve at the mouth under near marine salinity (30 psu), including species *Penaeus japonicus*, *P. indicus, P. monodon, P. semisulcatus* and *Metapenaeus monoceros*. Adult *Penaeus japonicus* numbers were comparable to those found in St Lucia at that time, all other species were negligible or from single specimens. Macrocrustacea resident in the system, in particular burrowing sand prawn (*Callianassa kraussi*) distribution was investigated, and found in lower numbers on the northern shore of Lake 2 and the southern shores of Lake 1. Where prolific, *Callianassa* were in areas above 5m of water, particularly on eastern and western shores of Lake 1 in salinity 10-15 psu.

A site visit in February 2016 found *C.kraussi* to occupy the same areas but at deeper subtidal locations, down to 8m. Also, the sandprawn was prolific in Mtando Channel, which may attest to the elevated salinities there. The use of macrocrustacea by local communities was investigated by Pederson et al. (2003), in particular the subsistence use of *Neosarmatium meinerti*. In the late 1980s, it was calculated that up to 638 000 crabs.yr^{-1} were dug up around the lake by local women and children, including far fewer numbers of *Scylla serrata* and the land crab *Cardisoma carnifex*. These species are all associated with mangroves and apart from *S.serrata*, all were observed in 2016, including *Uca* spp. The earliest study on Kosi noted 22 macrocrustacea species from the estuary itself, with *Clibanarius longitarsus, Cyclograpsus punctatus, Epixanthus frontalis, Eriphia smithii, Grapsus strigosus, Matuta lunaris, Metapograpsus messor, Pseudograpsus erythraeus* being common (Broekhuysen and Taylor 1959). At that time *Palaemon pacificus* was common in Lake 1 and today (February 2016), *Palaemon* is still abundant there and between Lakes 1 and 2 in amongst mangrove root stocks. In Lake 4, a similar littoral niche is occupied by freshwater associated *Caridina nilotica*. *Hymenosoma* and *Rhyncoplax* are small crabs (<1cm) found on or in sediments and are often part of the macrobenthos. Both were prolific in Lake 2 (Broekhuysen and Taylor 1959, Hemens et al. 1971, Cyrus and Blaber 1984) and into the less saline Lake 3, particular along lake margins (Broekhuysen and Taylor 1959, Hemens et al. 1971, Boltt & Allanson 1975). These Hymenosomatidae are still abundant in the system. In February 2016 a notable occurrence of the grapsid, euryhaline crab *Varuna litterata* was noted in Lakes 1-4, but in particular an abundance of adults (males and females) were actively swimming up the Mthando Channel into Lake 3. The occurrence was so notable it was questioned if it was post breeding aggregation, as the species is known to travel down to lower reaches of estuaries early in the year and megalopae ingress in large numbers back into systems from the sea in April/May.

Table 4.27 Invertebrate groupings and their defining features and typical/dominant species.

Main groupings	Defining features and typical/dominant species
Zooplankton	
Marine	This group represents species that are typically marine, but occupy the polyhaline areas of the lower estuary. Few studies focussed on the estuary, given its shallow nature and hydrodynamics that do not support a stable zooplankton community. Surprisingly, no meroplankton were noted but copepods found included poecilostomatoid forms, which are ectoparasites of saltwater fish or invertebrates (including molluscs and echinoderms) and Harpacticoida species, which are benthic dwellers e.g. *Maraenobiotus* sp., *Metis* sp. Copepoda developmental stages at nauplius copepodite were found, but were depauperate.
Estuarine/marine	This group includes typically estuarine species that are resident in the system and also estuarine species with a marine requirement at some life stage. The upper estuary and Lakes 1 and 2 were sparse in density. Studies report likely due to the oligotrophy of the system. Jerling & Weerts (2006) found *Acartia natalensis*, *Pseudodiaptomus stuhlmanni* (calanoid Copepoda) and *Mesopodopsis africana* (Mysidacea) dominated Lakes 1 and 2. Crustacea zoea and fish eggs were found in the meroplankton and the highest numbers of nauplii (multispecies) and copepodites (multispecies) were found in this component. Hemens et al. (1971) also reported large numbers of *Diaptomus* (Calanoidea juveniles) and *Cyclops* sp. (Cyclopoidea).
Freshwater	Freshwater species that are limnetic or typically from lotic environments (e.g. aquatic insects). Freshwater cyclopoid copepods *Mesocyclops* sp. and *Thermocyclops* sp. and mites were found only in Lakes 3 and 4. Extensive numbers of nauplii (multispecies) and copepodites (multispecies) were found in Lake 3 (Hemens et al. 1971), with few medusae and zoea larvae in the meroplankton.
Macrobenthos	
Estuarine resident	Dominant group in Kosi with important assemblage defined by *Corophium triaenonyx* (Lakes 1-3), *Grandidierella bonnieroides* (Lakes 1-2*), Iphinoe truncata* (Lakes 1-2), *Brachidontes virgiliae* (lake 2), *Ceratonereis keiskama* (lake 3).
Marine	Marine species limited to stations in lower Estuary. Dominated by Sipuncula and conspecifics of fossorial *Urothoe*, Nematoda, Nemertea and numerous polychaete taxa in very low abundance.
Freshwater	Dominated by Chironomidae (15 types), Oligochaeta (7 taxa), Nematoda in Lake 4. Oligochaetes are numerous in Lake 3, all taxa have little or no tolerance to salinity.
Macrocrustacea	
Estuarine resident	Dominated (numbers & biomass) by burrowing sandprawn *Callianassa kraussi* in Lakes 1 & 2.
Estuarine dependent marine and visa versa	Few species recorded and none are persistent in the system due to lack of suitable habitat (*Penaeus japonicus, P. indicus, P. monodon, P. semisulcatus & Metapenaeus monoceros*). *Scylla serrata* limited to Estuary and has likely declined in numbers since 1980s.
Marine	Some Calappidea (*Matuta lunaris*) on sand flats at the mouth, many species (up to 20 noted in past studies in lower reaches of the estuary in polyhaline conduitions).
Freshwater	*Varuna litterata* is a catadromous sp. with an obligatory marine reproductive stage.

ii) Description of factors influencing invertebrates

Table 4.28 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various groupings of Invertebrates.

Zooplankton			
Variable	**Grouping**		
	Marine	**Estuarine resident & estuarine dependent marine**	**Freshwater**
Open water area	Proportional reduction of zooplankton biomass with loss of open water area		
Mouth condition	Mouth closure will prevent exchange of marine zooplankton between the estuary and the coastal		Mouth closure resulting in long term freshwater conditions will

Zooplankton			
Variable	Grouping		
	Marine	Estuarine resident & estuarine dependent marine	Freshwater
	marine environment or *vice versa* in the short term. Extended periods of mouth closure will lead to fresher conditions, but will not necessarily influence the abundance or dominance of *Pseudodiaptomus stuhlmanni*. *P.stuhlmanni* and *P.hessei* have been shown to actually flourish under these conditions, should microalgae be available (Jerling et al. 2010) Extended mouth closure will prevent the migration of certain crustacean larval stages, e.g. crab zoeae and megalopae relying on an open connection with the sea to complete their life cycles. Directional movement will be to exit the system and the return for some species to further develop into adults for catadromous species.		enhance the production of freshwater taxa such as freshwater cyclopoids, mites and cladocerans.
Flow (tidal inflow or surface water input)	Strong flows create unstable water column conditions for all groups and will reduce the abundance of the typical and dominant communities e.g. *Pseudodiaptomus stuhlmanni* and *Mesopodopsis africana* that are typical of Lakes 1-3.		
Retention times of water masses	Components respond to food sources, thus if phytoplankton and microphytobenthos are elevated with water retention, these fauna respond accordingly.		
Salinity	Elevated salinities, around seawater levels will support marine taxa and therefore also a more diverse zooplankton community.	This component is generally tolerant of wide ranging salinity and if a stable water column persists (with good primary production) this assemblage will expand or reduce in area depending on the salinity gradient.	Freshwater taxa (particularly insects) will only be supported at very low salinities>2 psu.
Turbidity	Unlikely that elevated turbidity from flooding or surface runoff will persist in marine influenced areas, given changing tide.	Most species will tolerate elevated turbidity for sustained periods or even in a typically turbid system (e.g. Jerling et al. 2010).	
Dissolved oxygen	Low oxygen levels (<50% saturation) will reduce zooplankton diversity and abundance.		
Microalgae	An increase in phytoplankton would result in an increase in zooplankton.		

Macrobenthos			
Variable	Grouping		
	Marine	Estuarine resident	Freshwater
Open water area	Reduction in open water that reduces subtidal habitat will influence macrobenthos total biomass. In particular, Lakes 1and 2 that have a perimeter of shallow bathymetry and a deeper central basin.		
Mouth condition	Short term mouth closure will prevent exchange of marine taxa between the lower estuary and the coastal marine environment or *vice versa* in the short term. The lower reaches are prolific in biodiversity for this component as it is still functional habitat for marine species. Long periods of closure will lead to less saline conditions and this will influence the abundance of macrofauna in the most abundant reaches to date (Lakes 1 and 2). This is the REI of the system and besides a large sand prawn biomass is also where biomass of shall, subtidal macrobenthos peaks.		Mouth closure resulting in long term freshwater conditions will enhance the production of freshwater taxa such as larvae of insects that are found only in Lake 4.

	Many species present are direct developers and are euryhaline to a large degree. Although diversity overall will decrease (loss of marine species), the macrobenthos will still retain a functional role in the ecology.		
Flow (tidal inflow or surface water input)	Unless strong flows are accompanied by high bottom turbulence such as during a flood or in the lower reaches in small channels in an outgoing tide, most species will be unaffected. Floods will temporarily scour surficial sediments and resident fauna, but this will be localised given the coarse and medium sand grains distributed across the system which are not conducive to prolonged entrainment. Bottom microalgae is a food source to many species, this being stable and available is a requirement of macrobenthos of the lakes in particular.		
Retention times of water masses	Components respond to food sources, thus if microphytobenthos is productive during long retention times, the macrobenthos will respond accordingly. If retention leads to stagnation and elevated primary productivity that is not remineralised, bottom dissolved oxygen levels and within sediments will be reduced and thus affect the abundance and distribution of all important species. Only the polychaete *Capitella capitata* is tolerant of persistent low dissolved oxygen. It is not prolific at present.		
Salinity	Elevated salinities, around seawater levels (30-35 psu) will support marine taxa that ingress the lower system and therefore also a consistently diverse macrobenthos.	Estuarine macrobenthos are widely tolerant of salinity and more fresh conditions. The REI for macrobenthos is in Lakes 1 and 2. For this component to remain comparable to natural communities, a longitudinal salinity gradient across the system (polyhaline to oligohaline) must persist that facilitates the perpetuation of six distinct assemblages that are lake specific two in the estuary, the last being specific to the fully marine conditions of the lower system.	Freshwater taxa (particularly insects) will only be supported salinities>2 psu. Depending on the distribution of salinity, these fauna occupy only Lake 4, but if more fresh conditions persist (with mouth closure and freshwater input), they will form a more important component of the macrobenthos in Lake 3.
Turbidity	Unlikely that elevated turbidity from flooding or surface runoff will persist in marine influenced areas, given changing tide.	Most species will tolerate elevated turbidity for sustained periods, given that many of these taxa found also occur in the highly turbid St Lucia system. However key fossorial taxa such as the *Urothoe* Amphipoda are typical in sandy, clear systems only. *Urothoe* are abundant from Lake 2 to the mouth.	
Dissolved oxygen	Low oxygen levels (<50% saturation) will reduce macrobenthos diversity and abundance. However, if species tolerant of low oxygen (e.g. *Capitella capitata*) expand into this niche of a less diverse fauna, abundance can remain fairly high. This polychaete can attain high biomass if monospecific in an area.		
Microalgae	An increase in microphytobenthos is food available for grazing infauna, which will also influence macrobenthos through an increase in abundance.		
Macrophytes	Macrophytes across the system and salinity ranges provide a habitat for various groups of littoral macrobenthic invertebrates. In the lower reaches it is the mangroves, in the lakes it is submerged macrophytes, reeds and sedges. All provide detritus which is a staple diet for key taxa (tanaids, polychaetes).		

Macrocrustaceans				
Variable	**Grouping**			
	Estuarine resident	**Estuarine dependent marine**	**Marine**	**Freshwater**
Mouth condition	Closed mouth conditions benefit estuarine species as they generally create more uniform conditions throughout the system and allow these species to expand into the upper and lower reaches e.g. Hymenosomatidae	Only few *Penaeus* occur in the system, but larval stages of other species rely on an open mouth to allow access to the estuarine nursery area. An open mouth also creates a salinity gradient and more variable salinities, thus increasing the chances of these species finding appropriate habitats. Timing of mouth closure is critical to the recruitment of crabs and prawns, and prawns require an open mouth in early summer.		Migration of catadromous crabs (e.g. *Varuna*) requires an open mouth for adults to exit in late summer and for the post alrvae (megalopae) to return in autumn and agin in spring.
Salinity	Larval development requires brackish water, with most species requiring salinities of around 8-20 psu. Salinities below 5 will affect larval development.		Any marine prawns in the system will be restricted to the mouth area under marine salinities and will perish if salinities drop with prolonged mouth closure.	*Caridina* prawns require freshwater conditions for development.
Dissolved oxygen	Macrocrustaceans are generally sensitive to reduced oxygen levels and their survival will be affected <3mg/l.			
Tidal flow	-	*Uca* are intertidal species, associated with mangroves in the lower reaches and whose lifestyles are dependent on tidal rise and fall.		-
River flow	River flow is important due to its effect on mouth status and salinities, flood related flows strong flows will wash epibenthic prawns out of the system	Strong river flows will create low salinity conditions along the entire system, except for a small and very steep salinity gradient at the mouth. This will push developing prawn larvae and subadults out to sea, prematurely, as they cannot withstand low salinities. The possibility is that this creates better conditions for freshwater prawns, if low salinity conditions persist.		Strong river flows will create more suitable conditions for freshwater crustaceans (inclusing *Potamonautes* crabs) throughout the system, allowing them to expand into Lake 3 from freshwater dominated Lake 4.
Macrophytes	Macrophytes across the system and salinity ranges provide a habitat for various groups of Macrocrustacea. In the lower reaches it is the mangroves with associated crabs, in the lakes it is submerged weeds, reeds and sedges that provide habitats for various species of crabs and prawns			

Table 4.29 Summary of Invertebrate responses to different abiotic states.

State	Response
Zooplankton	
State 1: Open, fresh	As with microalgae biomass and species structure of assemblage is dependent on nature of flows. Freshwater groups in particular insect larvae, mites and freshwater cyclopoids, and cladocerans will be the dominant assemblage and extend further down the system into Lake 3 and possibly Mthando channel. Overall zooplankton community is depauperate.
State 2: Open, saline	An open, saline state would support a well-defined salinity gradient into Lake 3. If Lakes 1 and 2 sit within the REI salinity range (15-20 psu), in terms of biomass and species an abundant community will be resident in Lakes 1 and 2, dominated by mysids and few species of copepods (e.g. *Mesopodopsis* and *Pseudodiaptomus*).
State 3: Open, very saline	Some loss in biomass and those species intolerant of higher salinities.
State 4: Closed	A more stable system in terms of water retention will lead to increased zooplankton productivity of a few species, in particular if microalgae biomass increases. With time salt intolerant species will be the dominant group. Loss of species that ingress via an open mouth.
Macrobenthos	

State 1: Open, fresh	The macrobenthos will be a less diverse and abundant component of invertebrates. Current high diversity is afforded by an open mouth and marine conditions in the lower system. The dominant assemblage in Lake 4 will extend into Lake 3, constituting freshwater affiliated insects (Chironomidae larvae), oligochaetes, nematodes and resident estuarine species that have high tolerance for extended fresh conditions. The REI will be compressed and move into the Estuary, where sediment conditions are more coarse and less conducive to a productive infauna.
State 2: Open, saline	An open, saline state would support a well-defined salinity gradient into Lake 3 and a range of salinity from polyhaline/euhaline to oligohaline. If Lakes 1 and 2 remain in the mesohaline REI salinity range, an abundant community will reside there and be dominated by typically estuarine fauna found elsewhere in KZN e.g. *Ceratonereis keiskama*, *Grandidierella bonnieroides* and the cumacean *Iphinoe truncata*.
State 3: Open, very saline	Some loss in biomass and those species intolerant of higher salinities, particularly further in the system. Sipuncula and Nemertea (multi species) are confined to the lower reaches. Given similar sediment distribution these marine types would be able to ingress into Lake 1 and if sustained low freshwater input, into Lake 2. Abundance would decline significantly as most macrobenthos are within the REI, but diversity many not decline significantly, due to increased opportunities for marine species.
State 4: Closed	A more stable system in terms of water retention will initially translate into increased biomass (of a few species) if microalgae biomass increases. With time salt intolerant species will be the dominant group. Loss of species that ingress via an open mouth.
Macrocrustaceans	
State 1: Open, fresh	The majority of species rely on an open mouth, but with good saline penetration into the system, The post larvae using salinity as a cue to settle into adult habitats.
State 2: Open, saline	An open, saline state would support a well-defined salinity gradient into the system. This is the best state to retain an abundant and diverse Macrocrustacea.
State 3: Open, very saline	Some loss in biomass and those species intolerant of higher salinities e.g. *Caridina* and *Varuna*. Hymenosomatidae that prefer the REI would ingress higher up into the system.
State 4: Closed	A closed system is catastrophic for all forms associated with mangroves that would inundate and eventually disappear and also other littoral macrophytes from lake habitats, particularly if water levels rise rapidly.

iii) Reference condition

Zooplankton: Direct threats to the zooplankton are through changes to hydrodynamics (volume, flow, mouth state), which directly alter the habitat, or changes to the water chemistry, which influence various physicochemical tolerances of Kosi species (e.g. low oxygen). Neither of these estuary properties has changed significantly from the reference condition. It is assumed that the zooplankton is largely natural other than a loss of one species in particular, *Pseudodiaptomus hessei* (which was not recorded in the last collections of 2002-2003). Potential future changes are increased fertiliser, sewage and other nutrient inputs with increased habitation in the greater catchment and immediately adjacent to the system. Any increased use of freshwater (ground or surface waters) that potentially should have ended up in the system will reduce pelagic habitat and therefore potential for zooplankton to remain at current levels.

Macrobenthos: Aside from changes to the water column chemistry brought about by hydrodynamic influences or input of excess nutrients or toxicants, the macrobenthos are typically highly influenced by sediment type. Hydrodynamic conditions and water chemistry have not changed significantly from reference conditions. The macrobenthos is largely natural in the metrics of abundance and diversity and to a lesser degree community composition. The latter recent change is brought about by an infestation over a large spatial area of the Asian invasive mollusc *Tarebia granifera*, a freshwater resident with slight euryhaline properties. As of February 2016, *T.granifera* was confined to Lakes 3 and 4, but was also observed in the Mthando Channel between Lakes 3 and 2. Infestation is thought to have occurred in the mid 2000s. Past studies report on numerous species of molluscs across the system. Although no targeted sampling approaches have been conducted recently, it does appear as if the system supports fewer species than before anthropogenic influence. Future changes relate to occupation of the catchment and the indirect effects of livestock farming, agriculture and vegetation clearance. Direct effects will be from this occupation and the use of freshwater resources, in particular groundwater and runoff of wastewater. The influence of groundwater seepage and directly as porewater in the littoral macrobenthos is completely unknown. It is suspected that this is an important influence and should be studied further. Seepages offer refugia, but are also an invisible transport mechanism of catchment toxicants and excess nutrients that will directly affect fauna residing in sediments.

Macrocrustacea: This group is influenced variously by the conditions within habitat (sediments, macrophytes, water physicochemistry), but also these fauna have planktonic stages in their lifecycles that are directly affected by conditions of the water column and also are highly dependent in most cases on an open mouth to leave the system and to recruit back. Marine species also ingress as adults and make use of suitable habitat in the lower estuary. All threats to habitat (as for zooplankton and macrobenthos) will also be highly pertinent for Macrocrustacea. Changes to water flow and thus mouth conditions and salinity will be important for this group. One anthropogenic effect that has a direct effect on macrocrustaceans is extraction as food resource. Several species are harvested at present, and over a decade ago was documented as substantial. Use will increase with an increasing population relying on subsistence resources from the system.

Table 4.30 provides and overview of the relative changes in Invertebrates from Reference Condition to Present state.

Table 4.30 Summary of relative changes in Invertebrates from Reference Condition to Present state.

Zooplankton	
Key drivers	**Change**
Groundwater input & surface water inflow	Slight increases in salinity influence, particularly higher up in the system have reduced the freshwater component. The communities that were typical of Lakes 1 and 2 have extended slightly into Lake 3.
Salinity	Small changes in salinity would decrease/increase species richness from natural in the various compartments. Currently, the communities are separate in the estuary, Lakes 1 and 2, Lake 3 and Lake 4.
Nutrients	Marginal, site specific increases have occurred, but these do not extend to large lake or estuary areas thereby influencing plankton. Increases in input coupled with higher retention times in areas would create low oxygen conditions not suitable for zooplankton.
Toxic compounds	Organochlorine insecticide use (DDT) has been numerously reported for the catchment and region over decades. DDT is highly toxic to many aquatic invertebrate species including marine forms and is persistent over many years, particularly as it sorbs tightly to organic matter. Although the system is a poor supporter of zooplankton, some repression of the community due to extensive DDT use to the present day is assumed.
TOTAL CHANGE	**Overall small changes in habitat for zooplankton and small decreases in biomass and species richness.**

Macrobenthos	
Key drivers	**Change**
Groundwater input & surface water inflow	Slight increases in salinity influence, particularly higher up into the system. The communities that were typical of Lakes 1 and 2 have extended slightly into Lake 3. The macrobenthos of Lake 4 that was typically freshwater dominated, now include freshwater tolerant estuarine species.
Salinity	Small changes in salinity decrease/increase species richness from natural in the various compartments. Currently, there are six distinct macrobenthos communities, but with overlapping taxa in areas dependent on salinity regime; lower and remaining estuary, Lakes 1 and 2, Lake 3 and Lake 4.
Nutrients	Marginal, site specific increases have occurred, but these do not extend to large lake or estuary areas thereby influencing macrobenthos. Increases in input coupled with higher retention times in areas would create low oxygen conditions because of elevated microalgal production that is not taken up.
Toxic compounds	DDT use and influences has been numerously reported for the catchment and region over decades. DDT is highly toxic to many aquatic invertebrate species including marine forms and is persistent over many years. There is no direct evidence to support the reported decline in Mollusca (which may be a natural cycle over the extreme long-term), persistent effects of toxic compounds with relatively long half-lives is a possible explanation.
Invasive species	Thus far, the influence of *Tarebia* is confined to the macrobenthos as the snail is a sediment dweller. Thus far, it is assumed that the physical presence of *Tarebia* reduces potential habitat for estuarine fauna tolerant of freshwater and freshwater species. Little is known of the effects of possible chemical effects of the snail or zoonotic pathogens that affect the macrobenthos.
TOTAL CHANGE	**Overall small changes in habitat for macrobenthos and small decreases in biomass and species richness, but large changes to community composition related to Mollusca species loss and the invasion of *Tarebia*.**

Macrocrustaceans	
Key drivers	**Change**
Hydrodynamics (flow, mouth state)	The system is characterised by a range of marine-freshwater species that for various reasons require an open mouth for recruitment (of post larvae) or movement in and out of adults. Thus far, the system is permanently open and this is not an issue for Macrocrustacea diversity and abundance in the system.
Salinity gradient	Small changes in salinity decrease/increase species richness from natural in the various compartments, particularly in Lakes 3 and 4, but which are characterised by low diversity and abundance.
Macrophytes	Many species spend much of the time associated with macrophytes of various forms (e.g. Hymenosomatidae in submerged grasses of Lakes 1 and 2, *Uca* and Sesarmidae associated with mangroves in the estuary, *Palaemon* and *Caridina* spp. throughout the lakes in root stocks) Given the increase in mangrove density, changes to abundance and community composition are related to an increase in this component.
Toxic compounds	DDT use and influences has been numerously reported for the catchment and region over decades. DDT is highly toxic to many aquatic invertebrate species including marine forms and is persistent over many years.
TOTAL CHANGE	**The macrocrustaceans are largely natural but changes relate to an increase in mangroves and therefore the species that are associated with them. This is counter-balanced by the harvesting of this resource (mangrove species in particular) by subsistence users.**

4.7.2 Invertebrate health

The present health of Zooplankton, Macrobenthos and Macrocrustacea remains largely natural. The scores and description of variables are presented in Table 4.31.

Table 4.31 Invertebrate component health score.

Zooplankton			
Variable	**Summary of change**	**Score**	**Conf**
1. Species richness	Reported as consistently depauperate. Loss of signature species, *Pseudodiaptomus hessei*.	85	L
2. Abundance	Reported as consistently depauperate. Loss of P.hessei abundance replaced by estuarine mysid *Mesopodopsis africana*	90	L
3. Community composition	Loss of signature species, *Pseudodiaptomus hessei* to community in Lakes 1 and 2 in particular	85	L
Biotic component health score		**85**	**L**
% of impact non-flow related		10	L
Adjusted score		87	

Macrobenthos			
Variable	**Summary of change**	**Score**	**Conf**
1. Species richness	Recent studies are comparable to various *ad hoc* studies (e.g. Hemens et al 1971, Connell et al. 1976). These were estimated close to reference 2002/3 study reports larger numbers of taxa. This is likely a reflection of attention to taxonomy detail. System supports marine, typically estuarine and freshwater assemblages dependent on salinity distribution. Unique taxa to South African estuaries are limited to marine reaches and are related to biogeography (southern limit of tropical species). Kosi supports a rich assemblage of fauna relative to other estuaries in the country. If *Tarebia granifera* invasion increases, this will influence current diversity.	85	L
2. Abundance	Similar to reference conditions. Loss of large numbers of molluscs across various species reported as lost to the system (Begg 1978), and attributed to possible organo-pesticide (DDT) input.	90	M
3. Community composition	Slight change to the relatively recent arrival of *Tarebia*, and loss of some part of the mollusc component due to DDT input and/or replacement in the niche by the invasive thiarid snail.	85	M
Biotic component health score		**85**	**M**
% of impact non-flow related		90	M
Adjusted score		99	

Macrocrustaceans			
Variable	**Summary of change**	**Score**	**Conf**
1. Species richness	Original assemblage remains, changes in numbers due to increase in mangrove habitats and associated species.	90	L
2. Abundance	Extensive subsistence use (mangrove crabs) and sand prawn for bait collection has altered abundance. Reported decline in crabs since 1980s (e.g. Pederson et al. 2003)	75	L
3. Community composition	Similar component of marine dependent estuarine and freshwater taxa (e.g. Sesarmidae, *Uca* spp, Grapsidae) and marine species e.g. *Matuta* and Calapidae spp, located around the permanently open mouth.	90	M
Biotic component health score		**75**	**L**
% of impact non-flow related		85	L
Adjusted score		96	

Overall Invertebrates score			
Variable	**Summary of change**	**Score**	**Conf**
1. Species richness	Zooplankton reported as consistently depauperate. Loss of signature species *Pseudodiaptomus hessei*. System supports marine, typically estuarine and freshwater macrobenthic assemblages dependent on salinity distribution. Unique taxa to South African estuaries are limited to marine reaches and are related to biogeography (southern limit of tropical species). Kosi supports a rich assemblage of fauna relative to other estuaries in the country	85	L
2. Abundance	Extensive subsistence use (mangrove crabs) and sand prawn for bait collection has altered abundance. Reported decline in crabs since 1980s (e.g. Pederson et al. 2003).	75	L
3. Community composition	Loss of signature zooplankton species, *Pseudodiaptomus hessei* to community in Lakes 1 and 2. Slight change in macrobenthos assemblage due to the arrival of *Tarebia*, and loss of some part of the mollusc component due to DDT input and/or replacement in the niche by this snail.	85	L
Biotic component health score		**85**	**L**
% of impact non-flow related		90	L
Adjusted score		99	

4.8 Fish

4.8.1 Overview

i) Main groupings and baseline description

The Kosi estuarine system is unique in South Africa as a series of connected estuarine lakes with very clear subtropical waters and salinities ranging from fresh (0 psu) to near seawater (35 psu). Kosi is also the only estuarine system of significant size that flows into an area of coastal sea where coral reefs occur, a reflection of its location on the warm, Agulhas influenced coast of KwaZulu-Natal near the South Africa / Mozambique border. The estuarine lakes and a coastal strip stretching over 200 km to the south fall into the iSimangaliso Wetland Park, a UNESCO World Heritage Site. These factors contribute to the system supporting a particularly wide diversity fishes, including species not reported from any other South African estuaries.

Fishes with a variety of life histories use South African estuaries and overall the same broad groupings of fishes occur in the Kosi lakes as other estuarine systems in the country, and elsewhere in the word. Several estuarine association guilds have been applied to categorise the South African estuarine ichthyofauna. Most widely used has been that of Whitfield (1994), although more recent refinements have been applied (e.g. Harrison and Whitfield 2008) based on functional use categories more globally applicable (e.g. Elliot et al. 2007). For the purposes of the current assessment, Whitfield’s categorisation (Table 4.32) was used as a basis to classify fishes as:

- Estuarine resident: Species that complete their life cycles in South African estuaries (Whitfield’s categories Ia and Ib).

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

Table 4.32 Classification of South African fish fauna according to their dependence on estuaries (Whitfield 1994).

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

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

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

These categories are not exhaustive and most estuarine fishes rely upon a variety of food sources. Many species feed across these categories, either opportunistically taking advantage of food and prey items, which are easily available, or because of shifts in diet with ontogenetic development. In the majority of species ontogenetic changes involve shifts in diet from zooplankton to zoobenthos. These dietary shifts are extremely common and occur in size ranges of fishes that occupy estuaries.

As indicated above, Kosi is characterised by an extremely high diversity of fish species, including species of importance in recreational and subsistence fisheries (e.g., Begg 1978, Blaber 1978, 1982, Blaber and Cyrus 1981). Many species not reported from other estuarine systems in South Africa have been reported from Kosi. The presence of a small section of reef at the estuary mouth is largely responsible for this. This reef is inhabited by an abundance of marine species which are primarily associated with reef habitats and have little or no dependence on estuaries. These include members of the Acanthuridae, Scaridae, Labridae, Chaetodontidae, Pomacentridae, Serranidae and Muraenidae. Most of the species in this group do not occur in any of the systems estuarine habitats (see Blaber 1978). However, several species, which are normally associated with reef and other marine habitats, also occur in what are typical estuarine habitats in the lower reaches of the Kosi estuary (where salinities are > 25 psu). For example, Apogonidae, Scorpaenidae, and even Sargassumfish *Histrio histrio* (Antennariidae) have been sampled in *Zostera* and *Ruppia* seagrasses near the estuary mouth, as have Muraenidae and Blenniidae from mangrove areas (Weerts, unpublished). The occurrence of many of these marine species, although interesting, cannot be attributed to any estuarine function of the system, and has not strongly influenced the present assessment of the freshwater requirements of the Kosi estuarine lakes.

There are, however, an abundance of marine fishes which occur in the Kosi system, and which are strongly associated with its estuarine nature. Many of these fishes occur in the lakes in higher abundances and at larger size classes than in other South Africa system. This holds true for several estuarine dependent marine fishes (Whitfield's fish categories IIa, IIb and Vb) as well as estuarine opportunistic marine species (Whitfield's fish categories IIc and III). In the case of both these latter groups these fishes occur in the lakes as juveniles as well as adults, and rich prey abundances appear to be an influential factor in this. There appear to be some linkages between estuarine habitats, particularly clear water mangroves, and the offshore coral reefs. This is evidenced by the abundance and large sizes of several members of the Lutjanidae (snappers) in the Kosi lakes. This family of fishes includes many species that rely on linkages and demonstrate strong connectivity between mangroves and coral reef habitats in other parts of the world (e.g. Nagelkerken et al. 2000, 2002, Mumby et al. 2004, Mumby 2006).

There are also several obligate estuarine dependant species (estuarine residents; Whitfield's fish categories Ia and Ib), which occur in the Kosi lakes in higher abundances and frequencies of occurrence than any other South Africa system. These are typically small-bodied species, which are important in the trophic dynamics of the system. They also include several members of the Gobiidae and Syngnathidae, which are otherwise rare in our estuaries. This is probably also true of several of the Eleotridae that have been reported from the system, although little is known about these species because of the cryptic habits.

Several freshwater species of fish also occur in Kosi. These include euryhaline freshwater forms with varying degrees of salinity tolerance and which typically also occur in estuaries elsewhere in South Africa. Examples are the Mozambique tilapia *Oreochromis mossambicus*, which occurs throughout the system (Blaber 1978) and Sharptooth catfish which penetrates into the Mtando

Channel between Lakes 3 and 2 at least (pers. obs). More stenohaline freshwater species occur but are restricted to the freshwater in the upper reaches of the Kosi linked lake system, and in the inflowing streams. Although not typically included in estuarine freshwater requirement studies, these fishes warrant inclusion in this assessment because of the nature of the system as a series of linked lakes ranging in salinity from fresh- to near seawater. Because of the flat topography of the region and small size of peripheral freshwater streams, these fishes are most threatened by reduced freshwater inputs, and are at greatest risk in the Kosi system during times of drought.

Obligate catadromous fishes in Kosi are represented solely by eels of the family Anguillidae. These eels occur as elvers, juveniles and adults in the lakes as well as their connected freshwaters, although spawning and egg and larval distribution occur in the adjacent marine environment. Kosi's catchments are not particularly large but its associated freshwaters are probably significant for the shortfin eel, *Anguilla bicolor bicolor*, a species apparently restricted to coastal lowlands (Skelton 1993). Kosi is also the only (near) permanently open estuary, connecting the marine environment with estuarine and freshwaters along a very long stretch of coast from Mfolozi-St Lucia to Maputo, a distance of some 300 km. This renders the system important for all anguillid eels, as well as other estuarine associated marine spawning fishes.

In terms of feeding guilds the fishes in the Kosi Estuary are representative of all four major feeding groups, detrivores, zooplanktivores, zoobenthivores and piscivores, indicating the availability of food and prey for all groups within the system.

ii) Description of factors influencing fish

The influences of the main freshwater supply (flow) related factors on the fish fauna of the Kosi Estuary are presented in Table 4.33 whilst a summary of the responses of the fish to different estuarine states is given in Table 4.34.

Table 4.33 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various groupings of fish.

Variable	Influence
Salinity	Salinity is a primary determinant of the distribution of fishes (and their prey items) over the system. Primary freshwater species are restricted to far upper reaches of the system and are affected by salinity at times of low flow. Estuarine residents occur across the full system, but dominate Lake 3 and 4 where low salinities preclude large (adult) marine migrants. Salinity (with other characteristics of riverine waters) acts as a migration cue for eels (and other marine spawned species).
Water clarity	Waters are characteristically very clear. As a result there is very little refuge from fish or bird predators in clear open waters, especially in the shallows. This renders structured habitat (most often vegetation) very important for fishes in Kosi (see below).
Structured habitat (vegetation)	Clear water results in fishes having a high dependency on vegetation as a predation refuge, especially during daylight hours.
Prey distribution and availability	Sand prawns are the major prey item for several keystone fish species. Their presence and distribution is an important driver of fish productivity and distribution.

Dissolved oxygen	Generally not a constraint in the Kosi system, but low oxygen levels precludes the use of some deep areas at times by fishes (and their prey). Overturn events are rare but can result in fish kills naturally. Cold temperature can have a similar or exacerbating effect. This occurs very infrequently under natural conditions and is limited to deepwater lakes (Lakes 2 and 3).
Mouth dynamics	Mouth dynamics govern connectivity between estuarine habitats and clear marine waters and reef habitats. Mouth closure prevents recruitment of marine spawned fish into the system, and may also prevent movement (migration) of fishes within the system towards the mouth during spawning periods. It also results in loss of tidal currents and water movement in the system. This has long-term implications for salinity gradient and biotic distributions. Prolonged closure will result in vegetation changes and die off (which could in turn result in oxygen depletion).

Table 4.34 Summary of fish responses to different abiotic states

State	Response
State 1: Open, fresh	Typical salinity gradients are established. Marine species are mostly confined to the estuary, Lake 1 and Lake 2. Sand prawn, a significant prey item for many marine and estuarine dependant marine fishes, is restricted to these areas. Lake 3 is dominated by small estuarine species, co-occurring with secondary freshwater fishes. Primary freshwater species are restricted upper end of lake 3 and Lake 4, as well as the inflowing rivers.
State 2: Open, saline	Typical salinity gradients are established. Marine species are mostly confined to the estuary, Lake 1 and Lake 2. They occur in higher abundance and diversity that is the case for State 1.The main prey species (sand prawn) is restricted to these areas (Lakes 1 and 2). Lake 3 fish fauna is dominated by small estuarine species, co-occurring with secondary freshwater fishes. Primary freshwater species are restricted upper end of Lake 3 and Lake 4, as well as the inflowing rivers.
State 3: Open, very saline	Salinity across the full system is elevated. Impacts are most pronounced in Lake 3 and Lake 4. Sand prawns, along with other estuarine invertebrates (and marine fish) extend their ranges up Mtando Channel and into Lake 3. Estuarine species in Lake 3 are increasingly prone to predation pressure, although this is not marked below 10 psu. Primary freshwater species do not occur in the lakes, and are restricted to freshwater refugia.
State 4: Closed	Recruitment of marine spawned fishes (and prey invertebrates) cannot occur. Tidal currents cease. Tidal movement of fishes in the lower lakes ceases, and fish traps probably become ineffective. Salinity impacts occur as above and are initially most pronounced under this state. If prolonged and co-occurring with drought that affects freshwater refugia (which is most likely) this has severe implications for the freshwater component of the fish assemblage. Localised extinctions may occur in some small inflowing streams. Salinity implications of prolonged closure may ameliorated by low freshwater inflows which could reduce salinity slightly. Backfilling however, has severe implications for lake vegetation and may cause die-off of large areas of reed bank. Resulting breakdown of organic material will result in deoxygenation of water and have severe implications for the marine, estuarine and freshwater components of the fish assemblage. Breeding cycles are disrupted.

iii) Reference condition

In terms of both its overall morphology and physicochemical conditions, Kosi was similar in its reference condition as it is in the present day. As such, the system was used by a diversity of fishes from all groupings as estuarine habitat for breeding, nursery and feeding purposes. Indeed the species assemblages and abundances of the freshwater and estuarine resident component of the fish assemblage were likely to have been very similar to those of the present day. There is however, clear indication of resource utilisation that has impacted the system and its fishes. This is evident in the harvesting of various forms of vegetation, both in the system and the surrounding lowlands, as well as clearing of vegetation for footpaths, cattle paths, and increasingly for vehicles. Most noticeable from aerial photography is the proliferation of fish traps, which have undoubtedly changed the nature of the system to some degree at least, through impacts on sediment movement and stimulating growth of mangroves “islands” in basin areas. Fish traps of course also have a direct impact on the fishes of the system in being the primary method of exploitation and forming the basis for a fishery, which has increasing impacts on the systems present ecological state. Key species impacted in the system are *Acanthopagrus vagus*, *Lutjanus argentimaculatus*, *Pomadasys commersonnii*, *Rhabdosargus sarba*, and various mullet species. These species are all estuarine dependant marine species that characterised the system in its reference condition. Others, such as *Chanos chanos*, and (perhaps) *Caranx* spp., appear to have undergone declines regionally. It is therefore also likely that increasing fishing pressure on estuarine dependant marine species elsewhere on the coast (in South Africa and Mozambique) has affected the fishes in the Kosi linked lakes, although this is secondary in terms of impact compared to direct exploitation in the system itself.

On the basis of recent field survey of the Kosi system (February 2016) supplemented by work done in 2002 – 2004 (pers. obs), an understanding of effects of abiotic and biotic variables on the fish fauna and their response to different abiotic states, changes in the fish fauna (and drivers) can be identified. These are summarised in table 4.35 below.

Table 4.35 Summary of relative changes in Fish from Reference Condition to Present state.

Key drivers	Change
Salinity gradients and penetration	Salinity regimes in Kosi fluctuate naturally on tidal, seasonal and long-term hydrological cycles. There is evidence that present day salinities are high in the system compared to the norm. Cycles of elevated salinity do occur in Lake 3, and more rarely salinity penetrates into Lake 4. If prolonged this will have marked impacts, especially on the freshwater component of the fish assemblage (species with little tolerance of salinity). Changes are probably minimal at present (see below), but with increasing salinity in Lake 4, as well as the drying up of inflowing streams and freshwater refugia, these species may be on the threshold of localised extinction is some small peripheral freshwater systems.
Prey abundance and distribution	Sand prawns are the main prey item for several keystone species. Their abundance in the system appears to be relatively unaffected. Increased salinity sees their distribution spread from Lakes 1 and 2 into Lake 3. This is presently occurring in the lower reaches of Lake 3. This will facilitate greater penetration of estuarine dependent marine species into this lake and change its characteristic ichthyofaunal assemblage. At present fluctuations are within natural ranges however, so this has little impact in terms of rating as a change from reference condition to present state.
Submerged and emergent vegetation (habitat)	Aquatic vegetation provides important habitat for nearly all fishes in the system (relatively more so than in other KZN estuaries because of the very low turbidities that characterise the systems waters). There appear to be natural fluctuations in beds of submerged aquatic vegetation. These will be affected by lake water level changes as well as salinity changes, but appear to be within natural ranges to present. Harvesting of reeds and mangroves has occurred, but impacts are probably offset by increases in these vegetation forms as a result of nutrient inputs (reeds) and natural succession and fish traps (mangroves). Fish traps themselves provide an additional form of structured habitat.
Fishing pressure	Undoubtedly this has the largest impact on the present ecological state of the fishes of Kosi (see Section 4.8.2 below). Estuarine dependant marine species are most affected. Fish traps are probably the main source of fishing pressure, but line fishing (subsistence and recreational) also contributes to change from reference condition.

4.8.2 Text Box: Kosi Estuarine Lake System Fisheries

Background

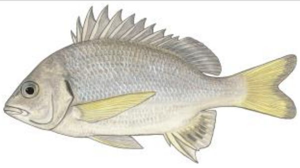
Kosi Bay fisheries comprise the traditional and artisanal trap and spear fisheries, gillnetting, recreational angling and small-scale / subsistence linefisheries (Kyle 1996, 2013). The latter includes the 'jigging" fishery in which small fish are foul-hooked by hook and line. There is a cast-net component in both the recreational and small-scale fisheries. Gillnetting was once permitted in controlled areas but closed due to targeting of prohibited species and unsustainable increases in effort and catch. This said, there exists a substantial illicit gillnet fishery which for obvious reasons is difficult to monitor and is therefore assumed to have at least the same catch rates as the legal fishery had in the past.

Catch

Approximately 200 tons of fish are caught annually in the Kosi System (Lamberth & Turpie 2003, Table 4.36). Contributions in decreasing order of landed catch are gillnetting 90 t, traps 73 t, angling 18 t and spear 16 t. Gillnet landings may have changed since then but the trap contribution has remained fairly constant this despite the almost doubling of traps in the last decade or so of a 35 year monitoring period (Kyle 2013). Kosi fisheries production is about 56 kg.ha^{-1}yr^{-1} and the 200 t landed annually represents 26% and 11% of the total KZN (Port Edward to Kosi) and national (Orange Estuary to Kosi Bay) estuarine catch respectively (Lamberth & Turpie 2003).

Table 4.36 Estuarine fisheries production of South Africa.

Fisheries production (tonnes per annum)



	Size (ha)	Gill-net	Seine-net	Angling	Castnet	Fish traps	Spear	Total
Tugela/Thukela	55	10	2	2	3	0	0	17
Matigulu/Nyoni	192	5	5	3	2	0	0	15
Siyaya	8	0	0	0	0	0	0	0
Mlalazi	203	5	2	5	3	0	0	15
Mhlathuze	1637	15	20	5	3	0	0	43
Richard's Bay	1800	2	8	68	10	0	0	88
Nhlabane	470	5	2	1	1	0	0	9
Mfolozi	180	10	2	3	1	0	0	16
St Lucia	41700	150	30	70	10	0	0	260
Mgobezeleni	1	1	0	1	0	0	0	2
Kosi	3500	90	0	18	0	73	16	197
West Coast		625	0	15	2	0	0	642
South Coast		38	3	103	8	0	0	152
East coast		35	0	152	14	0	0	201
KZN		297	72	245	52	73	16	755
Total		995	75	515	76	73	16	1750

Monitoring

Most if not all of the following information (including tables and figures) on the Kosi Bay fish traps has been taken from the 30 years of monitoring published in Kyle (2013). Monitoring, selection and training of monitors was a consultative and formal process from the start with the local headman and chief providing candidate monitors and the interface between community and management authority. Traps occur from the mouth into lakes Makhawulani, Mpungwini and Nhlange although construction in the latter lake has only happened since 2010. Each trap has one or more basket into which the fences guide the fish. The number of traps and baskets remained fairly constant at <100 traps from the 1950s to 1994 whereupon there was a substantial increase with traps doubling and baskets trebling by a 2001 peak. After this numbers declined slightly and a 200-trap ceiling was negotiated and agreed to by the fishing community. Another factor driving trap fishing effort and increased catches is that better access to markets as well as a growing local economy have seen the fishery changing from subsistence to commercial in nature. A downside is that the local community's food security and access to cheap protein have been compromised by the export of the trap catch from the region.

Long-term catches

Annual catches in the earlier years of monitoring were in the region of 40 t so the later estimates of 70-80 t are probably reasonable given the doubling of traps. A total of 43 species from 23 families have been recorded in fish trap catches with seven providing 95% of the catch by number and mass.

These were spotted grunter Pomadasys commersonnii, flathead mullet Mugil cephalus, river bream Acanthopagrus vagus, bluetail mullet Valamugil buchanani, largescale mullet Liza macrolepis, Natal stumpnose Rhabdosargus sarba and evenfin pursemouth Gerres methueni. Spotted grunter and flathead mullet dominated catches throughout most of the monitoring period but with substantial increases in the contribution of Natal stumpnose and largescale mullet from 1995 onwards. With the exception of a negative relationship between salinity and bluetail mullet Valamugil buchanani, there were no significant relationships between broad-scale abiotic variables such as annual rainfall and total catch. However, increases in Natal stumpnose trap catches from 1995 onwards may be flow related and a reflection of the relative unavailability of St Lucia compared to Kosi and other estuarine nursery habitats since then (Mann & Pradervand 2007).

Seasonality

Seasonality of catches is largely a function of the life histories of the species caught. River bream caches peak just prior to spawning outside the Kosi mouth whereas spotted grunter catches are often highest in mid to late summer associated with heavy rains when darker tannin-rich freshwater inflow increases susceptibility to capture. Flathead mullet catches peak in late summer, which may reflect their leaving the system prior to winter spawning a behaviour apparent throughout its South African range. Fish-trap maintenance is manipulated to maximise catches during the "runs" of the latter two species.

River bream catches and mark-and-recapture studies indicate a distinct Kosi population which makes them more susceptible to trap-fishing pressure compared to spotted grunter and flathead mullet which recruit from much larger populations outside the Kosi System. Kosi trap catches of grunter sometimes mirror recreational catches along the rest of the KZN coastline.

Short-term catches

On a shorter time-scale Kosi-trap catches are characterised by distinct 2-week cycles with peaks during high water levels at spring tide. Spotted grunter catches peak at each spring tide whereas diamond mullet Liza alata peak only during dark-moon spring tides. Water levels and subsequently catches are also sensitive to atmospheric pressure, wind and rainfall especially event-scale perturbations such as cyclone Domoina in 1984 which resulted in high catches of spotted grunter and other species.

Trap-fishing effects

There has been a marked decline in the size distribution of the main target species flathead mullet, Natal stumpnose and spotted grunter over the past 30 years. This may be attributed to one or a combination of the following factors; change in trap orientation from upstream to downstream, increasing use of synthetic materials, illicit gillnetting and regional changes in the availability of estuarine nursery habitat. Historically and by agreement, trap-openings were faced upstream to catch larger fish exiting the system after their estuarine sojourn whereas nowadays there's a trend towards orientating them downstream to catch recruiting and therefore smaller fish. There's also a tendency to deviate from traditional materials such as reeds, palm fronds and wild banana leaves to construct and line traps towards gum poles and synthetic materials such as plastic and even gillnet.

The overall effect is to reduce the "mesh-size" of the traps and increase the catch of smaller fish. Illicit gillnetting may also be playing a role selecting for larger fish before they're caught in the traps. The end result is that recruitment and growth overfishing are occurring in the system. Alternatively or concomitantly, the unavailability of St Lucia over much of the past two decades may have seen more juvenile and adolescent fish using the Kosi system as an alternative estuarine nursery area.

Prior to 1994 trap numbers were low and catches sustainable and there was little overlap with recreational and other fishing sectors. Since then and emigration and mortality aside, a very high recapture rate (35%) of tagged fish suggest a very high and unsustainable impact on the stocks of the main species caught. There has also been an increase in the proportion of immature fish across all species caught. Whilst some of this may be due to the closure and unavailability of the St Lucia nursery, the main drivers are likely to be the reorientation of the traps from upstream to downstream and synthetic trap materials catching smaller fish. Overall, the increase in fishing power and commercialization of the trap fishery has led to it becoming unsustainable. Management realises this and has recommended and initiated appropriate action to maintain sustainable catches and livelihoods in this World Heritage Site.

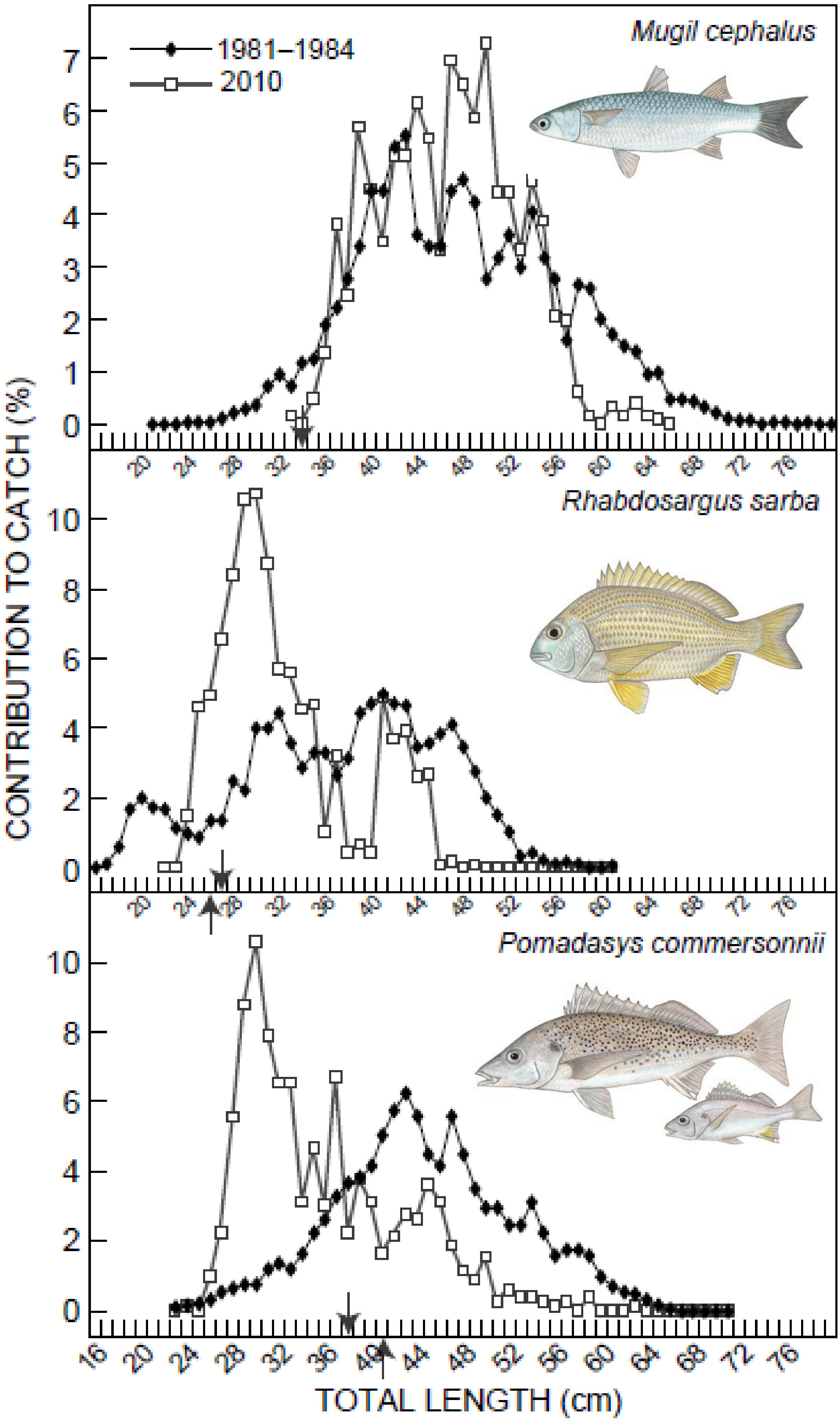


Figure 4.7 The contribution of the Kosi Estuarine Lake System to overall catches.

4.8.3 Fish health

The Present Ecological State of the Kosi Estuary fish assemblage is described and scored in Table 4.37.

Table 4.37 Fish component health score.

Variable	Summary of change	Score	Conf
Freshwater fishes			
1. Species richness	No freshwater species are lost from the system, but some are stressed by penetration of salinity under current low flows.	100	M
2. Abundance	Possible minor water quality impacts and effects from habitat disturbance in the system. Loss of surrounding swamps may have impacted the abundance of (*Ctenopoma multispine*). Some reduction in abundance of primary freshwater species, but the secondary freshwater species unaffected.	90	L
3. Community composition	Relative abundances of primary freshwater species reduced. Impact of the infestation of invasive *Tarebia granifera* unknown, but likely.	85	L
Estuarine resident fishes			
1. Species richness	All estuarine residents still occur in the Kosi Lakes. No alien species.	100	M
2. Abundance	Abundances fluctuate naturally, (probably) in long-term cycles. Some loss and/or disturbance of habitat (emergent and submerged vegetation) has occurred, but these impacts are small. Reduced predation pressure from piscivorous fish (which are over exploited, see Section 4.8.2 and below).	95	L
3. Community composition	Relative abundances of different species are probably close to reference condition. Impact of the infestation of invasive *Tarebia granifera* unknown.	95	L
Marine fishes (comprising predominantly estuarine dependant marine species)			
1. Species richness	Recruitment potential is very similar to reference conditions, as is habitat availability for all marine spawned species that naturally occur in the system. However some species no longer occur in the system and others occur with less regularity (e.g. milk fish).	85	M
2. Abundance	Abundances of this group of fishes fluctuate naturally, (probably) in long-term cycles. Some loss and/or disturbance of habitat has occurred (emergent and submerged vegetation), but these impacts are small. Fisheries have had a major impact on larger marine fishes (see Section 4.8.2 above). Fisheries related impacts on habitat (fish traps) and disturbance also occurs.	60	M
3. Community composition	Impact of *Tarebia granifera* unknown, but its impacts will be largely in Lakes 3 and 4, whereas most marine fishes occur in the estuary, Lake1 and lake 2. There is a significant impact of fisheries on the relative abundance of species, with a strong fisheries focus on select species. There has been an increase penetration and abundance of some marine species (e.g. *Atherinomorus lacunosus*), which may be related to increased salinities.	60	M

Overall fish scores (based on average metric criterion)			
1. Species richness		92	M
2. Abundance		82	L
3. Community composition		80	L
Biotic component health score		**80**	**M/L**
% of impact non-flow related		35	
Adjusted score		87	

4.9 Birds

4.9.1 Overview

i) Main grouping and baseline description

The waterbirds of Kosi can be grouped, based on their feeding, into four feeding guilds. An important component of the bird fauna are those that feed predominantly on fish. These may be categorised into the birds that feed on large (>10 cm) fish and those that feed on the smaller (<10 cm) fish. The birds that feed on the larger fish include the predators that swim after their prey (the cormorants and the darters), those that ambush their prey (Goliath heron), and those that pounce on their prey (Fish eagle, Osprey).

The birds that feed on the smaller fish include those that stalk or ambush their prey in shallow water (Grey, Purple and Little herons) and those that drop down on to their prey from above (Terns and Kingfishers).

The fish-feeders that are absent from the system are those that catch their prey in turbid water – such as the Great white pelican, Spoonbill and Yellow-billed stork.

There is a feeding guild that feeds predominantly on invertebrates. The Greater flamingoes feed by sieving through the sediment to catch benthic invertebrates – such as small crabs and prawns, clams and a variety of worms and small crustaceans. The small Palaearctic waders and species such as the Greenshank and Whimbrel feed in the intertidal sand flats where they pick small benthic invertebrates out of the substratum. Included in the invertebrate feeders are the birds that skulk in emergent and shoreline vegetation, and on water lily covered sites. These include the small herons (e.g. Green heron, Little bittern, Squacco), Jacanas and the Finfoots.

Birds from this guild that are absent from the counts are Black herons which are specialised to feed in shallow standing water by creating an umbrella by spreading their wings. This attracts small fish and insects to seek the shelter of the shadow thus created.

In the feeding guild classed as plant feeders the birds often feed on insects and other invertebrates as well as on plants. These include those birds that skulk in lush shoreline vegetation (e.g. Black crake, Moorhen, Purple gallinule). The other birds of the plant-feeder category are the swimming birds (e.g. Yellow-bill ducks, Spurwing goose and Pygmy goose). The Pygmy goose is very strongly associated with water lilies and feed to a large extent on the ripening seeds.

There are a few noteworthy specialist feeders in the Kosi System. One is the iconic Palm-nut vulture that is associated with the Raphia palms and feed on the oily coating of their seeds as well as on carrion and crabs.

For the purposes of this study four feeding guilds were recognised. The defining features of these guilds as well as the dominant species that were found to be present are given in Table 4.38.

Table 4.38 Waterbird feeding guilds and their defining features and typical/dominant species.

Main foraging guilds	Defining features and typical/dominant species
Piscivores: Large fish	Feed on large fish (>10 cm) e.g. cormorants, darters, goliath heron, fish eagle
Piscivores: Small fish	Feed on small fish (<10 cm) e.g. terns, kingfishers, smaller herons
Invert feeders	Feed on invertebrates. E.g. flamingoes, waders, whimbrels, small herons
Plant feeders	Feed on plants (and insects associated with plants) e.g. ducks gallinules, moorhen

ii) Description of factors influencing birds

There is a wide range of factors that influence the birds. Members of the different guilds each select for habitats in which they can feed effectively. Thus the birds that feed on large fish select mainly for habitats where there is clear and reasonably deep water. The birds that feed on smaller fish are found more where their prey is – in the shallow shoreline areas where the small fish shelter from predation.

The Palaearctic waders feed in the intertidal areas when they are exposed at low tide, and the flamingoes in water in which they are able to stand.

The birds of vegetated areas are divided into the swimming birds – which fed on submerged and floating plants (and associated insects). There is also a group of birds that specialise in skulking in rank shoreline vegetation feeding on plants and associated invertebrates. These birds include the Purple gallinule, Moorhen and Black crake.

In addition to this selectivity, many of the birds choose parts of the system that are either estuary dominated or river dominated. This is likely to be related to the salinity gradient that occurs between the sea at the mouth end of the system, and the inflowing river at the end furthest from the mouth. The birds are selecting for habitat or prey which has a spatial distribution determined by salinity and the influence of the sea.

In addition to the above, there are some scarce birds, which have very specific habitat requirements. These include the Pel's fishing owl that selects for quiet waters with tall overhanging trees; the Pygmy goose which is very closely associated with water lilies, the Palmnut vulture that feeds to a large extent of the fruits of the Raphia palm and the Skimmer that selects for calm water and exposed sand banks.

Table 4.39 and 4.40 below lists the effects of various abiotic and biotic factors on the different water bird feeding guilds found to be present at the Kosi Estuary.

Table 4.39 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various groupings of birds.

Variable	Piscivores: large fish	Piscivores: small fish	Invertebrate feeders	Plant feeders
Mouth condition	Extended mouth closure will exclude those fish and crustaceans that have to spawn at		This will have a severe effect on the	No influence

Variable	Piscivores: large fish	Piscivores: small fish	Invertebrate feeders	Plant feeders
	sea - thus changing prey items available.		Palaearctic waders that rely on tidally exposed sand banks	
Salinity	A change in salinity will affect those species that feed on fish – if the fish sizes and composition change The result will be more of the birds characteristic of the estuary and Lakes 1 & 2 will be present in lakes 3 & 4		A change in salinity will affect those species that feed on inverts – if the invert sizes and composition change. The result will be more of the birds characteristic of the estuary and Lakes 1 & 2 will be present in lakes 3 & 4	This will alter plant distribution patterns – and hence affect hervbivores. Less biomass of submerged plants will mean fewer of the swimming herbivores
Turbidity	Increased turbidity will attract Pelicans. But: increased turbidity could affect other fish feeders by making prey detection more difficult	Increased turbidity will affect fish feeders by making prey detection more difficult	Increased turbidity could attract Yellow-bill storks and spoonbills. Will make fishing more difficult for visual feeders – e.g. small herons	Reduce submerged plant growth so fewer swimming herbivores
Intertidal area	No influence	No influence- except for specialists such as the skimmer	Reduction in area will affect small waders	No influence
Basking area - mouth	No influence	Human disturbance will affect terns	No influence	No influence
Primary productivity	An increase in primary production will result in an increase in most bird numbers (as long as turbidity is unaffected)			
Submerged macrophytes abundance	No influence	No influence	No influence	Will increase habitat for herbivores – especially ducks and geese. Coots may become common
Emergent and shoreline reeds and sedges	No influence	No influence	Increase in small herons	No influence
Floating vegetation	No influence	No influence	Increase in Jacanas	Increase in Pygmy geese
Mangrove abundance	Little impact			
Estuarine invertebrate abundance	No influence	No influence	Increase in this guild as inverts increase and vice versa	No influence
Fish traps	More perches for cormorants Feed in fish traps	More perches for terns and kingfishers Feed in traps	No influence	No influence
Small fish availability	No influence	Increase/decrease in this guild dependent on food availability	No influence	No influence
Large fish availability	Increase/decrease in this guild depends on food availability	No influence	No influence	No influence
Raphia palms	A change in abundance will affect the iconic Palm-nut vulture	No influence	No influence	No influence

Table 4.40 Summary of Bird responses to different abiotic states.

State	Response
State 1: Closed	Loss of intertidal habitat in the marine-dominated parts of the estuary will displace the Palaearctic waders. If the mouth is closed for a long period the summer tern roosting will not occur. Die-back of lake margin vegetation will reduce the abundance of those birds using this habitat.
State 2: Open, Tidal	More marine conditions will encourage those birds that are currently most associated with the mouth and lower parts of the system.
State 3: Open, Freshwater dominated	This will reduce bird numbers by displacing those birds that rely in the salinity of the lower reaches of the estuary – but will promote the birds currently found in the freshwater upper parts of the system.

Reference condition

There is a count that dates back to 1949, another one from 1980 and then regular counts since 1992. These show few significant trends – none of which can be closely related to estuary conditions. There has been a decrease in Cattle egrets, Greater flamingoes and Yellowbill ducks – all of which could also be related to the onset of a drought.

Two counts a year have been regularly done in summer and winter since 1992 as part of CWAC. However there are limitations in the data which are of a fairly coarse resolution. The main limitation is that the records give a total per species for the full Kosi System. There is no spatial breakdown of bird numbers, so it is not possible to relate bird abundances to changes in habitats

The study assumes that the present condition, which includes all the CWAC counts, is very similar to reference condition.

Table 4.41 provides an overview of the relative changes in the bird component from Reference Condition to Present state.

Table 4.41 Summary of relative changes in Birds from Reference Condition to Present state.

Key drivers	Change
Disturbances along the shoreline and at the mouth	Increased disturbance – especially at the mouth affects summer-roosting terns.
Agriculture and other anthropogenic modifications in the floodplain	Little effect on estuarine species.
Fish traps and other fishing by locals	Selective and heavy fishing has reduced the numbers of large (>10 cm) fish. This would promote the birds that are small –fish feeders. The traps act as perches for cormorants, kingfishers and terns.
Poaching	Not extensive but may target ducks.
Regional effects	Depression of duck populations.
Changes in vegetation	This affects skulking birds (Reeds and sedge shorelines), macrophyte feeders (submerged plants), pygmy geese and jacanas (water lilies), palm-nut vultures (Raphia palms)
TOTAL CHANGE	**10%**

4.9.2 Bird Health

Water bird species richness is probably similar to that under the Reference Condition although there could well have been some changes in abundance. The Present Ecological State of the Kosi Estuary bird assemblage is described and scored in Table 4.42.

Table 4.42 Bird component health score (PES).

Variable	Summary of change	Score	Conf
1. Species richness	No changes that we are confident about – some queries about birds such as skimmer and avocet – but we consider their presences when recorded to have been unusual events	98	H
2. Abundance	Reduced due to regional effects and disturbance/poaching	92	M
3. Community composition	Little change (but possibly fewer ducks due to hunting)	92	M
Biotic component health score		**92**	M
% of impact non-flow related		50	
Adjusted score		96	

5 PRESENT ECOLOGICAL STATUS

5.1 Overall Estuarine Health Index Score

The Kosi Estuary in its Present State is estimated to be 91 % similar to the Natural Condition, which translates into a Present Ecological Status (PES) of an A/B Category. This is mostly attributed to the following factors:

- Ground water abstraction;
- Over exploitation of fish resources (e.g. fish traps and poaching of fish);
- Harvesting of Mangroves and reeds;
- Invasive alien invertebrate Tarebia Granifera displacing indigenous species;
- Over exploitation of invertebrate resources (e.g. crab collection and bait collection);
- Muti trade of fish eagle fledglings and vegetation;
- Recreational activities at the mouth; and
- Agricultural activities in the Estuary Functional Zone causing loss of estuarine habitat.

The overall current Estuarine Health Score as well as the score with non-flow related pressures removed is given on Table 5.1 below.

Table 5.1 Estuarine Health Score (EHI) for the Kosi Estuary.

Variable	Estuarine health score			
	Weight	Ecological condition	Excluding non-flow related pressures	Conf
Hydrology	25	90	90	L
Hydrodynamics and mouth condition	25	100	100	L
Water quality	25	94	94	L/M
Physical habitat alteration	25	95	100	M
Habitat health score		**95**	96	
Microalgae	20	95	95	M
Macrophytes	20	90	100	M
Invertebrates	20	75	98	Low
Fish	20	80	87	L/M
Birds	20	92	96	M
Biotic health score		**86**	95	
ESTUARY HEALTH SCORE		**91**	**95**	**L**
PRESENT ECOLOGICAL STATUS (PES)		**A/B**	**A**	
OVERALL CONFIDENCE		**Low**	**Low**	

5.2 Trajectory of change

The Kosi Estuary is on a **downwards trajectory** of change that is contributed to the following:

- As the human population in the surrounding areas increase, groundwater use and direct abstraction is expected to increase unless actively managed.
- Similarly, increase population densities will increase direct resource abstraction and use (e.g. fishing, mangrove harvesting, crab collection) of the system.
- The traditional artisanal fishery (fish traps) is in the process of switching to a commercial fishery, which will put additional pressure on the fish and bait resources of the system.
- The invasive alien invertebrate species *Tarebia granifera* is a relatively new introduction to the system and is still increasing in abundance (density).
- Current ground water usage (abstraction and forestry) has increase the probability of mouth closure which will have severe consequences on the biodiversity of the system, e.g. die back of mangroves.

5.3 Relative contribution of flow and non-flow related impacts on Estuarine Health

Estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an increase in the health score from a PES of 91 to 95 (see table above), which would raise the health score to an A Category. This suggests that non-flow related impacts have played some role in the degradation of the estuary to an A/B, but that some flow-related impacts are also driving the current condition.

5.4 Overall Confidence

Confidence levels for two of the four abiotic components were rated as Low, with one component rated as Medium. Three of the five biotic components had enough data to yield Medium Confidence assessments. However, the overall confidence assessment for this study is **LOW** as the hydrology and hydrodynamics are of low confidence.

6 THE RECOMMENDED ECOLOGICAL CATEGORY

6.1 Conservation Importance

As indicated before, the Kosi estuarine system is unique in South Africa as a series of connected estuarine lakes with very clear subtropical waters and salinities ranging from fresh (0 psu) to near seawater (35 psu). Kosi is also the only estuarine system of significant size that flows into an area of coastal sea where coral reefs occur, a reflection of its location on the warm Agulhas influence coast of KwaZulu-Natal near the South Africa / Mozambique border.

The Estuary Importance Score (EIS) takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (Table 6.1). Biodiversity importance, in turn, is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. The scores have been determined for all South African estuaries (DWAF 2008, Turpie *et. al.,* 2012b), apart from functional importance, which is scored by the specialists in the workshop (Table 6.1). The Estuary Importance scores for five components and the importance rating are presented in Tables 6.2 and 6.3, respectively.

The functional importance of Kosi Estuary is VERY HIGH with a score of 100. It serves a very important movement corridor for invertebrates (e.g. *Varuna litterata)* and fish (e.g. eels) which spawn in the sea. The system also serves as an important area for Kingfish and Barracuda that use the reef in the estuary mouth. From an estuarine connectivity perspective, Kosi Estuary links St Lucia and Maputo Bay along a 300 km coastline.

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

Functionality	Score
a. Estuary: Input of detritus and nutrients generated in estuary	30
b. Nursery function for marine-living fish	60
c. Movement corridor for river invertebrates and fish breeding in sea	100
d. Migratory stopover for coastal birds	50
e. Catchment detritus, nutrients and sediments to sea	10
f. Coastal connectivity (way point) for fish	100
Functional importance score - Max (a to f)	**100**

The EIS for the Kosi Estuary, is 97 (Table 6.2), indicating that the estuary is rated as “Highly Important” (Table 6.3). Much of this is due to the ecological contributions made by the size of the system and the fact that the biodiversity is high.

Table 6.2 Estuarine Importance Scores (EIS) for the Kosi Estuary.

Criterion	Weight	Score
Estuary Size	15	100
Zonal Rarity Type	10	70
Habitat Diversity	25	100
Biodiversity Importance	25	100
Functional Importance	25	100
Estuary Importance Score		**97**

Table 6.3 Estuarine Importance Scores (EIS) and significance.

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

In addition, the Kosi falls within the iSimangaliso Wetland Park, a UNESCO World Heritage Site. The system forms part of the core set of priority estuaries in need of protection to achieve biodiversity targets in the 2011 National Estuaries Biodiversity Plan defined as part of the National Biodiversity Assessment 2011 (NBA 2011) (Turpie et al., 2012c). The NBA 2011 (Van Niekerk and Turpie 2012) recommended that the minimum Category for the Kosi be an A, that the system be granted partial no-take protection, and that 75 % of the estuary margin be undeveloped (Table 6.4).

Table 6.4 National Estuary Biodiversity Plan requirements for the Kosi Estuary (Turpie et al. 2012c).

Estuary Requirements	Kosi
Current health category	A
National and/or Regional Priority set	SA
Recommended extent of protection	Partial
Recommended extent of undeveloped margin	75%
Provisional estimate of Recommended Ecological Category	A

6.2 Recommended Ecological Category

The Recommended Ecological Category represents the level of protection assigned to an estuary. The first step is to determine the 'minimum' Ecological Category based on its PES. The relationship between Environmental Health Index (EHI) Score, PES and minimum REC is set out in Table 6.5.

Table 6.5 Relationship between the EHI, PES and minimum REC.

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

The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of importance and level of protection or desired protection of a particular estuary (Table 6.6).

Table 6.6 Estuary protection status and importance, and the basis for assigning a Recommended Ecological Category.

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

* BAS = Best Attainable State

The PES for the Kosi Estuary is an A/B. The Estuary is rated as "Highly Important" from a biodiversity perspective and the target recommended by the National Estuaries Biodiversity Plan for the National Biodiversity Assessment (Turpie *et al*., 2012c) indicate it should be in an A Category.

Based on this study, the above National Estuary Biodiversity Plan targets and the reversibility of current impacts, the Recommended Ecological Category for the Kosi Estuary is an A Category.

7 EVALUATION OF FLOW SCENARIOS

7.1 Future scenarios

Table 7.1 provides a summary of a range of water resource development scenarios that could affect the Kosi Estuary.

Table 7.1 Summary of the change in low flow conditions to the Kosi Estuary from the Reference Condition to the Present State and future scenarios.

Scenario Description	Mean Annual Runoff (x 10 ^{6} m^{3})	% Similar
Reference (natural conditions)	69.09	100
Present uses (all use)	63.79	92.0
1: Lawful use	65.87	95.3
2a: Artificial breaching to address mouth closure (assume double abstraction and plantations)	58.49	84.7
2b: Allow for extended mouth closure (assume double abstraction and plantations)	58.49	84.7

Scenario 1 (Table 7.2) represents a 3% increase in freshwater input (surface water and groundwater) to the system through the curbing of illegal use of freshwater resources in the catchment.

As mentioned in Section 1.6 under the assumptions and limitations of the study, of particular concern, is the short simulation period used in this EWR assessment. The very limited time series covered by the freshwater simulation dataset did not allow for a strong correlation with the critical period of 1965/66 when estuary mouth closed. The simulated period is relative similar in inflow volumes and therefore does not provide the study with sensitivity to a reduction to freshwater input. An additional concern is that the various groundwater reports available for the region indicate different impacts on the average groundwater level. Lack of long-term monitoring data precluded any of the studies from achieving a high confidence in groundwater and surface water input. Nevertheless, the study teamed observed a 5 to 7 m decline in the water table during the February 2016 field visit, which is not reflected in the freshwater inflow data supplied for this study. The observed drawdown in the groundwater table would present an additional stress to the ecological system as it would remove/reduce the buffering effect the groundwater input provides to the riparian vegetation, i.e. reduce salinity in sediments. Therefore, to provide for some indication of the consequences of mouth closure on the Kosi Estuarine Lake System two additional scenarios were developed (current abstraction and forestry were doubled to provide some resolution in the simulation period, Table 7.3):

- Scenario 2a: Assumes that the relevant authorities will artificial breach the system within 3 to 6 months of closure to prevent die-back of the mangroves. As a result of this management intervention, salinity is expected to increase to above 10 psu in Lake 3 and 1 psu in Lake 4 as a result of the open mouth state under low freshwater input conditions.

- Scenario 2b: Assumes that the mouth will be allowed to remain closed until the system fills to its breaching capacity. Closure will last months to years. Salinity will be less than 5 psu in Lake 3 and 1 psu in Lake 4. No connection will exist with the sea to the duration of the closed period.

However, it should be stressed that there is a risk of mouth closure occurring even at the present water resource utilisation levels. The February 2016 field visit showed that the present freshwater input to the Kosi System is very low, resulting in a very constricted mouth (inlet) at present. Therefore, the system is at a very high risk of closure if high wave condition were to develop at sea during the low flow season.

Table 7.2 A summary of the ground water monthly volume (in $10^6 m^3$) distribution under the under Scenario 1.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1997								3.71	2.35	2.90	16.89	4.85	
1998	6.19	8.15	3.08	0.00	0.00	1.25	1.23	0.00	0.00	3.06	0.00	4.71	27.67
1999	8.64	18.31	5.62	2.11	0.00	0.00	1.12	2.03	2.97	3.77	9.09	3.39	57.03
2000	10.64	13.59	18.22	2.27	2.19	0.00	2.17	0.00	6.56	4.14	15.12	3.69	78.59
2001	5.76	11.76	3.69	1.62	0.00	1.83	1.21	0.00	0.00	1.86	4.30	5.24	37.26
2002	0.00	0.00	0.00	3.12	0.00	1.89	2.31	0.00	0.00	0.00	0.00	3.07	10.39
2003	0.00	5.67	0.00	0.00	1.98	1.37	2.78	0.00	0.00	0.00	3.59	0.00	15.38
2004	7.51	6.14	7.05	5.63	0.00	0.00	2.08	0.00	0.00	0.00	6.15	0.00	34.55
2005	8.20	1.82	7.80	3.21	1.72	0.00	1.43	0.00	0.00	0.00	7.76	0.00	31.94
2006	2.68	3.84	2.25	5.73	0.00	2.59	0.00	3.54	0.00	0.00	4.89	9.42	34.94
2007	0.00	0.00	3.52	9.67	0.00	3.96	3.75	0.00	1.13	0.00	8.74	8.05	38.82
2008	0.00	1.90	2.71	3.87	0.00	8.69	1.34	0.00	0.00	0.00	0.00	2.58	21.08
2009	9.28	5.51	1.99	0.00	2.40	1.70	0.00	0.00	0.00	1.79	2.99	2.88	28.54
2010	7.71	2.95	3.73	6.29	1.10	1.15	6.26	0.00	0.00	4.27	7.09	4.95	45.49
2011	11.54	2.26	0.00	1.89	0.00	1.85	7.97	1.35	0.00	3.16	1.89	1.95	33.85
2012	0.00	3.82	14.01	0.00	0.00	0.00	0.00	0.00	12.57	1.55	1.78	0.00	33.72
2013	7.22	0.00	0.00	3.12	0.00	0.00	1.89	3.12	0.00	3.26	2.68	7.42	28.72
2014	2.61	5.05	18.18	0.00	0.00	0.00	1.80	0.00	0.00	0.00	2.36	0.00	30.00
2015	5.30	3.36	3.43	0.00	0.00	0.00	0.00	0.00					34.59

Table 7.3 A summary of the ground water monthly volume (in $10^6 m^3$) distribution under the under Scenario 2a and b.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1997								3.71	1.39	1.48	16.89	3.99	
1998	6.15	8.15	0.89	0.00	0.00	0.23	-0.10	0.00	0.00	1.87	0.00	3.77	20.95
1999	8.64	18.31	5.53	0.48	0.00	0.00	-0.23	0.80	1.82	2.75	9.09	1.73	48.92
2000	10.64	13.59	18.22	1.07	1.14	0.00	1.81	0.00	6.56	4.14	15.12	2.01	74.30
2001	5.34	11.76	2.46	-0.01	0.00	1.53	0.21	0.00	0.00	0.18	3.93	4.53	29.92
2002	0.00	0.00	0.00	1.96	0.00	1.53	2.03	0.00	0.00	0.00	0.00	1.16	6.68
2003	0.00	5.51	0.00	0.00	0.64	0.83	2.74	0.00	0.00	0.00	2.38	0.00	12.10
2004	7.51	6.14	7.05	5.63	0.00	0.00	1.60	0.00	0.00	0.00	6.15	0.00	34.08
2005	8.20	-0.63	7.80	2.51	0.22	0.00	0.50	0.00	0.00	0.00	7.76	0.00	26.38
2006	0.42	2.65	-0.06	5.73	0.00	2.59	0.00	3.34	0.00	0.00	4.57	9.42	28.67
2007	0.00	0.00	1.99	9.67	0.00	3.96	3.75	0.00	-0.54	0.00	8.74	8.05	35.62
2008	0.00	-0.13	1.35	3.87	0.00	8.69	0.74	0.00	0.00	0.00	0.00	0.54	15.05
2009	9.28	5.51	0.00	0.00	2.03	1.34	0.00	0.00	0.00	0.22	1.95	1.03	21.36
2010	7.71	1.69	2.97	6.29	-0.17	0.29	6.26	0.00	0.00	4.14	7.09	4.41	40.68
2011	11.54	0.27	0.00	0.28	0.00	1.45	7.97	0.15	0.00	2.19	-0.20	-0.57	23.09
2012	0.00	2.72	14.01	0.00	0.00	0.00	0.00	0.00	12.57	-0.37	-0.29	0.00	28.64
2013	7.22	0.00	0.00	2.38	0.00	0.00	1.38	2.75	0.00	2.18	1.03	7.42	24.37
2014	0.67	4.84	18.18	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.63	0.00	25.24
2015	5.30	2.08	2.04	0.00	0.00	0.00	0.00	0.00					29.18

7.2 Abiotic Components

Table 7.4 provides a summary of the changes in freshwater inflow that have occurred under the different scenarios.

Table 7.4 Summary of the change in low flow conditions to the Kosi Estuary from the Reference Condition to the Present State and future scenarios.

Scenario		Total freshwater inflow (X 10^6 m^3)	% Similarity
No	Description		
Reference	Natural	69 086 766	
Present	Current uses (all use)	63 790 466	92
1	Lawful use	65 867 468	95
2a	Artificial breaching to address mouth closure (assume X2 abstraction and plantations)	58 494 166	85
2b	Allow for extended mouth closure (assume x2 abstraction and plantations)	58 494 166	85

In addition to contributing to the total freshwater inflow into the Kosi Estuarine Lake System, ground water also maintains the water table in the estuary functional zone. This in turn supports the development of the riparian habitat and micro- habitats along the lake margins and banks. A key concern is therefore the degree to which abstraction has reduced the groundwater inflow under the low flow periods (Table 7.5).

Table 7.5 Summary of the groundwater usage as a percentage of the total groundwater inflow.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Present	5.5	5.6	3.7	7.4	46.2	13.5	9.8	68.0	32.2	30.8	9.6	9.1
Scenario 1	5.4	5.4	3.5	6.9	35.8	12.8	9.0	60.2	30.7	26.6	9.1	8.3
Scenario 2	5.7	6.1	4.1	8.4	86.9	15.0	11.4	85.8	35.0	41.3	10.5	10.9

7.2.1 Hydrological health

Table 7.6 provides a summary of the hydrology scores for the Kosi Estuary.

Table 7.6 EHI scores for Hydrology under different scenarios.

Variable	Scenario				
	Present	1	2a	2b	Conf
Similarity in total inflow	**92**	95	85	85	L
Similarity in groundwater	**86**	91	72	72	L
Hydrology score	**92**	**94**	**81**	**81**	**L**

7.2.1 Hydrodynamics and mouth condition

Tables 7.7 and 7.8 provide a summary of the resultant water balance of the total freshwater input and losses to the Kosi Estuarine Lake System (x10^6 m^3) under Scenario 1 and 2(a and b).

Table 7.7 The resultant water balance of the total freshwater input and losses to the Kosi Estuarine Lake System (x10^6 m^3) under Scenario 1

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Months < - 3
1997								3.1	-0.2	-0.2	37.6	4.1		
1998	7.3	13.4	-0.3	-5.7	-8.1	-2.1	-3.3	-7.4	-6.6	0.6	-6.8	4.2	-2.7	6
1999	14.9	41.8	6.9	-1.2	-6.7	-6.4	-3.3	-0.9	0.4	2.0	16.1	1.7	65.3	3
2000	20.7	29.3	41.1	-0.7	-1.0	-4.7	0.2	-6.6	9.8	3.4	32.5	1.6	125.8	2
2001	7.2	24.4	2.3	-2.6	-6.2	-0.3	-2.8	-7.0	-5.3	-2.3	3.9	5.3	16.7	3
2002	-7.5	-7.2	-7.2	0.0	-9.2	-0.7	0.2	-5.8	-6.6	-8.0	-6.8	-0.1	-58.8	8
2003	-7.7	7.5	-6.7	-6.5	-2.0	-1.9	0.9	-8.2	-5.9	-7.1	1.5	-5.6	-41.7	7
2004	11.4	8.6	10.4	7.1	-7.2	-5.2	-0.6	-5.2	-5.8	-7.5	8.1	-5.1	9.0	6
2005	13.8	-1.5	12.9	1.4	-2.2	-5.9	-2.1	-7.8	-5.9	-7.9	12.0	-6.2	0.6	5
2006	-0.6	3.1	-1.5	7.5	-6.5	1.6	-6.8	2.2	-6.7	-6.8	5.1	16.8	7.5	4
2007	-5.7	-4.4	2.2	18.8	-7.3	4.9	4.1	-5.5	-2.0	-3.7	17.3	15.1	33.8	5
2008	-4.1	0.1	1.6	4.8	-5.0	18.0	-1.6	-4.5	-4.5	-6.9	-3.8	0.8	-5.2	6
2009	18.0	9.3	-0.1	-3.6	0.5	-1.0	-6.4	-6.0	-5.5	-0.8	2.6	2.2	9.2	4
2010	15.0	3.3	4.5	11.4	-2.1	-2.3	11.2	-4.7	-6.0	5.7	13.0	7.1	56.0	2
2011	23.6	0.2	-7.6	-1.0	-4.5	-0.4	15.4	-2.2	-5.8	2.5	-0.5	-0.7	19.0	3
2012	-3.7	4.2	30.8	-4.1	-6.4	-5.8	-4.8	-4.8	27.5	-1.5	-0.9	-3.9	26.7	7
2013	12.3	-5.4	-4.0	2.4	-6.1	-4.6	-0.5	2.1	-6.0	2.3	1.1	13.1	6.9	5
2014	2.0	8.6	43.2	-4.3	-5.6	-5.7	-1.0	-5.8	-6.5	-3.6	1.4	-3.2	19.6	7
2015	8.5	4.2	3.6	-4.3	-6.2	-4.5	-4.8	-6.3						Total= 83

Table 7.8 The resultant water balance of the total freshwater input and losses to the Kosi Estuarine Lake System (x10^6 m^3) under Scenario 2a and 2b.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Months < - 3
1997								3.1	-1.2	-1.6	37.6	3.2		
1998	7.2	13.4	-2.4	-5.7	-8.1	-3.2	-4.6	-7.4	-6.6	-0.6	-6.8	3.2	-3.9	7
1999	14.9	41.8	6.8	-2.8	-6.7	-6.4	-4.6	-2.1	-0.8	1.0	16.1	0.1	57.2	3
2000	20.7	29.3	41.1	-1.9	-2.1	-4.7	-0.2	-6.6	9.8	3.4	32.5	-0.1	121.5	2
2001	6.8	24.4	1.0	-4.2	-6.2	-0.6	-3.8	-7.0	-5.3	-4.0	3.6	4.6	9.3	6
2002	-7.5	-7.2	-7.2	-1.1	-9.2	-1.0	-0.1	-5.8	-6.6	-8.0	-6.8	-2.0	-62.5	8
2003	-7.7	7.3	-6.7	-6.5	-3.3	-2.5	0.8	-8.2	-5.9	-7.1	0.3	-5.6	-44.9	8
2004	11.4	8.6	10.4	7.1	-7.2	-5.2	-1.1	-5.2	-5.8	-7.5	8.1	-5.1	8.5	6
2005	13.8	-4.0	12.9	0.7	-3.7	-5.9	-3.0	-7.8	-5.9	-7.9	12.0	-6.2	-5.0	7
2006	-2.9	1.9	-3.8	7.5	-6.5	1.6	-6.8	2.1	-6.7	-6.8	4.7	16.8	1.2	5
2007	-5.7	-4.4	0.6	18.8	-7.3	4.9	4.1	-5.5	-3.7	-3.7	17.3	15.1	30.6	6
2008	-4.1	-1.9	0.2	4.8	-5.0	18.0	-2.2	-4.5	-4.5	-6.9	-3.8	-1.3	-11.2	6
2009	18.0	9.3	-2.1	-3.6	0.1	-1.4	-6.4	-6.0	-5.5	-2.4	1.6	0.4	2.0	4
2010	15.0	2.0	3.8	11.4	-3.4	-3.2	11.2	-4.7	-6.0	5.6	13.0	6.6	51.2	4
2011	23.6	-1.8	-7.6	-2.6	-4.5	-0.8	15.4	-3.4	-5.8	1.5	-2.6	-3.2	8.3	5
2012	-3.7	3.1	30.8	-4.1	-6.4	-5.8	-4.8	-4.8	27.5	-3.4	-2.9	-3.9	21.7	8
2013	12.3	-5.4	-4.0	1.7	-6.1	-4.6	-1.0	1.7	-6.0	1.3	-0.5	13.1	2.5	5
2014	0.1	8.4	43.2	-4.3	-5.6	-5.7	-1.9	-5.8	-6.5	-3.6	-0.4	-3.2	14.8	7
2015	8.5	2.9	2.2	-4.3	-6.2	-4.5	-4.8	-6.3						Total = 97

Table 7.9 Summary of the abiotic states distribution.

PARAMETER	Reference	Present	Scenario 1	Scenario 2a	Scenario 2b
State 1: Open, fresh	30	28	29	27	27
State 2: Open, Saline	57	59	58	53	53
State 3: Open, Very Saline	13	13	13	18	10
State 4: Closed	0	0	0	2	10

This section provides a description of the changes in the occurrences of mouth conditions for each of the scenarios based on the distribution of abiotic states provided above in Table 7.9.

<table>
<tr><td>Present</td><td>Mouth closure occurs less than 1% of the time under the Present State, which is similar to the Reference condition. Scenario 1 is very similar to the Present. Under Scenario 2 the low flows reduce significantly increasing the probability of mouth closure.</td></tr>
<tr><td>Scenario 1, 2a and 2b</td><td>Predicted % mouth closure under the future scenarios:
<table>
<tr><th>Natural</th><th>Present</th><th>1</th><th>2a</th><th>2b</th></tr>
<tr><td>99</td><td>99</td><td>99</td><td>97</td><td>90</td></tr>
</table>
</td></tr>
</table>

Table 7.10 provides a summary of the hydrodynamics and mouth condition scores for the Kosi Estuary.

Table 7.10 EHI scores for hydrodynamics and mouth condition under different scenarios.

Variable	Scenario				
	Present	1	2a	2b	Conf
Hydrodynamics and mouth conditions score	100	100	95	90	**L**

7.2.2 Water Quality

A summary of the water quality characteristics for the various states (distribution presented in Table 7.11), in each of the zones is presented in Table 7.12 to 7.14. This summary was derived from available information on the estuary as presented in the Abiotic Data Summary Report (Appendix B.1). Salinity characteristics in the system are largely influenced by freshwater inputs and tidal exchange. While these processes also have some influence on the other water quality characteristics (i.e. inorganic nutrients, turbidity and dissolved oxygen), *in situ* processes such as wind mixing and remineralisation also have a strong influence, at times greater than the character of freshwater inputs and tidal exchange. It is not expected for the water quality characteristics in the various zones to have changed between reference or future scenarios except for toxic substances where spraying of DDT and plastic pollution are introduced in future scenarios. Also extensive die-back of submerged marcophytes in Lake 3 under Scenario 2a (when salinity in this lake increases to 10) will affected nutrients, turbidity and dissolved oxygen in the lake and adjacent channels. A summary of the average water quality condition in each of the zones, under Reference and Present State is presented in Table 7.13. The tables in this section provide a summary of the water quality changes under the various future scenarios.

Table 7.11 Occurrence of the abiotic states under the different scenario groups.

Abiotic State	Reference	Present	Scenario		
			1	2a	2b
State 1: Open, fresh	30	28	29	27	27
State 2: Open, Saline	57	59	58	53	53
State 3: Open, Very Saline	13	13	13	18	10
State 4: Closed	0	0	0	2	10

Table 7.12 Estimated changes in Water Quality in different zones under different scenarios.

Parameter	Summary of change	Scenario	EST	L1	C1	L2	C2	L3	C3	L4	C4
Salinity	Slight increase due to decrease in the surface and ground water inflow to the system	**Reference**	27.7	22.7	20.2	17.7	8.4	0.7	0.4	0.1	0.1
		Present	27.9	22.9	20.4	17.9	8.6	0.7	0.4	0.1	0.1
		Sc1	27.8	22.8	20.3	17.8	8.5	0.7	0.4	0.1	0.1
		Sc2a	28.2	23.2	20.8	18.2	8.9	2	1.4	0.6	0.1
		Sc2b	27.8	22.8	20.6	17.8	8.5	1	0.6	0.2	0.1
DIN (µg/ℓ)	No marked difference, except Sc2a. Increase in salinity in Lake 3 causes extensive die-back of submerged macrophytes, resulting in excessive organic loading increasing nutrient generation in the lake and adjacent zones	**Reference**	80	80	150	100	100	50	100	101	170
		Present	80	80	150	100	100	50	100	99	172
		Sc1	80	80	150	100	100	50	100	100	171
		Sc2a	80	80	151	101	101	200	150	150	173
		Sc2b	72	72	155	105	105	50	100	85	173
DIP (µg/ℓ)		**Reference**	10	10	10	10	10	10	14	10	10
		Present	10	10	10	10	10	10	14	10	10
		Sc1	10	10	10	10	10	10	14	10	10
		Sc2a	10	10	10	10	10	20	20	15	10
		Sc2b	10	10	10	10	10	10	14	10	10
Turbidity (NTU)	No marked difference, except Sc2a. Increased nutrients in Lake 3 and adjacent areas have increased phytoplankton growth increasing turbidity	**Reference**	2	2	2	2	2	2	7	12	12
		Present	2	2	2	2	2	2	6	11	11
		Sc1	2	2	2	2	2	2	6	11	11
		Sc2a	2	2	2	2	5	5	6	11	11
		Sc2b	2	2	2	2	2	2	6	11	11
DO (µg/ℓ)	No marked difference, except Sc2a. Increased organic loading results in decrease in DO especially in sheltered adjacent channel (wind mixing in Lake 3 will prevent mark drop in DO	**Reference**	7	7 2	7	7 4	7	7	7	7	5
		Present	7	7 2	7	7 4	7	7	7	7	5
		Sc1	7	7 2	7	7 4	7	7	7	7	5
		Sc2a	7	7 2	7	7 4	5	6	5	7	5
		Sc2b	7	7 2	7	7 4	7	7	7	7	4
Toxic substances	Some DDT contamination and plastics in littoral zones	90% similar throughout									

Table 7.13 Summary of Water Quality changes under different scenarios.

Parameter	Summary Of Changes
Changes in longitudinal salinity gradient and vertical stratification	Scenario 1 is similar to Reference. Scenario 2a will, during drought conditions, have salinity values greater than 10 in Lake 3 and 1 in Lake 4. While under Scenario 2b there will only be a limited increase in salinity due to reduced freshwater input.
Inorganic nutrients in estuary	Increase in Lake 3 and adjacent areas under Sc2a as a result of extensive die-back of submerged macrophytes, resulting in excessive organic loading increasing nutrient generation
Turbidity in estuary	Increase in Lake 3 and adjacent areas under Sc2a as a result of higher phytoplankton growth associated with increasing nutrient generation
Dissolved oxygen in estuary	Decrease in Lake 3 and adjacent areas under Sc2a as a result of organic loading
Toxic substances in estuary	Some DDT contamination and plastics in littoral zones

Table 7.14 EHI scores for Water Quality under different scenarios.

Variable		Scenario				
		Present	1	2a	2b	Conf
1	**Salinity**					
	Similarity in salinity	99	99	61	85	L
2	**General water quality in the estuary**					
A	DIN and DIP concentrations	100	100	66	99	M/L
B	Turbidity	100	100	69	99	M/L
C	Dissolved oxygen	100	100	93	100	M/L
D	Toxic substances	90	90	90	90	L
	Water quality score	**94**	**94**	**64**	**88**	**L**

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

7.2.3 Physical Habitats

Tables 7.15 and 7.16 provide a summary of the physical habitat changes under the various future scenarios.

Table 7.15 Summary of Physical Habitat changes under different scenarios.

Parameter		Scenario 1, 2a and 2b
1a	% Similarity in intertidal area exposed	Sedimentation processes are very similar to the Reference conditions, but there is some loss of intertidal habitat due to agricultural activities.
1b	% Similarity in sand fraction relative to total sand and mud	Very similar to reference. While there is large scale land transformation in the catchment this does not translate into a significant shift in sediment composition as there is very little clay and muds in the catchment.
2	% Similarity in subtidal area: depth, bed or channel morphology	Very similar to reference, but assume some deepening of the channels due to boat action under low water levels conditions. Limited localised impact on sediment movement around fish traps.

Table 7.16 EHI scores for Physical Habitat under different scenarios.

Variable	Scenario				
	Present	1	2a	2b	Conf
1a. Intertidal areas and sediments	95	95	95	95	L
1b. Similarity in sand fraction	95	95	90	90	L
2. Subtidal area and sediments	95	95	95	95	L
Physical habitat score	**95**	**95**	**94**	**94**	**L**

7.3 Biotic Components

7.3.1 Microalgae

Tables 7.17 to 7.19 provide a summary of the changes in the microalgae fauna under the various future scenarios.

Table 7.17 Summary of change in Microalgae component under different scenarios.

Scenario	Summary of Changes
1	Scenario 1 represents a small increase in freshwater input to the system but this does not change the distribution of states and therefore the microalgal response.
2a	Scenario 2a the estuary remains open but may close for a few months (3-6). For Lake 3 the salinity increases to 10 and Lake 4 salinity increases to 3 psu. The increase in salinity in Lakes 3 and 4 will result in some loss of microalgal species. During the closed mouth state microalgal biomass may increase in areas where tidal flushing no longer occurs as a result of increased water retention. However an increase in salinity will result in a loss of freshwater species and a change in community composition.
2b	For Scenario 2b the estuary will remain closed for approximately 2 years but salinity will remain at 5 in Lake 3 and Lake 4 at salinity 1; this is similar to present conditions. Water level will increase slowly to 1 m. The increase in water level will change the shallow water habitats where the microphytobenthos biomass is high. Die-back of fringing macrophytes will cause a detrital pulse, remineralisation and an increase in nutrients which may increase phytoplankton biomass.

Table 7.18 EHI scores for Microalgae component under different scenarios.

Variable	Summary of change	Score	Conf
1. Species richness	<u>Scenario 1</u> Decrease in groundwater inflow and changes in salinity would lead to some loss of microalgal species <u>Scenario 2a</u> The increase in salinity will result in some loss of microalgal species. <u>Scenario 2b</u> The loss of the marine connection and salinity gradient will result in a loss of microalgal species.	95 90 85	L
2. Abundance	<u>Scenario 1</u> Loss of benthic microalgal habitat due to disturbance of the riparian zone by cattle and people. <u>Scenario 2a</u> When the mouth is closed there is a possible increase in phytoplankton biomass due to an increase in water retention but a loss of benthic microalgal biomass particularly in the intertidal area. <u>Scenario 2b</u> Extended mouth closure may result in an increase in	95 70 70	L

Variable	Summary of change	Score	Conf
	biomass in calm areas but there would also be competition for available nutrients from other primary producers such as the floating and submerged macrophytes.		
3. Community composition	Scenario 1 No changes expected Scenario 2a Possible increase in dinoflagellates in the phytoplankton in response to more saline, stratified waters. When the mouth is closed there is a possible increase in phytoplankton biomass but a loss of benthic microlalgal biomass. Scenario 2b Lower salinity in Lakes 1 and 2 will increase the abundance of Cyanophyceae (blue-green algae), and to a lesser degree Chlorophyceae in the phytoplankton. When the mouth is closed there is a possible increase in phytoplankton biomass but a loss of benthic microlalgal biomass.	100 80 70	L

Table 7.19 EHI scores for Microalgae component under different scenarios.

Variable	Scenario				
	Present	1	2a	2b	CONF
1. Species richness	95	95	90	85	L
2 Abundance	95	95	70	70	L
3. Community composition	100	100	80	70	L
Biotic component score	**95**	**95**	**70**	**70**	

7.3.2 Macrophytes

Tables 7.20 and 7.21 provide a summary of the changes in the macrophyte fauna under the various future scenarios. The human pressures resulting in disturbance of the macrophyte habitats remain as described for the present day assessment.

Table 7.20 Summary of change in Macrophyte component under different scenarios.

Scenario	Summary of Changes
Scenario 1	Small increase in freshwater input to the system but this does not change the distribution of states or macrophytes. There may be site specific increases in groundwater input which would increase macrophyte productivity at different sites but the overall effect is very small and has therefore not been scored.
Scenario 2a	The estuary closes for a few months (3-6), Lake 3 salinity increases to 10 psu & Lake 4 salinity to 3 psu. The increase in salinity in Lake 3 will cause die-back of the submerged macrophytes and in Lake 4 some die-back of the floating macrophytes (e.g. lilies). In summary, there will be a loss of species due to increase in salinity in Lakes 3 and 4 e.g. water lilies and some freshwater sedges and grasses. Overall loss of vegetated area but will be replaced by more salt tolerant species. Some loss of floating macrophytes due to an increase in salinity. Within the submerged macrophytes salt tolerant species will become abundant.
Scenario 2b	The estuary will remain closed for approximately 2 years but salinity will remain at 5 psu in Lake 3 and at 1 psu for Lake 4. Water level will increase slowly to 1 m flooding all fringing emergent vegetation. This will cause an initial detritus pulse to the estuary, remineralization will occur with a subsequent nutrient pulse. The intertidal habitat will be flooded resulting in a die-back of mangroves after approximately 3 months of inundation. Slowly over time the previously exposed habitat will be occupied by submerged and floating macrophytes. In summary, there will be a loss of species due to increase in water level and flooding of surrounding emergent vegetation. Loss of mangroves due to flooding of the intertidal habitats and some loss of swamp forest but refuge areas would be available. Loss of emergent macrophytes although over time

	there will be an increase in area covered by submerged and floating macrophytes. Submerged / floating macrophytes replace emergents. Mangroves lost due to inundations. Other communities likely to remain intact as within the community there are brackish species.

Table 7.21 EHI scores for Macrophyte component under different scenarios.

Variable	Scenario				
	Present	1	2a	2b	CONF
1. Species richness	95	95	80	50	L
2 Abundance	90	90	70	70	L
3. Community composition	90	90	70	50	L
Biotic component score	**90**	**90**	**70**	**50**	

7.3.3 Invertebrates

Tables 7.22 to 7.24 provide a summary of the changes in the invertebrate fauna under the various future scenarios.

Table 7.22 Summary of change in Invertebrates component under different scenarios.

Scenario	Summary of Changes
Zooplankton	
1	This scenario represents a small increase in freshwater input to the system but this does not change the distribution of states and therefore the zooplankton response.
2a	The estuary remains largely open, but may close for a few months (3-6). The increase in salinity in Lakes 3 (10 psu) and 4 (3 psu) will result in some change to the zooplankton community with loss of primarily freshwater species and those that rely on a permanent exchange with the marine environment. During the closed mouth state biomass may increase in areas where tidal flushing no longer occurs as a result of increased water retention if artificial breaching does not occur. Under conditions of consistent breaching, Lakes 1 and 2 support larger numbers of polyhaline taxa, but retention times are lower due to potential frequency of breaching, with negative consequences for a persistent zooplankton component. Breaching has added negative influences on the stability of salinity gradients (decreased overall abundance) and lack of recruitment unless mouth open state and duration are appropriately timed.
2b	The estuary will remain closed for an extended period (2 years) but salinity will remain at current conditions of 5 psu in Lake 3 and 1 psu in Lake 4. Water level will increase slowly by 1 m. Die-back of fringing macrophytes will cause a detrital pulse, remineralisation and an increase in nutrients which may increase phytoplankton biomass, thereby increasing zooplankton production but without recruitment from the marine environment and loss of taxa that require movement in and out of the system. Only species complete life cycles within the system persist (dependent on food availability).
Macrobenthos	
1	This scenario represents a small increase in freshwater input to the system but this does not change the distribution of states and therefore the macrobenthos response.
2a	The increase in salinity in Lakes 3 (10 psu) and 4 (3 psu) will result in a fundamental change to species richness and abundance of these lakes. This is in part due to the possible ingression of the bio-engineer *Callichirus kraussi*, decreasing habitat availability in shallow sub-tidal areas for smaller infauna, but also due to losses of salinity intolerant species. The likelihood of higher detrital input with loss of macrophytes also has habitat altering consequences for macrobenthos and loss of diversity because of direct associations with these plants (e.g. Broekhuysen & Taylor 1959). Although Lakes 1 and 2 support larger

	numbers of polyhaline taxa, there is decreased macrobenthic abundance overall.
2b	The estuary will remain closed for an extended period, which will result in slightly depressed abundance and species richness. Few, and eventually no, marine taxa will be found in the lower reaches of estuary, these taxa contribute to the overall diversity at present. With no tidal flow during mouth closed conditions, *Tarebia* could spread successfully from Lakes 3 & 4 through to Lake 2. Increased organic matter and lower salinity provides a mechanism for rapid and extensive expansion of this invasive species.
Macrocrustacea	
1	This scenario represents a small increase in freshwater input to the system but this does not change the distribution of states and therefore the macrocrustacea response.
2a	*Callichirus kraussi* has had limited opportunity to spread into the largest subtidal habitat of Lake 3. This will change with the ingression of the sand prawn into Lake 3 if the mouth is closed and salinity is persistently >10 psu for >1-2 yrs. This scenario will reduce freshwater habitat for *Varuna* adults that currently reside in Lakes 3 and 4. Mouth open state duration and timing (in particular under a breaching scenario) may be inappropriate for species recruitment. Many macrocrustacea require a marine phase in the life cycle.
2b	The estuary will remain closed for an extended period, which will result in elevated water levels, fresher conditions and likely catastrophic losses of mangroves. All species (e.g. *Uca*, Sesarmidae) associated with mangroves will disappear as will species relying on the rise and fall of tide. No recruitment for long periods from the marine environment and all species with obligatory marine lifecycle phases are affected e.g. *Scylla* and *Varuna* megalopae. Only species that can complete life cycles in the system persist (fiddler and sesarmid crabs, but this is contingent on mangrove area remaining).

Table 7.23 EHI scores for Invertebrates component under different scenarios.

Zooplankton			
Variable	**Summary of change**	**Score**	**Conf**
1. Species richness	Scenario 1 Reported as consistently depauperate. Loss of signature species, *Pseudodiaptomus hessei.* Scenario 2a Fundamental change to species richness of Lakes 3 and 4 from reference, with a change to more mesohaline communities. Loss of water mite/copepod in plankton of Lakes 3 and 4. Lakes 1 and 2 support larger numbers of polyhaline taxa. Scenario 2b No recruitment for long periods from the marine environment. A naturally poor zooplankton component will lack a marine component.	85 60 75	L
2. Abundance	Scenario 1 Reported as consistently depauperate. Loss of *P.hessei* abundance replaced by estuarine mysid *Mesopodopsis Africana.* Scenario 2a Decreased overall abundance due to instability of hydrodynamic processes e.g. salinity conditions. Fundamental change to abundance of Lakes 3 and 4 from reference. System retention times are lower due to potential frequency of artificial breaching, with negative consequences for a persistent zooplankton component to develop. Scenario 2b No recruitment for long periods from the marine environment. A naturally poor zooplankton component will lack a marine component.	90 60 80	L
3. Community composition	Scenario 1 Loss of signature species, *Pseudodiaptomus hessei* to community in Lakes 1 and 2 in particular. Scenario 2a Mouth open state, duration and timing may be inappropriate for species recruitment. Scenario 2b Only species that can compete life cycles in the system persist (dependent on food availability).	85 50 70	L

	Macrobenthos		
Variable	**Summary of change**	**Score**	**Conf**
1. Species richness	Scenario 1 Recent studies are comparable to various ad hoc studies (e.g. Hemens et al 1971, Connell et al. 1976). These were estimated close to reference 2002/3 study reports larger numbers of taxa. This is likely a reflection of attention to taxonomy detail. System supports marine, typically estuarine and freshwater assemblages dependent on salinity distribution. Unique taxa to SA estuaries are limited to marine reaches and are related to biogeography (southern limit of tropical species). Kosi supports rich assemblage of fauna relative to other estuaries in SA. If invasive *Tarebia* increases, may influence current diversity. Scenario 2a Fundamental change to species richness of Lakes 3 and 4. Loss of macrophyte habitat that contributes to invertebrate diversity (e.g. Broekhuysen & Taylor 1959). Lakes 1 and 2 will support larger numbers of polyhaline taxa. Scenario 2b Numbers of different species decline slightly. With fewer marine taxa in lower reaches of the estuary. These taxa contribute significantly to overall system diversity	85 50 75	L
2. Abundance	Scenario 1 Similar to reference. Loss of large numbers of molluscs, across various species reported as lost to the system (Begg 1978) and attributed to possible DDT input. Scenario 2a Fundamental change to abundance of lakes 3 and 4. Lakes 1 and 2 will support larger numbers of polyhaline taxa. Decreased overall abundance. Scenario 2b If Lake 2 is colonised by *Tarebia*, a rich, littoral oligohaline-mesohaline tolerant estuarine assemblage will lose shallow subtidal habitat. These fauna currently contribute to abundance of Lakes 1 and 2. Lake 2 is the most abundant basin at present.	90 50 80	L
3. Community composition	Scenario 1 Drop due to relatively recent arrival of *Tarebia*, loss of other mollusc species reported. Scenario 2a Possible ingression of bio-engineer *Callichirus kraussi*, decreasing habitat availability in shallow sub-tidal for smaller infauna. Higher organic input has habitat altering consequences for macrobenthos. Fundamental alteration to feeding guild structure with possible change to deposit feeders associated to higher organic sediments. Scenario 2b Increased ingression of *Tarebia granifera* from Lakes 3 & 4 through to Lake 2. Increased organic matter and lower salinity provides a mechanism for rapid and extensive expansion of the species. It is habitat altering for other infauna.	85 50 65	L

Macrocrustaceans			
Variable	**Summary of change**	**Score**	**Conf**
1. Species richness	Scenario 1 Original assemblage remains, changes due to increase in mangrove habitats and associated species. Potential changes result from addition of species due to increase in mangrove areas. Scenario 2a Change in hydrodynamics and flow related to repeated change in mouth state, results in interruption of lifecycles within the system and also of species that require connection with the marine environment at very specific times. Scenario 2b Only species that can compete life cycles in the system persist (Fiddler and sesarmid crabs).	90 60 70	L
2. Abundance	Scenario 1 Extensive subsistence use (mangrove crabs) and sand prawn for bait collection has altered abundance. Reported decline in crabs since 1980s (e.g. Pederson et al. 2003) Scenario 2a Potential ingression of sand prawn into Lake 3 if mouth is closed and salinity is persistently >10 psu for >1-2 yrs. Scenario 2b Mangrove losses influence abundance distribution of associated crabs.	75 60 70	L
3. Community composition	Scenario 1 Similar component of marine dependent estuarine and freshwater taxa (e.g. Sesarmidae, *Uca* spp, Grapsidae), marine species e.g. *Matuta* and Calapidae species. Scenario 2a Reduced freshwater habitat for *Varuna* adults that currently reside in Lakes 3 and 4. Scenario 2b No recruitment for long periods from the marine environment. All species with obligatory marine lifecycle phases are affected e.g. *Scylla* and *Varuna* megalopae.	90 60 70	L

Table 7.24 provides a summary of the invertebrate component scores under the various future scenarios (Scenarios 1, 2a and 2b).

Table 7.24 Summary of invertebrate component scores under different scenarios.

Variable	Scenario				
	Present	1	2a	2b	CONF
1. Species richness	85	85	50	70	L
2. Abundance	75	75	50	70	L
3. Community composition	85	85	50	65	L
Biotic component score	**75**	**75**	**50**	**65**	**L**

7.3.4 Fish

Tables 7.25 to 7.29 provide a summary of possible changes in the fish fauna under the various future scenarios.

Table 7.25 Summary of change in Fish component under different scenarios.

Scenario	Summary of Changes
Scenario 1	There is a small increase in freshwater input to the system that does not markedly change the distribution of states. The freshwater species assemblage is likely to benefit from these small changes, as a greater area of lake habitat will be available to salinity intolerant species, with greater frequency. This provides increased population resilience to this group of fishes. There is little implication for estuarine and marine species.
Scenario 2a	The estuary closes for a few months (3-6). Salinity in Lake 3 increases to 10 psu and in Lake 4 to 3 psu. The increase in salinity will cause die-back of macrophytes in Lakes 3 (submerged forms) and Lake 4 (floating forms). This reduces fish habitat, and may result in water quality effects (dissolved oxygen). These salinities are also above the tolerance ranges of primary freshwater species and these fish will disappear from lake habitats and take refuge in inflowing freshwater streams. If drought results in these streams drying out localized extinctions will occur. Depending on where these streams enter the lake (high of low salinity areas) recruitment during subsequent wet periods may not be possible, and impacts will be permanent. Absolute and relative abundances of estuarine fishes will be impacted, especially in Lakes 3 and 4. A higher abundance of marine species will occur in these lakes, including several forms that are predatory on small estuarine fishes. In addition to impacts on their distributions within the system, absolute and relative abundances of marine fishes will be impacted due to loss of recruitment during the closed mouth phases.
Scenario 2b	The estuary will remain closed for approximately 2 years but salinity will not reach levels associated with Scenario 2b, remaining rather at 5 psu in Lake 3 and at 1 psu in Lake 4. Water level will increase slowly flooding all fringing emergent vegetation. This will result in a detritus pulse to the estuary and remineralization and a subsequent nutrient pulse will occur. Impacts to water quality (dissolved oxygen) are possible. Intertidal habitat will be flooded resulting in a die-back of mangroves. Slowly over time new submerged and floating macrophyte habitats will establish, but the shifts, and impacts to water quality will impact the fish assemblages. Salinities in Lakes 3 and 4 will still be higher than what most primary freshwater species can tolerate and the freshwater fishes will be affected to some degree in the same manner as under Scenario 2a. Select secondary freshwater species may proliferate. Estuarine fishes are also impacted for the same reasons are those listed above (Scenario 2a), but to a lesser degree. Marine species, however, are affected by the prolonged mouth closure and can be expected to be more severely impacted under this scenario.

Detailed EHI scores for fish different groupings of fishes under the different scenarios are provided in Tables 7.26, 7.27 and 7.28 for Scenarios 1, 2a and 2b respectively, and aggregated scores are provided in Table 7.29.

Table 7.26 Changes in Fish component under Scenario 1.

Variable	Summary of change	Score	Conf.
Freshwater fishes			
1. Species richness	As PES	100	M
2. Abundance	Some increase in abundance of primary freshwater species (relative to present ecological state).	95	L
3. Community composition	Relative abundances of primary freshwater species increases and is closer to the system in its reference condition.	90	L
Estuarine resident fishes			
1. Species richness	As PES	100	M
2. Abundance	As PES	95	L
3. Community composition	As PES	95	L
Marine fishes (comprising predominantly estuarine dependant marine species)			
1. Species richness	As PES	85	M
2. Abundance	As PES	60	M
3. Community composition	As PES	60	M
Aggregated fish scores (average metric criterion)			
1. Species richness	See above motivation	92	M
2. Abundance	See above motivation	83	L
3. Community composition	See above motivation	82	L
Biotic component health score		**82**	**L**

Table 7.27 Changes in Fish component under Scenario 2a.

Variable	Summary of change	Score	Conf.
Freshwater fishes			
1. Species richness	Increased salinity and salinity penetration will result in losses of primary freshwater species from the system. Depending on state of refugia impacts may be long lasting (and permanent in some small inflows).	50	L
2. Abundance	Habitat losses occur in the system, as well as loss of surrounding swamps. Primary freshwater species impacted by salinity penetration and habitat losses (particularly of losses of floating macrophytes). Secondary freshwater fishes will be less affected, and select species (e.g. *Oreochromis mossambicus*) may proliferate. Possible longer term impact to water quality (dissolved oxygen) may occur and impact freshwater fishes further.	80	L
3. Community composition	Relative abundances of primary freshwater species are markedly reduced under this scenario.	50	L
Estuarine resident fishes			
1. Species richness	As PES	100	M
2. Abundance	Abundances of these fishes fluctuate naturally, in long-term cycles, but this Scenario introduces extreme conditions. Salinities in Lake 3 allow penetration of marine species (sand prawn and fish). This results in increased predation on estuarine fishes in this lake. These impacts are relatively short term (3-6 months). Some loss of habitat (submerged vegetation) occurs which may result in longer term changes, along with impacts to water quality (dissolved oxygen).	80	L
3. Community composition	Relative abundances of species, especially in upper two lakes, changes quite markedly.	75	L
Marine fishes (comprising predominantly estuarine dependant marine species)			
1. Species richness	Mouth closure results in recruitment potential being reduced, and some habitat losses occur for marine spawned species. Salinity ranges and prey availability do not become limiting however (and prey availability might improve for piscivorous species).	70	L
2. Abundance	Abundances fluctuate naturally in (probably) long term cycles. Loss of recruitment of these species will impact their abundance. Habitat losses are also likely to have some impact, but mangroves are expected to survive the relatively short closed periods. Die-off of some vegetation may result in impacts to water quality (dissolved oxygen). During closed periods the fishery (especially the fish traps) may be affected, but its influence is long lasting as no recruitment can take place. Exploitation (even if reduced, with further reduce abundance).	55	L
3. Community composition	As PES	60	L
Overall fish scores (average metric criterion)			
1. Species richness		73	L
2. Abundance		72	L
3. Community composition		62	L
Biotic component health score		**62**	**L**

Table 7.28 Changes in Fish component under Scenario 2b.

Variable	Summary of change	Score	Conf.
Freshwater fishes			
1. Species richness	Increased salinity and salinity penetration will result in losses of primary freshwater species from the system. Depending on state of refugia impacts may be long lasting (and permanent in some small inflows). Increases in salinity into Lake 4 are not as marked as Scenario 2a, and even though they persist for longer losses of species are likely to be less severe.	60	L
2. Abundance	Habitat losses occur in the system, as well as loss of surrounding swamps. Primary freshwater species impacted by salinity penetration and habitat losses (particularly of losses of	80	L

	floating macrophytes). Secondary freshwater fishes will be less affected, and select species (e.g. *Oreochromis mossambicus*) may proliferate. Possible longer term impact to water quality (dissolved oxygen) may occur and impact freshwater fishes further.		
3. Community composition	Relative abundances of primary freshwater species are markedly reduced under this scenario, although not to the same degree as in Scenario 2a.	60	L
Estuarine resident fishes			
1. Species richness	As PES	100	M
2. Abundance	Abundances of these fishes fluctuate naturally, in long-term cycles, but this Scenario introduces extreme conditions. Salinities in Lake 3 allow penetration of marine species (sand prawn and fish). This results in increased predation on estuarine fishes in this lake, although not to the same degree as Scenario 2a. However, impacts are longer terms and include loss of habitat (submerged and emergent vegetation) which may result in longer term changes, along with impacts to water quality (dissolved oxygen). In short-lived estuarine species this may become problematic.	85	L
3. Community composition	Relative abundances of species, especially in upper two lakes, changes quite markedly, but not to the same degree as Scenario 2a.	80	L
Marine fishes (comprising predominantly estuarine dependant marine species)			
1. Species richness	Mouth closure results in recruitment potential being reduced, and habitat losses occur for marine spawned species. Salinity ranges and prey availability do not become limiting however (and prey availability might improve for piscivorous species). The prolonged closure results in greater potential impacts than Scenario 2a.	60	L
2. Abundance	Abundances fluctuate naturally in (probably) long-term cycles. Loss of recruitment of these species will impact their abundance. Habitat losses are also likely to have some impact, but mangroves are expected to survive the relatively short closed periods. Die-off of some vegetation may result in impacts to water quality (dissolved oxygen). During closed periods the fishery (especially the fish traps) may be affected, but its influence is long lasting as no recruitment can take place. Exploitation (even if reduced, with further reduce abundance). The prolonged closure results in greater potential impacts than Scenario 2a.	50	L
3. Community composition	As PES	60	L
Overall fish scores (average metric criterion)			
1. Species richness	See above for motivation	73	L
2. Abundance	See above for motivation	72	L
3. Community composition	See above for motivation	67	L
Biotic component health score		**67**	**L**

Table 7.29 provides a summary of the fish component scores under the various future scenarios.

Table 7.29 EHI scores for Fish component under different scenarios.

Variable	Scenario				
	Present	1	2a	2b	CONF
1. Species richness	92	92	73	73	L
2. Abundance	82	83	72	72	L
3. Community composition	80	82	62	67	L
Biotic component score	**80**	**82**	**62**	**67**	**L**

7.3.5 Birds

There are a large number of variables that affect the bird fauna of Kosi. These start with the physicochemical changes caused by altered hydrodynamics. The most important of these being altered salinity and the effects of mouth closure, altered water levels, lack of tides, nutrient enrichment and changes in turbidity; all of which are very important to specific species of birds. Most of the impacts of these physical changes are on the plants, invertebrates and fish that the birds feed on, as well as alterations of the areas of habitat that the birds can utilise. For scenario 1 where there is less flow into the river, the habitat of Finfoot is reduced when lower flows in the Sihadla Channel (Channel 4) allow more sections of the channel to be covered with rafts of the floating *Pycreus nitidus* sedge. For scenario 2a the species richness is the same as for reference conditions, but there is likely to be an increase in the 'estuary' birds as salinity increases into the system. This would cause an shift to more of the estuary bird communities – at the expense of the birds that prefer fresh water. As water lilies are killed by salinity there will be a loss of Pygmy geese. For scenario 2b there will be an immediate decrease in the species of waders using the system as the water level rises - flooding the formerly intertidal sandbanks. This will also result in a loss of the waders. There also will be a loss of terns as their summer aggregations may no longer occur in the former mouth area. As shoreline vegetation is reduced by flooding, so there will be a reduction in those birds that use this habitat. Specialist birds such as Finfoot and Little biterns will be reduced in abundance. With these changes there will also be severe alterations in community composition of all the feeding guilds.

The headline messages for the various scenarios for birds are:

- If the mouth closes for a long period (Scenario 2b) then it is likely that the tern roost at the mouth will be lost. This will also occur if there is excessive human disturbance here.
- If the lake level rises to a large degree (scenario 2b) then we are likely to loose the waders.

The tables 7.30 and 7.31 provide a summary of the changes in the bird fauna under the various future scenarios.

Table 7.30 Summary of change in bird component under different scenarios.

Scenario	Summary of Changes
1	Little change as it is close to current scenario
2a	Salinity will penetrate into the system getting to >10 psu in Lake 3. Lake level remains more or less constant.
2b	Salinity is unlikely to exceed 5 psu and likely to be below that throughout the system. Water level can rise drastically – up to 3 m amsl if the mouth has been closed for a long time.

Table 7.31 EHI scores for Bird component under different scenarios.

Variable	Scenario				
	Present	1	2a	2b	CONF
1. Species richness	98	98	95	70	Low
2. Abundance	92	92	80	50	Low
3. Community composition	92	92	50	50	Low
Biotic component score	**92**	**92**	**50**	**50**	

7.4 Ecological Categories associated with scenarios

The Recommended Ecological Category (REC) represents the level of protection assigned to an estuary. The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of importance and level of protection or desired protection of a particular estuary. The PES for the Kosi Estuary is an A/B. Taking the current conditions (PES = A/B), the reversibility of the impacts, the ecological importance and the conservation requirements of the Kosi Estuarine Lake System the Recommended Ecological Category for the estuary is an A Category.

The individual EHI scores, as well as the corresponding ecological category under different scenarios are provided below in Table 7.32.

Table 7.32 EHI scores and corresponding Ecological Categories under the different runoff scenarios.

COMPONENT	Weight	Present	Scenario 1	Scenario 2a	Scenario 2b	Confidence
Hydrology	25	90	94	81	81	L
Hydrodynamics and mouth condition	25	100	100	95	90	L
Water quality	25	94	94	64	88	L
Physical habitat alteration	25	95	95	94	94	M
Habitat health score		**95**	**96**	**83**	**88**	
Microalgae	20	95	95	70	70	L
Macrophytes	20	90	90	70	50	L
Invertebrates	20	75	85	50	65	L
Fish	20	80	82	62	67	L
Birds	20	92	92	50	50	L
Biotic health score		**86**	**89**	**60**	**60**	
ESTUARY HEALTH SCORE		**91**	**92**	**72**	**74**	**L**
ECOLOGICAL CATEGORY		**A/B**	**A/B**	**C**	**C/B**	

None of the Future scenarios achieves the REC. Scenario 1 shows an improvement in condition from the present, but the system remains in an A/B category.

Under Scenario 2a (mouth closure mitigated with artificial breaching) all components with the exception of the physical habitat shows a sharp decline in health. The overall the ecological health of the system declines to a C Category, with important socio-economic component like the fish declining to a C/D Category and the invertebrates declining to a D Category. The motivation for this decline in health is related to the reduced freshwater input, that in combination with artificial breaching, elevates the salinity in Lake 3 to between 5 and 10 psu during droughts. This in turn causes major tropic shifts in Lake 3 and Lake 4.

Under Scenario 2b (mouth remains closed for months to years) the system fares marginally better with an overall ecological category of a C/B. Under this scenario, salinities do not elevate above 5 psu in Lake 3, but extended mouth closure causes die-back of the mangroves and related ecosystem impacts. However, the macrophytes, invertebrates, and fish components still show a marked decline in condition and productivity from the present.

Both Scenario 2a and 2b holds severe ecological and socio-economic consequences for the Kosi Estuarine Lake System. The headline message is that mouth closure cannot be mitigated for through artificial breaching in the absence surface and groundwater input. During periods of low flow (winter) and droughts, freshwater input is critical in maintaining the salinity regime and mouth status of the system. Without this critical driver, the system and the ecosystem services it provides will experience a severe decline in ecological health.

However, it should be stressed that there is a risk of mouth closure occurring even at the present water resource utilisation levels. The February 2016 field visit showed that the present freshwater input to the Kosi System is very little, resulting in a very constricted mouth (inlet) at present. Therefore the system is at a very high risk of closure if high wave condition were to develop at sea during the low flow season.

A critical concern under the present and future scenarios is the impact that mouth closure would have on the Kosi Estuarine Lake System. As indicated above none of the flow scenarios achieve the REC. A range of additional managed interventions is also required to address the negative trajectory of the Kosi system.

Scenario 1 is the recommend scenario to achieve the REC of an A in conjunction with the following key management actions:

- Cap the groundwater utilisation especially during drought conditions, i.e. reduce plantations, that decrease the winter freshwater input.
- Maintain the traditional subsistence fishery using traditional methods at sustainable levels. Traditional methods refer to the back facing traps, but exclude gear such as diving masks and spear guns, augmented baskets (lined with nets) and gill nets.
- Control and monitoring the crab harvesting (at present uncontrolled and sold in Durban).
- Control resource utilisation of reeds, sedges, and mangroves through the introduction of rest areas.
- Control the burning of the flood plain, swamp forest and mangroves, through for example, an education programme.
- Control the clearing and draining of the peatlands for gardening.
- Control the usage of DDT, herbicides and pesticides in the catchment. There is a growing concern that the use of DDT and organic phosphates will have an increasing impact on the system because of their long resident time and vulnerability of the lake system.

8 RECOMMENDATIONS

8.1 Ecological flow requirements

The 'recommended Ecological Flow Requirement' scenario, is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the Recommended Ecological Category. Where any component of the health score is less than 40, then modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. The REC for the Kosi Estuary is a Category A. The flow requirements for the estuary are the same as those described for the Scenario 1 and are summarised in Table 8.1.

Table 8.1 A summary of the ground water monthly volume (in $10^6 m^3$) distribution under the under Scenario 1.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1997								3.71	2.35	2.90	16.89	4.85	
1998	6.19	8.15	3.08	0.00	0.00	1.25	1.23	0.00	0.00	3.06	0.00	4.71	27.67
1999	8.64	18.31	5.62	2.11	0.00	0.00	1.12	2.03	2.97	3.77	9.09	3.39	57.03
2000	10.64	13.59	18.22	2.27	2.19	0.00	2.17	0.00	6.56	4.14	15.12	3.69	78.59
2001	5.76	11.76	3.69	1.62	0.00	1.83	1.21	0.00	0.00	1.86	4.30	5.24	37.26
2002	0.00	0.00	0.00	3.12	0.00	1.89	2.31	0.00	0.00	0.00	0.00	3.07	10.39
2003	0.00	5.67	0.00	0.00	1.98	1.37	2.78	0.00	0.00	0.00	3.59	0.00	15.38
2004	7.51	6.14	7.05	5.63	0.00	0.00	2.08	0.00	0.00	0.00	6.15	0.00	34.55
2005	8.20	1.82	7.80	3.21	1.72	0.00	1.43	0.00	0.00	0.00	7.76	0.00	31.94
2006	2.68	3.84	2.25	5.73	0.00	2.59	0.00	3.54	0.00	0.00	4.89	9.42	34.94
2007	0.00	0.00	3.52	9.67	0.00	3.96	3.75	0.00	1.13	0.00	8.74	8.05	38.82
2008	0.00	1.90	2.71	3.87	0.00	8.69	1.34	0.00	0.00	0.00	0.00	2.58	21.08
2009	9.28	5.51	1.99	0.00	2.40	1.70	0.00	0.00	0.00	1.79	2.99	2.88	28.54
2010	7.71	2.95	3.73	6.29	1.10	1.15	6.26	0.00	0.00	4.27	7.09	4.95	45.49
2011	11.54	2.26	0.00	1.89	0.00	1.85	7.97	1.35	0.00	3.16	1.89	1.95	33.85
2012	0.00	3.82	14.01	0.00	0.00	0.00	0.00	0.00	12.57	1.55	1.78	0.00	33.72
2013	7.22	0.00	0.00	3.12	0.00	0.00	1.89	3.12	0.00	3.26	2.68	7.42	28.72
2014	2.61	5.05	18.18	0.00	0.00	0.00	1.80	0.00	0.00	0.00	2.36	0.00	30.00
2015	5.30	3.36	3.43	0.00	0.00	0.00	0.00	0.00					34.59

8.2 Resource quality objectives

Ecological specifications are clear and measurable specifications of ecological attributes (in the case of estuaries, hydrodynamics; sediment dynamics; water quality; and different biotic components) that define a specific reserve category, which was decided upon by the authorities utilizing environmental, social and economic criteria. Thresholds of potential concern (TPC) are defined as measurable endpoints related to specific abiotic or biotic indicators that if reached prompts management action. In essence, thresholds of potential concern should be defined such that they provide early warning signals of potential non-compliance to ecological specifications. In essence, this concept implies that the indicators (or monitoring activities) selected as part of a long-term monitoring programme need to include biotic and abiotic components that are particularly sensitive to ecological changes associated with changes in river inflow into the system. The ecological specifications for the Kosi Estuary, as outlined in Tables 8.2 and 8.3, are set for the PES and Recommended Ecological Category A.

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

Abiotic Component	Ecological Specification	Threshold of Potential Concern	Causes
Hydrology	Maintain a flow regime to create the required habitat for birds, fish, macrophytes, microalgae and water quality.	River and ground water inflow distribution patterns differ by more than 5% from that of Scenario 1 (i.e. approved flow scenario for the Kosi system).	Forestry reducing groundwater baseflows Flow reduction Groundwater abstraction
Hydrodynamics	Maintain a mouth conditions and water levels to create the required habitat for birds, fish, macrophytes, microalgae and water quality.	Mouth closure occurs No tidal variation in Lake 1 and Lake 2 Water level in the system is above 1.3 m MSL for longer than a few days (not related to a flood).	Forestry reducing groundwater baseflows Flow reduction Groundwater abstraction
Water Quality	Salinity distribution not to cause exceedance of TPCs for fish, invertebrates, macrophytes and microalgae (see above).	Salinity > 5 in Lake 3 Salinity > 1 in Lake 4	Forestry reducing groundwater baseflows Flow reduction Groundwater abstraction
	System variables (pH, dissolved oxygen and turbidity) not to cause detrimental impacts on biota (beyond specified TPCs/Ecospecs).	River inflow: 7.0 < pH > 8 in any survey DO < 6 mg/ℓ Turbidity >10 NTU (low flow) Turbidity >15 NTU (higher flow – State 1) Estuary and Lakes: Average turbidity > 5 NTU 7.0 < pH > 8.5 at any station DO < 6 mg/ℓ in surface samples (up to ~5 m water depth)	No major impacts on Kosi system at present, but increase population growth around system poses a risk.
	DIN (NO_xN + NH_3-N) and DIP (PO_4-P) concentrations not to cause excessive macrophytes and microalgae (beyond specified TPCs/ Ecospecs).	River inflow DIN >100 µg/ℓ in 2 consecutive monthly sampling DIP > 10 µg/ℓ in 2 consecutive monthly sampling Estuary and Lakes: Average DIN >100 µg/ℓ in a sampling survey Average PO_4-P > 10 µg/ℓ in a sampling survey	No major impacts on Kosi system at present, but increase population growth around system poses a risk.

Abiotic Component	Ecological Specification	Threshold of Potential Concern	Causes
	Presence of toxic substances and plastics not to cause detrimental impact on biota (beyond specified TPCs/Ecospecs).	River inflow: Total metal concentrations (as per DWAF 1995 Freshwater Guidelines for Aquatic Ecosystems or updates thereof). DDT (as per DWAF 1995 Freshwater Guidelines for Aquatic Ecosystems or updates thereof). Estuary, channels and lakes: Total metal concentration and DDT in sediment exceeds target values as per sediment quality guidelines, e.g. WIO Region guidelines (UNEP/Nairobi Convention Secretariat and CSIR, 2009). No nuisance matter (plastics) present in estuary, channels and lakes.	DDT spraying (malaria) Plastic pollution
Sediment dynamics	Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) so as not to exceed TPCs for biota (see above).	River inflow distribution patterns (flood components) differ by more than 20% (in terms of magnitude, timing and variability) from that of the Present State (2015). Suspended sediment concentration from river inflow deviates by more than 20% of the sediment load-discharge relationship to be determined as part of baseline studies (Present State 2015). Findings from the bathymetric surveys undertaken as part of a monitoring programme indicate changes in the sedimentation and erosion patterns in the estuary have occurred (± 0.5 m).	Reduced floods Landuse change
	Changes in sediment grain size distribution patterns not to cause exceedance of TPCs in benthic invertebrates (see above).	The median bed sediment diameter deviates by more than a factor of two from levels to be determined as part of baseline studies (Present State 2015). Sand/mud distribution in middle and upper reaches changes by more than 20% from Present State (2015). Changes in tidal amplitude at the tidal gauge of more than 20% from Present State (2015).	Reduced floods Landuse change

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

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
Microalgae	Maintain low phytoplankton biomass throughout the estuarine lake. Maintain the distribution of phytoplankton groups throughout the estuary. Cyanophyceae and Chlorophyceae dominant in the fresher Lake 3 and Lake 4 and flagellates and Bacillariophyceae dominant in the brackish/marine Lake 1, Lake 2 and the estuary.	Phytoplankton biomass >5 $\mu g.l^{-1}$ in the estuary and > 15 $\mu g.l^{-1}$ in Lake 4. Observable blooms in the system. Change in the dominance of different phytoplankton groups in the different estuarine lakes due to changes in salinity or water retention. Salinity in Lake 3 should be < 5 and in Lake 4 < 1.	Excessive nutrient levels in the water. Nutrients from sewerage runoff from Manguzi and from nutrient enrichment of groundwater from pit latrines. Change in the salinity gradient or water retention time.
Macrophytes	Maintain the distribution and diversity of macrophyte habitats from the estuary to Lake 4. Lake 4 with a fringe of emergent reeds and sedges, large swamp forest areas on the west bank with *Raphia australis* (raphia palm) present. Extensive submerged macrophyte beds in Lake 3 with a diversity of species such as *Ceratophyllum demersum*, *Potamogeton sweinfurthii* and *Najas marina.* Dominant species throughout the lakes include *Hibiscus tilieaceus* (lagoon hibiscus) and *Acrostichum aureum* (mangrove fern). Six mangrove species present with Lumnitzera racemosa and *Bruguiera gymnnorhiza* as far upstream from the mouth as Lake 2. No invasive floating aquatic species present in the estuarine lake e.g. water hyacinth. *Azolla*, *Hydrilla*, *Pistia*.	Greater than 20 % change in the area covered by different macrophyte habitats due to salinity changes of greater than 5 in Lake 3 and greater than 1 in Lake 4. Loss of any of the dominant / characteristics species listed under ecological specifications. For example - loss of mangroves and raphia palms due to inundation (i.e. water depth greater than 60 cm for three months). Loss of mangroves from Lake 2 due to prolonged freshwater conditions (> 1 year in Lake 2). Loss of freshwater reeds, sedges and swamp forest species due to groundwater inflow reduction. Presence of invasive floating aquatic species or macroalgal scums.	Disturbance of the riparian zone due to grazing, fires, trampling, access roads. Salinity, inundation and turbidity changes away from that described for the present state (2016). Notwithstanding that large natural events such as cyclones, floods and sea storms can cause large changes in the macrophytes. The thresholds for the freshwater submerged macrophytes is 5 and for the brackish species 20 for a period of three months. Drying of groundwater inflow and 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	1. Maintain current zooplankton, macrobenthic and macrocrustacea abundance (including seasonal variation in particular during lifecycle recruitments/movements) and species richness in each of the estuary and four lake regions. 2. The full complement of all invertebrates	1. Over dominance (>50% contribution by abundance and biomass) of any non-invasive taxon, typically occurring in the system suggesting a shift in the ecological balance. Also, the disappearance of any group or indicator taxon. 2. Any invertebrate survey (across the benthos & plankton) should include species from a minimum of 8 Phyla and particularly the	• Hydrological (flow rates, mouth condition) • Long-term alteration of stable salinity states within system • Change in habitats through

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
	should be diverse and from a range of Phyla, Classes and other groups, including congenerics in the Copepoda, Isopoda, Amphipoda. 3. Present day ratios of polychaetes to micro Crustacea (Amphipoda, Isopoda) should be maintained in the sediments of Lakes 1 and 2. 4. Fossorial species and suspension feeders, algal grazers, detritus feeders, carnivores and omnivores should dominate guild types. 5. *Callichirus kraussi* biomass should remain stable and dominate shallow subtidal habitat of Lakes 1 and 2, only. 6. Mouth should be open during peak recruitment periods for crabs and larval stages of other macrocrustacea and macroinvertebrate species whose life cycle is dependent on an annual estuarine-marine link for larval and post larval recruitment. 7. Mouth should remain naturally open to continue to provide the salinity requirements for a marine complement of fauna in the lower reaches that contribute to the overall diversity of Kosi. 8. Well-developed horizontal salinity gradient providing the appropriate cues for fauna movement in and out of the system and into the individual salinity habitats as defined by the lower estuary, mid-estuary, and individually Lakes 1-4. Fauna should range from polyhaline species in the lower reaches to freshwater species in Lake 4. 9. Maintain status quo of grain size distribution across the system. 10. The species compliment should comprise indigenous species only. The current distribution of the invasive snail *Tarebia granifera* must be contained.	Annelida, Arthropoda and Mollusca. 3. The current status quo shifts to a dominance of Amphipoda/Crustacea indicating an abundance of microalgae or existing species of prey-eating polychaetes suggesting a loss of microphytobenthos. 4. A switch to surface/sub-surface deposit feeders indicates a change in habitat (grain size distribution and/or food source). 5. Ingression of sand prawn into Lake 3 suggests a prolonged ingression of saline water into Lake 3. 6-8.Salinity should retain a well-defined and typical gradient of polyhaline/euhaline in the lower reaches of the mouth (typically marine and never below 20), mesohaline to euhaline in the mid/lower reaches to reflect the influence of the uKhalwe River, Lakes 1 and 2 should remain typically mesohaline, occasionally slightly polyhaline but for limited periods, Lake 3 should remain in an oligohaline state and never be defined by salinity >5 psu, lake 4 should remain limnetic/oligohaline with maximum salinity measurements never >1 psu. Salinity states within each lake compartment are important for invertebrate diversity and function retaining a full complement and range and compliment of freshwater to marine organisms in this unique estuarine coastal lake system 9. No change to the grain size distribution and individual organic content relationships within each lake compartment. Lake 4 and the Estuary must typically support an average of 30% coarse sand, and Lakes 1-3 supporting fine to medium grained sands with little to no mud (<3%). 10. Spread of *Tarebia granifera* to areas inside the system beyond Lakes 3 and 4, or to surrounding pans, streams or wetlands.	alteration of sediment dynamics • Changes in food supply and nature of food supply altering feeding guild and ultimately diversity abundance distribution of all invertebrate groups • Spread of invasive to other waterbodies due to human, livestock & bird movement.

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
Fish	1. Lake 4, freshwater seep areas and inflowing streams support a diversity of primary freshwater fishes, along with secondary freshwater species. These should include *Hypseleotris dayi*, several *Barbus* and *Aplocheilichthys* species as well as *Clarias ngamensis*. 2. The system retains functionality and health as habitat for a diversity of estuarine resident species which includes pelagic and demersal groups, as well as species with a high degree of dependence on specific vegetation habitats. Estuarine resident fishes comprise both pelagic and demersal groups. The former is dominated by *Gilchristella aestuaria*, *Ambassis* spp., and to a lesser degree *Hyporhamphus capensis*. These fishes should occur in abundance and 100% frequency in Lakes 4, 3 and Mtando Channel at least. Benthic groups should include goby species (*Croilia mossambica*, *Silhouettea sibayi*, *Glossogobius callidus* with 100% frequency, but also other species such as *Redigobius dewaali*, *Glossogobius giuris*, *Psammogobius biocellatus*), as well as *Eleotris* spp. *Hippichthys* spp. should occur in suitable habitat (submerged aquatic vegetation). 3. The system acts as a nursery and feeding habitat to a diversity of benthic feeding estuarine dependent marine fishes. These should occur as juveniles, sub-adults and adults. Estuarine dependent species (Whitfield category IIa) should dominate fishes sampled in estuarine habitats (i.e.,	1. A lower than average abundance (to be defined as a mean with prediction limits) of freshwater fishes. Any two of the freshwater species *Hypseleotris dayi*, *Barbus* spp., *Aplocheilichthys* spp. and *Clarias ngamensis* not sampled on consecutive sampling trips. 2. A lower than average abundance (to be defined as a mean with prediction limits) of any of the main estuarine resident species (*Gilchristella aestuaria*, *Ambassis* spp., *Hyporhamphus capensis*, *Croilia mossambica, Silhouettea sibayi, Glossogobius callidus*). Any one of these species not sampled. *Hippichthys* spp. not sampled from suitable habitat on consecutive sampling trips. 3. Benthic feeding estuarine dependant marine species should occur throughout the linked lakes system as indicated below in all size classes, including adults. Their abundances should be greatest in Lakes 1 and 2. They should include mullet (to Lake 4), *Pomadasys commersonnii*, *Acanthopagrus vagus*, *Lutjanus argentimaculatus* and *Rhabdosargus sarba* (to Lake 2 at least). *Gerres* spp. should occur to Lake 3 at least as juveniles. All of these fishes should occur with 100% frequency. Size distributions should reflect those that would be expected under reference conditions. 4. Piscivorous species, including *Sphyraena* spp., *Caranx* spp. and *Scomberoides* spp. should occur as juveniles and sub-adults to Lake 2 at least, and juveniles of the former two species should penetrate into Lake 3. 5. Alien fish species occur.	1. Hydrological; surface and ground water flows are not sufficient to maintain fresh and near fresh conditions in Lake 4 and associated freshwater refugia. Habitat disturbance or habitat losses are occurring. Water quality is becoming limiting (e.g. low dissolved oxygen). 2. Habitat disturbance or habitat losses are occurring. Water quality is becoming limiting (e.g. low dissolved oxygen). Trophic dynamics are changing as a result of changes in water physicochemistry (changed hydrological regimes) and/or pollution (surface inflows or ground water impacts). Changes in predation pressure may be occurring because of changes hydrological regimes. Loss of suitable habitat. 3. Hydrological; surface and groundwater flows are not sufficient to maintain the system in an open state to allow recruitment of these species. Water quality may be becoming limiting. Prey abundances and distribution may also change as a reflection of hydrological factors (and or water quality)

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
	excluding reef areas near the system mouth). 4. Piscivorous fishes should occur as juvenile and late stage sub-adults. 5. Alien fish species should not occur.		with consequent impacts on these fish species. Over exploitation may be changing the abundance and size structure of populations of fishery species. 4. Hydrological; surface and groundwater flows are not sufficient to maintain the system in an open state. Abundance and diversity of prey items is declining (which is an indication of loss of estuarine nursery function). Water quality may be becoming limiting. Over exploitation may be changing the abundance and size structure of populations of fishery species. 5. Alien fish species has been introduced.
Birds	1. Maintain the abundance of birds using the system 2. Maintain the existing composition of feeding guilds	Overall bird abundance – but excluding the terns - is not less than 1000 in three consecutive counts. (The terns are excluded as their numbers show huge inter-annual variability.) The proportion of each of the guilds should be about 30% for each – and none should deviate by more than 20% from this for more than three consecutive counts. (i.e. the guilds should each be within 10 and 50 %. The guilds are: (i) the birds that feed on large (>10cm) fish; (ii) the birds that feed on small (<10 cm) fish; and (iii) the combined abundance of the vegetation feeders and the invertebrate feeders.	A large-scale change in the ecosystem will affect bird abundance. (e.g. a large change in water level, loss of tidal rise and fall, a rise in salinity up the system or an increase in nutrients). Overfishing may reduce the large fish in the system – affecting the large-fish feeders (b) More saline water in upper lakes will affect the distribution of fish and kill shoreline vegetation (c) Disturbance of the summer tern roost at the mouth, or prolonged closure of the mouth) will reduce their numbers

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
	3. Ensure the continued presence of specified habitat-specialist species (i.e. use them as indicators of health of the system).	Loss of any of the following sensitive species from the system: (i) Pels Fishing owl; (ii) Pygmy geese; (iii) Finfoot; (iv) Palmnut vulture.	(d) Loss of intertidal habitat will reduce wader numbers. (i) indicates a loss in riparian trees overhanging calm water (ii) indicates a loss in the water lily habitat (iii) indicates a loss in stretches of shoreline with rank overhanging vegetation (iv) Indicates a loss of Raphia Palms.

8.3 Monitoring Requirements

Recommended minimum monitoring requirements to ascertain impacts of changes in freshwater flow to the estuary and any improvement or reductions therein are listed in below. Table 8.4 provides baseline monitoring requirements and Table 8.5 provides long-term monitoring recommendations.

Table 8.4 Recommended baseline monitoring requirements.

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Hydrodynamics	Record water levels	Continuous	W7T004, W7T005, W7T003
	Measure freshwater inflow into the estuary	Continuous	Above the estuary in Sihadla River
	Aerial photographs of estuary (spring low tide)	Every 3 years	Entire estuary
	Borehole levels and flow rates	Continuous	Groundwater input/water table In Kosi catchment near estuary (5 to 10 sites)
Sediment dynamics	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detail in the mouth (every 100m). The vertical accuracy should be about 5 cm.	Every 3 years (with extra observations after a flood)	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	Every 3 years (with invertebrate sampling)	Entire estuary
	Longitudinal salinity and temperature profiles (and any other *in situ* measurements possible e.g. pH, DO, turbidity) at 1 m depth intervals	Once-off during dry period during neap and spring tide (i.e. maximum seawater intrusion/closed mouth) and wet period during neap and spring tide (maximum flushing by freshwater input)	Entire system (see Stations in Figure B.1)

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
	System variables (cation/anion, alkalinity, pH, temperature, EC, suspended solids), nutrients (N, P, Si) and toxic substances) in surface and groundwater inflow to the system	Monthly continuous Toxic substances: quarterly only if identified as issue in baseline or where input is expected	Sihadla River (e.g. steel bridge) Ukhalwa River into estuary Stream into Lake 3 Groundwater sampling stations
	Inorganic nutrients (DIN, DIP DRS) together with system variables (Salinity, temperature, pH, turbidity and DO) (surface and bottom samples where bottom water characteristics differ from surface waters)	Once-off during a dry period (i.e. maximum seawater intrusion/closed mouth) and a wet period (maximum flushing by freshwater input)	Entire system (see Stations in Figure B.1)
	In situ salinity probes (small instruments) about 1 m below the surface at nine sites	Continuous (data collected every 3 months)	Top of estuary, L1, C1,L2, C2, L3, C3, L4, C4
	Toxic substances (e.g. trace metals, DDT) in sediments across system focusing on sheltered depositional areas (must also include sediment organic content and grain size analysis of samples)	Once off	To be confirmed during baseline survey
Microalgae	Record algal blooms and surface scums. This can be done by 'citizen scientists' who should report eutrophication when seen - may need a reward system. Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae throughout the estuarine lake. Water column samples taken at the surface, 0.5 m and thereafter 1 m depths for phytoplankton biomass (chlorophyll-a measurements). Intertidal and subtidal benthic chlorophyll-a measurements. These are very variable and initially a baseline programme would be needed to establish expected biomass values.	Ad hoc – whenever blooms are detected. Quarterly sampling for 2 years thereafter annually or in response to events. Quarterly sampling for 2 years to understand responses to changes in groundwater inflow and nutrient input, thereafter annually.	Throughout the estuarine lake. Entire estuarine gradient to pick up changes along the salinity gradient as well as in the littoral zone. Use the 2016 study sites as a baseline.

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Macrophytes	Distribution and cover of littoral vegetation along an inundation and depth gradient, using the 2016 study as a baseline for fixed transects. Use fixed-point photos to detect macrophyte change. This would include an assessment of resource use patterns of mangroves and reeds. Additional monitoring of extractive uses besides the fixed point monitoring is needed to quantify and assess whether this use is sustainable. Map the area covered by the different macrophyte habitats during a field survey. Use GIS techniques to detect changes in areas of macrophyte types. Annual alien plant inspection including a qualitative assessment of abundance.	Repeat every 5 years or in response to a major event. Repeat fixed point photos every year for fast growing species (e.g. reeds) and every 5 years for slower-growing species (e.g. mangroves, swamp forest and raphia palms). Repeat a vegetation mapping exercise every 5 years. Alien plant inspection every year in summer.	Use 2016 study sites for comparison and establish these as fixed transects for monitoring. Fixed-point photographic sites at about 50 stations throughout the estuarine lake. Entire estuarine lake using the 2016 map as a baseline. Whole system – especially where disturbed or nutrient enrichment encourages alien plants.

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Invertebrates	Record species and abundance of zooplankton, macrobenthos and macrocrustacea using quantitative techniques (as per standard protocols) replicated at stations long the system (Estuary and 4 lakes). Zooplankton to be identified as holo- and meroplankton. Macrobenthos to include shallow subtidal, littoral and deeper lake basin stations. Sand prawn biomass to be ascertained per lake based on burrow hole count densities (to maximum depth of occurrence). Density of mangrove crabs to be ascertained by quadrat count method. Qualitative observations of less common macrocrustacea and other large invertebrates to be made by visual census along lake and estuary margins. All specimens to be photographed, sexed and measured where possible. Full assessment of Mollusca in the system, visual census and via deep coring to sample burrowing species. Sediment characteristics (grain size distribution and TOC) to be determined at each macrobenthos and macrocrustacea sampling station. Assessment of porewater chemistry to make possible links with groundwater using techniques that show catchment flow e.g. Radon seeding? Water column characteristics (physicochemistry) to be determined at each invertebrate station surface to bottom profiles.	Quarterly sampling for a minimum of two years to understand fluxes related to recruitment and lifecycle events. (thereafter follow long-term monitoring programme)	Zooplankton: A minimum of three stations per lake and estuary (15 stations). Macrobenthos: 25 stations but inclusive of 18 historical stations used by CRUZ, Univ. Zululand. Additional stations to be within deeper zones. 25 Littoral samples to be collected using same methods and inclusive of stations used to collect sediments in February 2016. Macrocrustacea: Replicated quadrats in at least four separate mangrove areas in the estuary. *Varuna* observations (adults and post larvae) to be made throughout the system. Sand prawn burrow counts to be done in three separate areas in each of Lakes 1 and 2.

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Fish	Record species, abundance and life stage (juvenile, sub-adult, adult) of fish. Representative sampling based on large and small seine net and gill net sampling must be carried out in each of five basin areas (Estuary, Lakes 1, 2, 3, 4). Sampling by visual census and underwater camera must be carried out in the channel between Lake 1 and 2, and Mtando Channel (between Lake 2 and 3). In the basins sampling must be carried out at multiple sites in waters < 6 m deep using gill nets (set a various depths) and along the shoreline (to include open water and vegetated habitats). Vegetated habitats must be identified (main species and % coverage) are information recorded as part of the metadata (together with GPS location of each sampling site). Vegetated habitats must be sampled using seine nets light enough not to damage the vegetation unduly. A minimum of two and not more than three replicate hauls must be made at each site. Initial baseline monitoring should cover freshwater seeps and streams flowing into Kosi. These system are unsampled and very little is documented on the areas' freshwater fishes. Specialised sampling methodologies may need to be employed (e.g. electro-shocker). Water quality must be measured at each site using a calibrated multiparameter probe. Parameters should include temperature, salinity (psu), turbidity (NTU), pH and dissolved oxygen (mg/L and % saturation). Calibration records must be kept and reported upon (together with other quality control measures). Fishes should be measured to the nearest 1 cm (SL), identified in the field and returned live to the water wherever possible. Representative specimens must be lodged in the national collection at the South African Institute of Aquatic Biodiversity. Fish by catch, e.g. macrocrustacea, should	Late spring, summer and two winter surveys every year for 3 years. Fisheries continuously, checked on a monthly basis.	Estuary, min. 3 sites Lake 1, min. 3 sites Lake 2, min. 3 sites Lake 3, min. 6 sites Lake 4, min. 2 sites Freshwater seeps and streams as appropriate but ideally a miniumun of three sites on each. For seine nets, replicate hauls must be made; a minimum of two and not more than three replicate hauls at each site.

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
	also be identified, measured and counted, and data supplied to the invertebrate specialist team. Fisheries returns (including recreational catches) should be monitored by Ezemvelo KZN Wildlife.		
Birds	[a&b] To monitor abundance and distribution of individual bird species. From this the overall abundance of the birds in the system is obtained and also the species composition. This is best done by conducting counts of all water-associated birds - identified to species level. These counts should be separated into the different zones within the lake. Do these counts in a manner to ensure maximum repeatability and quantification. Analysis should be to track changes in numbers and distribution in the system and changes in feeding guilds	Repeat this every two months for two years. Then design a 'beefed-up' CWAC count system that separates the counts into separate lake sectors.	Divide the count into the lake zones used in this report.
	[c] Maintain records of sightings of these habitat-sensitive species. This can be a citizen science project – but requires a website/cellphone contact number for sightings to be accepted and recorded	Continuous	All zones of the system.

Table 8.5 Recommended long-term monitoring requirements.

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Hydrodynamics	Record water levels.	Continuous.	At the mouth.
	Measure freshwater and groundwater inflow into the estuary.	Continuous.	Fresh water inflow measured above the estuary. Groundwater input/water table In Kosi catchment near estuary (5 to 10 sites)
	Aerial photographs of estuary (spring low tide).	Every 3 years.	Entire estuary.
Sediment dynamics	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detailed in the mouth (every 100m). The vertical accuracy should be about 5 cm.	Every 3 years (and after a flood).	Entire estuary.
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations).	Every 3 years (with invertebrate sampling).	Entire estuary (7 stations).
Water quality	System variables (cation/anion, alkalinity, pH, temperature, EC, suspended solids), nutrients (N, P, Si) and toxic substances) in surface and groundwater inflow to the system	Monthly continuous Toxic substances: quarterly only if identified as issue in baseline or where input is expected	Sihadla River (e.g. steel bridge) Ukhalwa River into estuary Stream into Lake 3 Groundwater sampling stations
	In situ salinity probes (small instruments) about 1 m below surface at nine stations	Continuous (data collected every 3 months)	Entire system, as a minimum station at top of estuary and in each channel and lake
	Longitudinal salinity and temperature profiles (and any other *in situ* measurements possible e.g. pH, DO, turbidity) at 1 m depth intervals	Quarterly	Entire system, final stations be confirmed after baseline (as a minimum station in estuary and in each lake)
	Inorganic nutrients (DIN, DIP DRS) together with system variables (Salinity, temperature, pH, turbidity and DO) (surface and bottom samples where bottom water characteristics differ from surface waters)	Coinciding with relevant biotic surveys or every 2-3 years. Include selected stations in DWS monthly monitoring programme	Entire system, final stations be confirmed after baseline (as a minimum station in estuary and in each lake)
	Toxic substances in sediments across system focusing on sheltered depositional areas, if identified as an issue in baseline (must also include sediment organic content and grain size analysis of samples)	Every 3-6 years	To be confirmed during baseline survey

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Microalgae	Record algal blooms and surface scums. This can be done by 'citizen scientists' who should report eutrophication when seen - may need a reward system Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae throughout the estuarine lake. Water column samples taken at the surface, 0.5 m and thereafter 1 m depths for phytoplankton biomass (chlorophyll-a measurements). Intertidal and subtidal benthic chlorophyll-a measurements. These are very variable and initially a baseline programme would be needed to establish expected biomass values.	Ad hoc – whenever blooms are detected Annual sampling or in response to events. Quarterly sampling for 2 years to understand responses to changes in groundwater inflow and nutrient input, thereafter annually.	Throughout the estuarine lake. Entire estuarine gradient to pick up changes along the salinity gradient as well as in the littoral zone. Use the 2016 study sites as a baseline.
Macrophytes	Distribution and cover of littoral vegetation along an inundation and depth gradient, using the 2016 study as a baseline for fixed transects. Use fixed-point photos to detect macrophyte change. This would include an assessment of resource use patterns of mangroves and reeds. Additional monitoring of extractive uses besides the fixed point monitoring is needed to quantify and assess whether this use is sustainable. Map the area covered by the different macrophyte habitats during a field survey. Use GIS techniques to detect changes in areas of macrophyte types. Annual alien plant inspection including a qualitative assessment of abundance.	Repeat every 5 years or in response to a major event. Repeat fixed point photos every year for fast growing species (e.g. reeds) and every 5 years for slower-growing species (e.g. mangroves, swamp forest and raphia palms). Repeat a vegetation mapping exercise every 5 years. Alien plant inspection to be conducted every year in summer.	Use 2016 study sites for comparison and establish these as fixed transects for monitoring. Fixed-point photographic sites at about 50 stations throughout the estuarine lake. Entire estuarine lake using the 2016 map as a baseline. Whole system – especially where disturbed or nutrient enrichment encourages alien plants.

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Invertebrates	Record species and abundance of zooplankton, macrobenthos and macrocrustacea using quantitative techniques (as per standard protocols and as used in baseline monitoring) Sediment characteristics (grain size distribution and TOC) to be determined at each macrobenthos and macrocrustacea sampling station. Water column characteristics (physicochemistry) to be determined at each invertebrate station surface to bottom profiles.	Full survey every 3 years or after mouth closure/ cyclone/se storm impact to the system. Frequency to coincide with cyclicity of drought.	Zooplankton: 15 stations. Macrobenthos: 25 subtidal stations, 25 littoral samples. Macrocrustacea: Replicated quadrats in at least four separate mangrove areas in the estuary. *Varuna* observations (adults and post larvae) to be made throughout the system. Sand prawn burrow counts to be done in three separate areas in each of Lakes 1 and 2.
Fish	Record species, abundance and life stage (juvenile, sub-adult, adult) of fish. Representative sampling based on large and small seine net and gill net sampling must be carried out in each of five basin areas (Estuary, Lakes 1, 2, 3, 4). Sampling by visual census and underwater camera must be carried out in the channel between Lake 1 and 2, and Mtando Channel (between Lake 2 and 3). In the basins sampling must be carried out at multiple sites in waters < 6 m deep using gill nets (set a various depths) and along the shoreline (to include open water and vegetated habitats). Vegetated habitats must be identified (main species and % coverage) are information recorded as part of the metadata (together with GPS location of each sampling site). Vegetated habitats must be sampled using seine nets light enough not to damage the vegetation unduly. A minimum of two and not more than three replicate hauls must be made at each site. Ongoing monitoring of freshwater seeps and streams flowing into Kosi is likely to be desirable. The need for this, and methods to be used, will be informed by baseline monitoring. Water quality must be measured at each site using a calibrated multiparameter probe. Parameters should include temperature, salinity (psu), turbidity (NTU), pH and dissolved oxygen (mg/L and % saturation). Calibration records must be kept and reported upon (together with other quality control measures).	Winter surveys every two years. Fisheries continuously, checked on a monthly basis.	Estuary, min. 3 sites Lake 1, min. 3 sites Lake 2, min. 3 sites Lake 3, min. 6 sites Lake 4, min. 2 sites Freshwater seeps and streams as appropriate based on findings of initial baseline survey (see above). For seine nets, replicate hauls must be made; a minimum of two and not more than three replicate hauls at each site.

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
	Fishes should be measured to the nearest 1 cm (SL), identified in the field are returned live to the water wherever possible. Representative specimens must be lodged in the national collection at the South African Institute of Aquatic Biodiversity. Fish by catch, e.g. macrocrustacea, should also be identified, measured and counted, and data supplied to the invertebrate specialist team. Fisheries returns (including recreational catches) should be monitored by Ezemvelo KZN Wildlife.		
Birds	Undertake counts of all water associated birds, identified to species level.	Winter and summer surveys every year – tie in with the CWAC counts.	Entire estuary. These counts should be separated into the spatial sectors used in this document.
	Record all bird breeding – especially of the colonially-nesting waterbirds	As and when detected	Whole system
	Keep records of the rare species	As and when detected	Whole system

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Appendix A

Data available on the Kosi used for the Study

Appendix A. Data available on the Kosi used for the study

Component	Baseline information requirements for high confidence	Data available for this study
Hydrology	Measure freshwater inflow into the estuary	No
	Aerial photographs of estuary	1942, 1959, 1976, 1984, 2010 and 2013
Bathymetry	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detailed in the mouth (every 100m). The vertical accuracy should be about 5 cm.	Limited historical data available
Hydrodynamics	Record water levels	W7T004, W7T005, W7T003
Sediments	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	No
Water quality	River inflow quality data	No data
	Water quality measurements (temperature pH, dissolved oxygen and turbidity) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at: end of low flow season peak of high flow season	Salinity and Temperature: Once off in Aug 1971, May 1987, Aug 1987, Mar 1987, Dec 1989, Feb 2016 pH: Once-off in Aug 1971, Feb 2016 DO: Once off in Aug 1971, May 1987, Aug 1987, Mar 1987, Feb 2016 Turbidity: Feb 2016
	Water quality measurements (inorganic nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at: end of low flow season peak of high flow season	Once-off Feb 2016
	Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary	No data, except littoral zone data collected for biotia, DDT (Humphries, 2013) and observation of plastics along shore in Feb 2016
Microalgae	Chlorophyll-a measurements taken at 5 stations (at least) at the surface, 0.5 m and 1 m depths thereafter. Cell counts of dominant phytoplankton groups i.e. flagellates, dinoflagellates, diatoms and blue-green algae. Measurements should be taken coinciding with the different Abiotic States.	Data from this study (February 2016).
	Intertidal and subtidal benthic chlorophyll-a measurements taken at 5 stations. Epipelic diatoms need to be collected for identification.	Data from this study (February 2016).
	The microalgal survey must be done at the same time as the water quality survey.	Data from this study (February 2016).
Macrophytes	Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the reference condition (earliest year available). A GIS map of the estuary must be produced indicating the present and reference condition distribution of the different plant community types.	2013 aerial photographs used together with ground truthing in 2016 for vegetation mapping.
	Number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit. The extent of anthropogenic impacts (e.g. trampling, mining) must be noted.	Some published literature available but main focus was the estuary and mangroves and not the lakes.

Component	Baseline information requirements for high confidence	Data available for this study
	Permanent transects (fixed monitoring stations that can be used to measure change in vegetation in response to changes in salinity and inundation patterns) must be set up along an elevation gradient: Measurements of percentage plant cover of each plant species in duplicate quadrats (1 m^2). Measurements of sediment salinity, water content, depth to water table and water table salinity.	No historical data. February 2016 field work has provided a baseline for future studies.
Invertebrates	Detailed study (at least four trips) sampling invertebrates (zooplankton, hyperbenthos, macrobenthos, macrocrustacea) along the full length of the estuary and four lakes across depth zones and including littoral habitats. Although limited data exist on the macrobenthos and even less on the zooplankton from over a decade ago, no recent, quantitative information exists for the invertebrates. This should be at multi stations per lake and the estuary on a repeated, seasonal basis.	Zooplankton – Quantitative data from seasonal sampling trips 2002/3 (four sites), historical qualitative data, see reference list. Macrozoobenthos – Data from multiple sampling trips, seasonally 2002-2004, winter 2006 2013 (shallow (<3m depth) subtidal habitats at 18 stations from mouth to Lake 4), historical qualitative data, see reference list. Macrocrustacea –No data other than documented historically >40 years ago.
Fish	Require detailed study (at least four trips) sampling fish along the full length of the estuary.	Data from multiple sampling trips, seasonally 2002-2004 (shallow subtidal habitats from mouth to Lake 4), historical qualitative data, see reference list.
Birds	Detailed study (at least four trips) sampling birds along the full length of the estuary – recording distribution and habitat selection patterns.	46 CWAC counts. Two other counts (from 1949 and 1980) giving spatial data

Appendix B

Data Report Abiotic Components

Appendix B. Specialist report abiotic components

B.1. WATER QUALITY

Historical water quality data on the Kosi System mainly comprise those provided in Allanson and Van Wyk, (1969), Hemens et al (1971), Ramm (1992) and Humphries (2013). As part of this study, water quality data were collected from the entire system during the period 7-11 February 2016. Sampling stations are presented in Figure B.1.

Figure B.1 Location of the sampling station in Kosi Bay during the survey conducted on 7-11 February 2016 (Source: Google Earth)

B.1.1. SALINITY

Very little salinity data exist that show the full salinity profile of the Kosi Estuarine Lake System. Salinity data collected in the Kosi System are presented in Figure B.2 along an axial distance calculated from the mouth (see blue line in Figure B.1). The data show sensitivity to freshwater inflow.

In August 1971 Hemens recorded values of 35 in the estuary, with weak stratification in Lake 1 varying from 19 at the surface to 26 at the bottom, Lake 2 varied between 13 to 17, while Lake 3 was at about 5 and Channel 4 less than 1.

Measurements conducted by the CSIR in December 1989 showed marked stratification in Lake 1 and 2. Surface salinities in Lake 1 were 14, while bottom salinity was 27. In Lake 2 surface salinity was 12 and bottom values of 17 were reported. Lake 3 salinities were less than 1.

The CSIR February 2016 field observations showed elevated salinity throughout the system, 34 in Lake 1, 25 in Lake 2, 5 in Lake 3, and 0.8 in Lake 4. During the survey, the channels took on the salinities of the lake feeding it. As the survey was conducted on a spring tide, the dominant flow was towards the head of the system, resulting in the channels taking on the salinity of the lake below it.

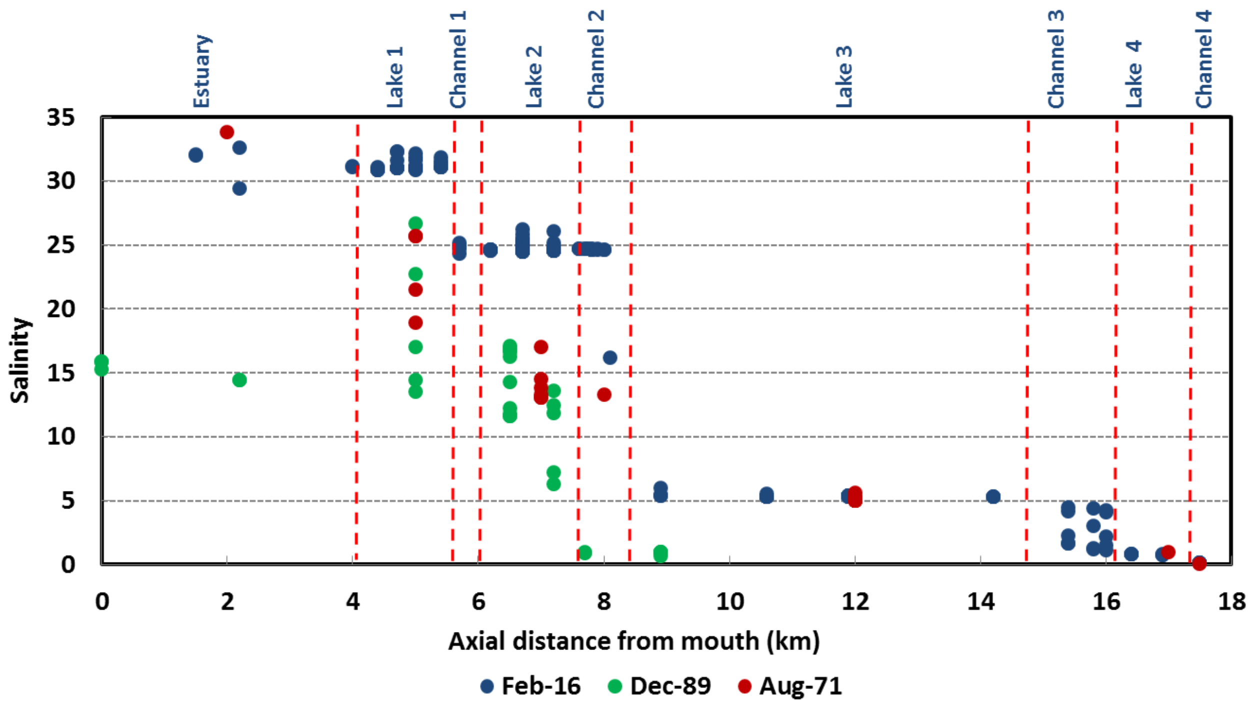


Figure B.2 Salinity data measured in the Kosi Bay system in August 1971, December 1989 and February 2016.

Figure B.3 provides an indication of the longitudinal salinity distribution in the Kosi system. What becomes very apparent from the data is that the system was very well mixed with little variance in salinity values in the individual water bodies. This is contributed too little freshwater input and wind mixing over time.

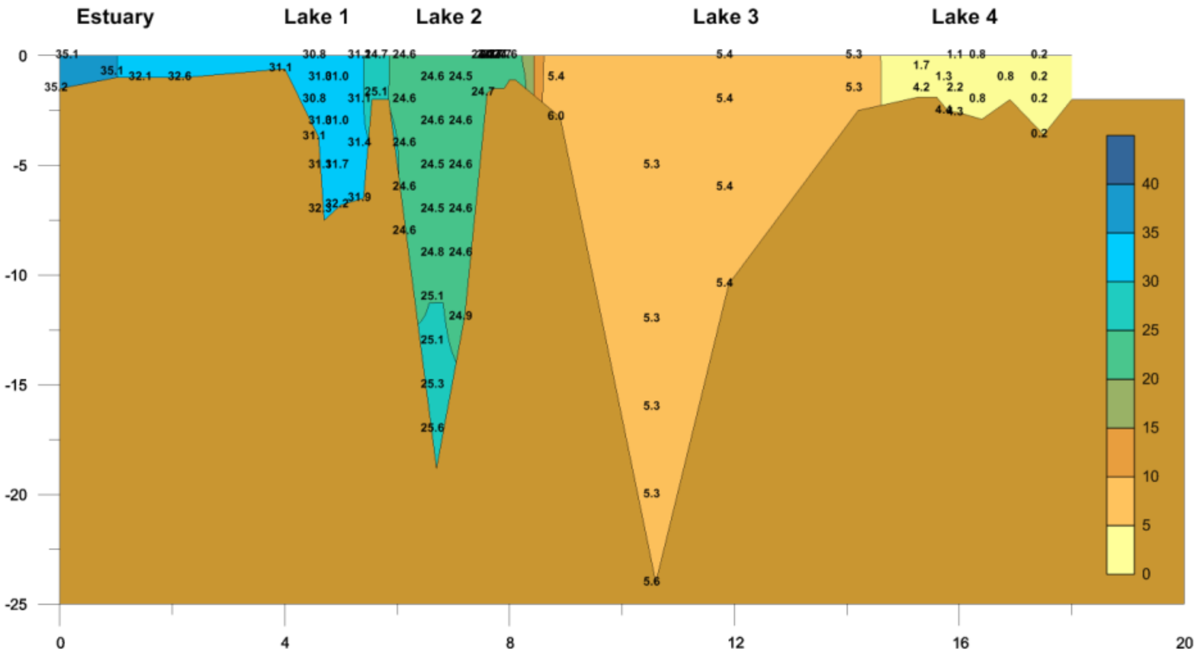


Figure B.3 Longitudinal salinity data measured in the Kosi Estuarine Lake system on February 2016.

B.1.2. TEMPERATURE

Temperature data collected in the Kosi System are presented in Figure B.4 along an axial distance calculated from the mouth (see blue line in Figure B.1). As expected, the data show a strong seasonal signal with low winter temperature (18-21 °C) and high summer temperature (22-30 °C).

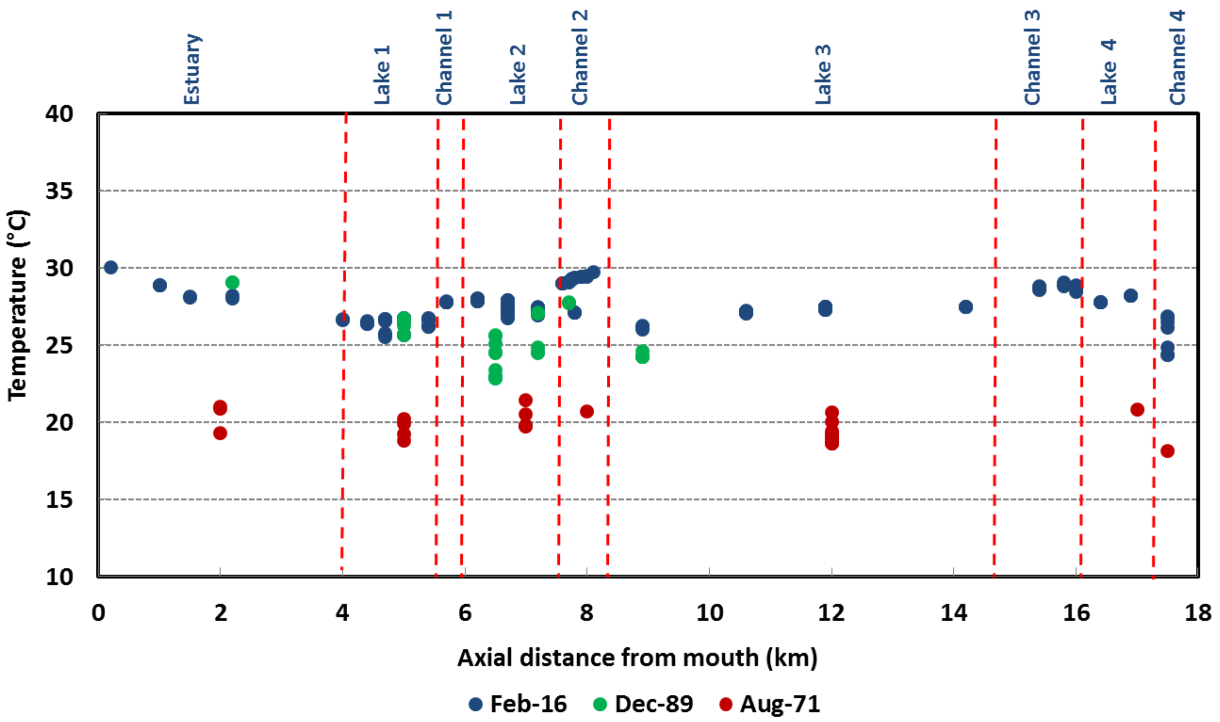


Figure B.4 Temperature data measured in the Kosi Estuarine Lake system in August 1971, December 1989 and February 2016.

Although there was a tendency for temperature to decrease with depth there was no marked vertical stratification evident in any of the lakes, even in their central, deeper reaches.

B.1.3. PH

pH data collected in the Kosi System is presented in Figure B.5 along an axial distance calculated from the mouth (see blue line in Figure B.1). On all occasions, pH values in Lake 3 were highest (>8) compared with the pH in the rest of the systems. The estuary, as well as Lakes 1 and 2 were in similar ranges (~8), while Lake 4 was lowest (<8), resembling lower pH in river inflow (see Channel 4). The pH ranges in the estuary, and in Lakes 1 and 2, were similar to that expected in seawater, and that in Lake 4 similar to what is expected in river waters. The higher pH in Lake 3 could not be explained, other that site specific geological factors or differences in *in situ* biochemical and biological processes.

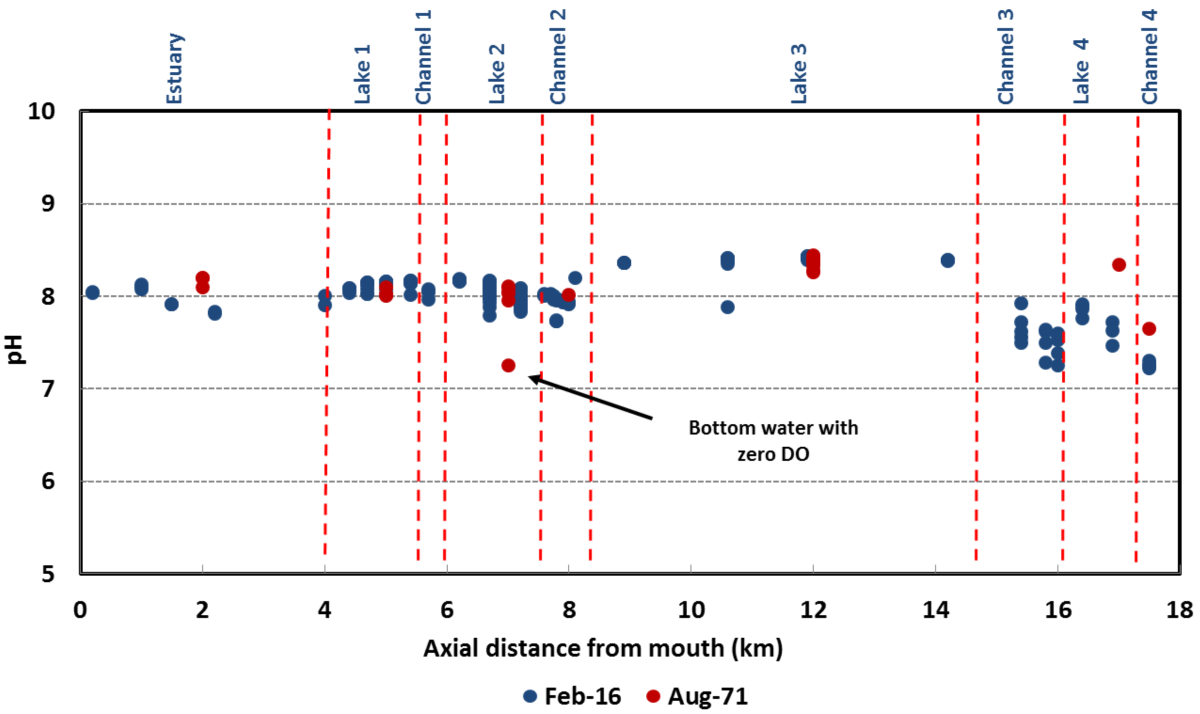


Figure B.5 pH data measured in the Kosi Estuarine Lake system in August 1971 and February 2016.

Investigating pH changes with depth (Figure B.6), the data in most lakes showed a tendency for pH to decrease with increase in depth and as the as dissolved oxyxgen (DO) levels decrease. No definitive explanation for this could be provided. A possible explanation is acidification associated with remineralisation processes (signalled by the decrease in DO). A product of microbial degradation of organic matter (remineralisarion) is carbondioxide (CO_2) which is associated with the lowering of pH in water (Wallace et al. 2014).

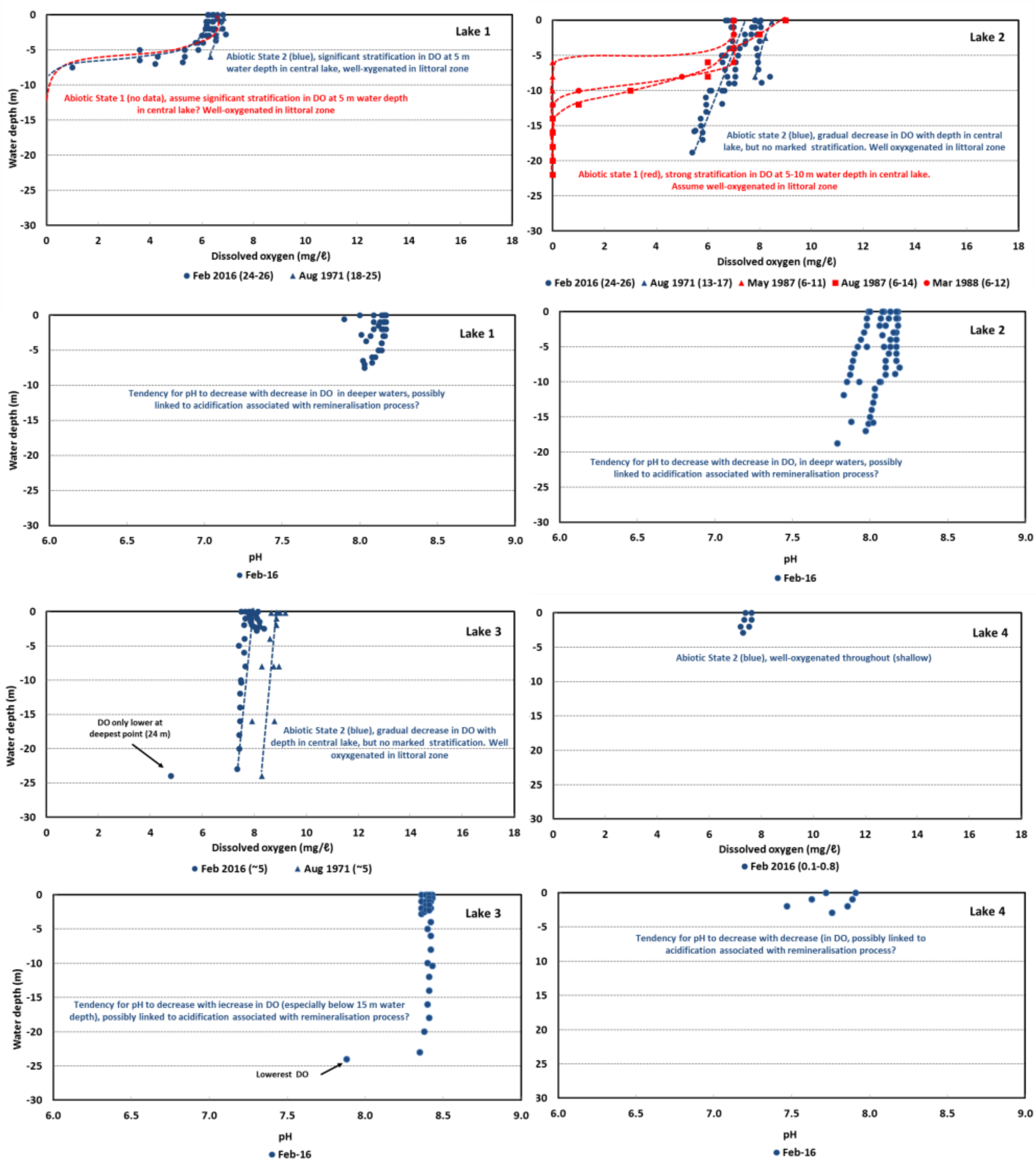


Figure B.6 Comparison of DO and pH changes with water depth in Lakes 1 to 4 in the Kosi System

B.1.4. DISSOLVED OXYXGEN

Dissolved oxyxgen (DO) data collected in the Kosi System are presented in Figure B.7 along an axial distance calculated from the mouth (see blue line in Figure B.1).

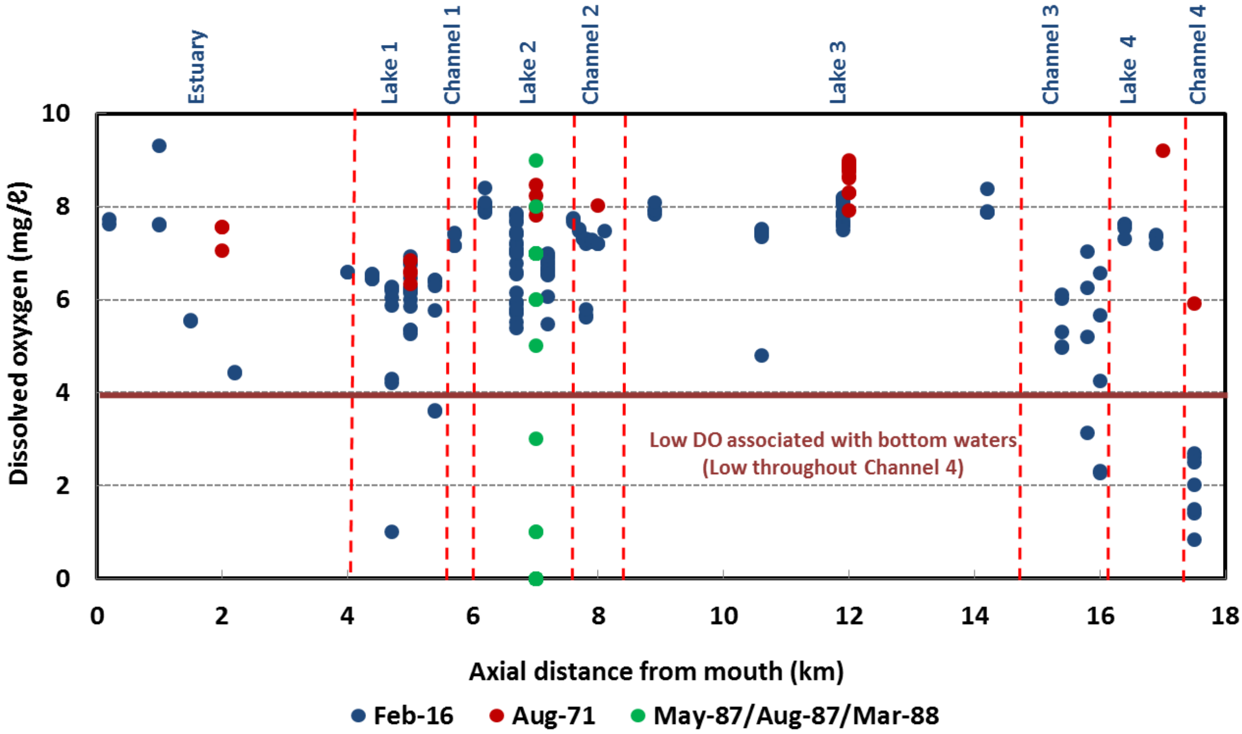


Figure B.7 Dissolved oxyxgen concentrations measured in the Kosi Estuarine Lake system during August 1971, May 1987/August 1987/March 1988 and February 2016

Results indicate that the estuary and Lakes 3 and 4 were generally well-oxygenated throughout, while Lakes 1 and 2 showed significantly lower DO in bottom water. Channels 1 and 2 were shallow and generally also well-oxygenated, with Channel 3 showing lower DO in some bottom waters. However, Channel 4 was hypoxic, most likely associated with *in situ* biochemical process accosiated with it being a shollow area with high sediment organic loading (e.g. characterised by muddy sediments).

Considering changes in DO levels with depth (Figure B.7), Lake 1 showed marked DO stratification at about 5 m water depth during February 2016 with DO in bottom water dropping to below 4 mg/ℓ (States 2/3: salinity profile ranging from 24-26). During the same period, DO levels in Lake 2 gradually decreased with depth (States 2/3: salinity profiles 24-26), but without any strong stratification as present in Lake 1. Bottom water DO levels in Lake 2 remained above 4 mg/ℓ. However, on three occasions during 1987/88 (State 1: salinity profiles ranging from 6 to 14) Lake 2 also showed strong vertical stratification between 5-10 m water depth, with bottom water being anoxic. DO profiles collected in Lake 3 during February 2016 also showed a gradually decrease with depth (State 3: salinity throughout 5), but bottom water concentrations remaining above 6 mg/ℓ. Although there were no data available for Lake 3 in State 1/2 (salinity ~0), it is not expected that this lake would stratify under State 1 as is the case in Lakes 1 and 2, primarily based on its size (strong wind mixing), weaker vertical salinity gradient (and possibly lower water column primary production – to be confirmed). During the February 2016 survey, Lake 4 was well-oyxgenated with DO levels above 6 mg/ℓ throughout. This was expected given the shallow nature of this lake, strong wind mixing, as well as uniform salinity (<1 throughout), i.e. limited stratification.

B.1.5. TURBIDITY/TRANSPARENCY

Turbidity data collected in the Kosi System are presented in Figure B.8 along an axial distance calculated from the mouth (see blue line in Figure B.1).

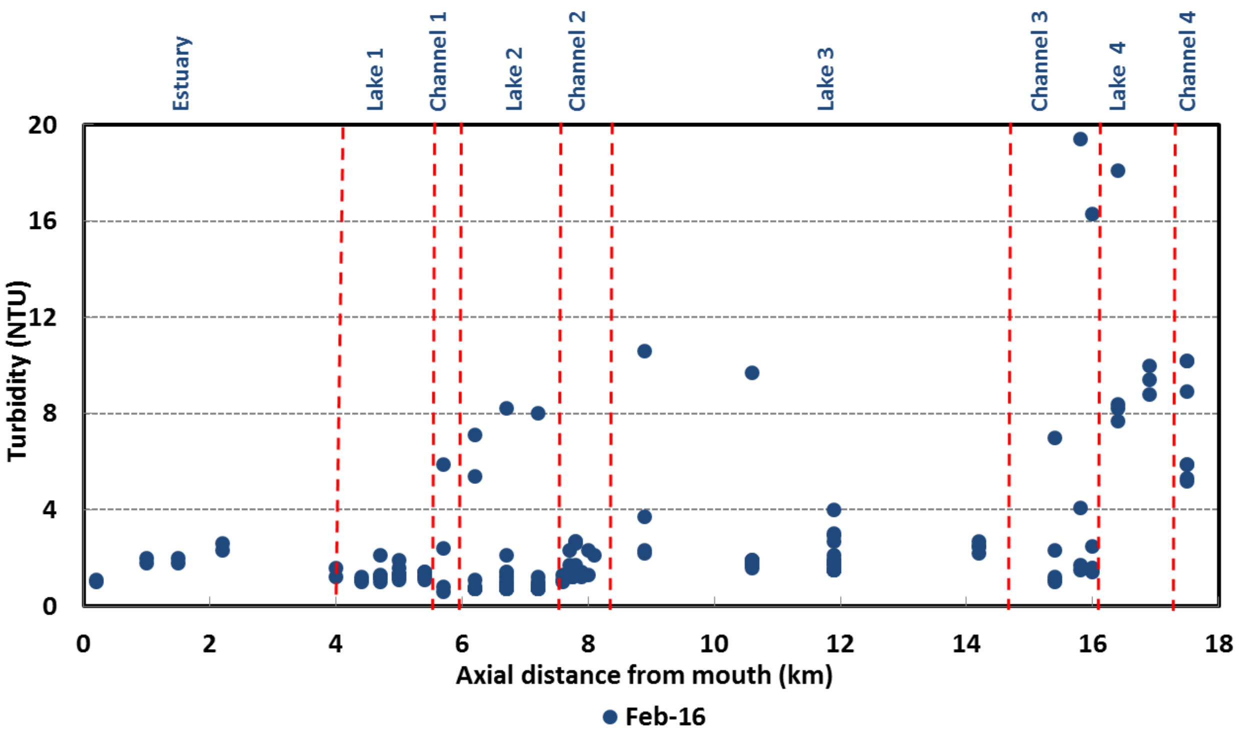


Figure B.8 Turbidity measured in the Kosi Estuarine Lake system during February 2016.

Turbidity through out the surface waters of this system was very low (< 5 NTU), but showed a tendency to increase moving upstream into Channel 4. Occasional higher levels (>10 NTU) occurred but these were all associated with near bottom waters most likely the result of re-suspension of fine matter from bottom sediments.

B.1.6. DISSOLVED INORGANIC NUTRIENTS

Dissolved inorganic nutrients measured in the Kosi system are presented in Figure B.9a (dissolved inorganic nitrogen nutrients) and Figure B.9b (dissolved inorganic phosphate and reactive silicate) along an axial distance calculated from the mouth (see blue line in Figure B.1).

Inorganic nitrate plus nitrite (NO_x-N) concentrations where low throughout the system, near-depleted in most channels and lakes, except Lakes 1 and 2 (~50 µg/ℓ). This suggests that there was no significant "new" NO_x-N nutrient entering the estuary and that which was entering was utilised effectively with a resultant near-depleted/low NO_x-N concentration. Inorganic total ammonia (NH_3-N plus NH_4-N) concentrations were also relatively low, but higher than NO_x-N (averaging ~50 µg/ℓ throughout the system), except for isolated high values asscociated with lower oxygen bottom waters in some channels and lakes. In the case of the Kosi system where there are no large urban development directly adjacent to the estuary (e.g. direct sewage inputs), the presence of total Ammonia-N can typically be associated with remineralisation processes. However, low concentrations are indicative that such *in situ* processes remain within the natural nutrient/primary productivity balance of the system.

Dissolved reactive/inorganic phosphate (DIP) was generally low throughout the system (mostly >10 µg/ℓ). An occasional high value in Channel 4 was associated with anoxic bottom waters. Dissolved reactive silicate concentrations showed a slight tendency to increase moving upstream into the fresher part of the system. This can be expected as concentrations in fluvial water are significantly higher compared with that of seawater.

B.1.7. TOXIC SUBSTANCES

Historical information on the accumulation of toxic substances in the Kosi system was not available. With no major urban or intensive commercial agricultural activities in the catchment it is not expected for the system to have had significantly accumulated toxic substances. There may be smaller, localised areas that could be affected (e.g. littoral zones near intense subsistence farming activities). However, DDT contamination has been reported in the sediments of Lake Mpungwini and Makhawulani at Kosi Bay (Kyle, 1995), but according to Humphries (2013) the actual records are unavailable. DDT also has been detected in blood obtained from Pied Kingfishers (*Ceryle rudis*) from Kosi Bay (241 µg/ℓ) (Evans and Bouwman, 2000). DDT is used in the control of malaria.

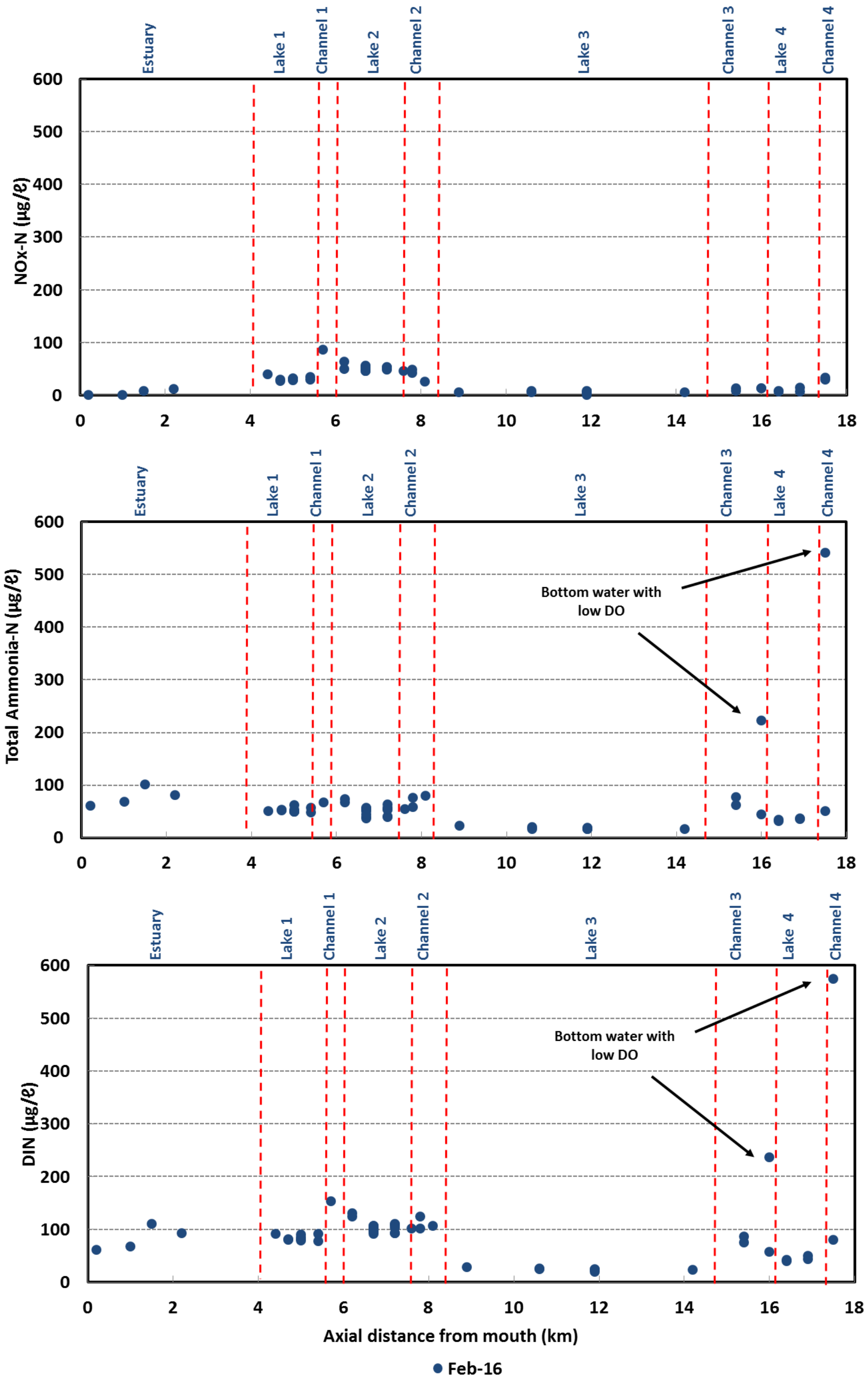


Figure B.9a Dissolved inorganic nitrogen nutrient concentrations measured in the Kosi Estuarine Lake system during February 2016

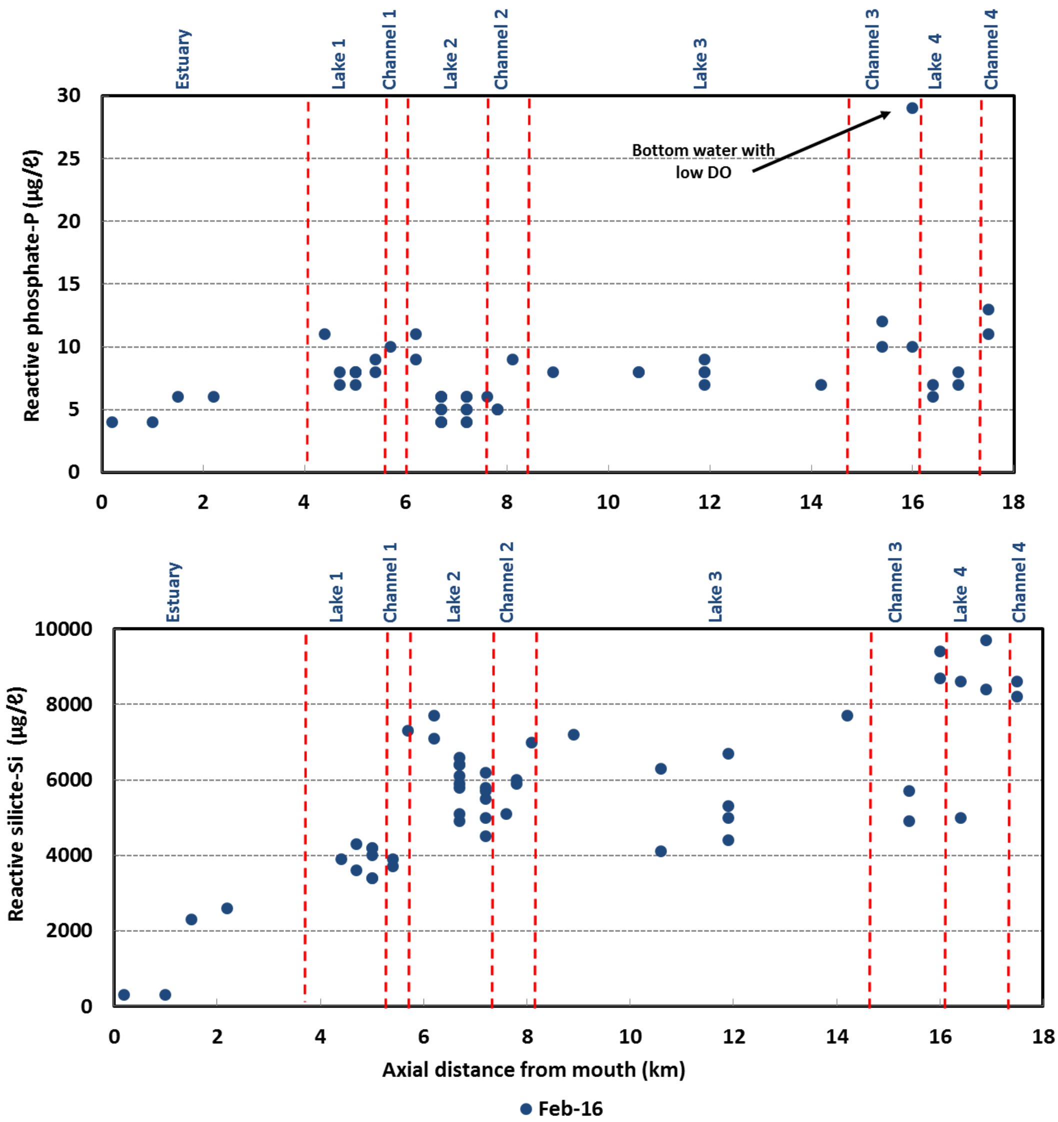


Figure B.9b Dissolved inorganic phosphate and reactive silicate concentrations measured in the Kosi Estuarine Lake system during February 2016

B.1.8. RAINFALLL VERSUS EVAPORATION

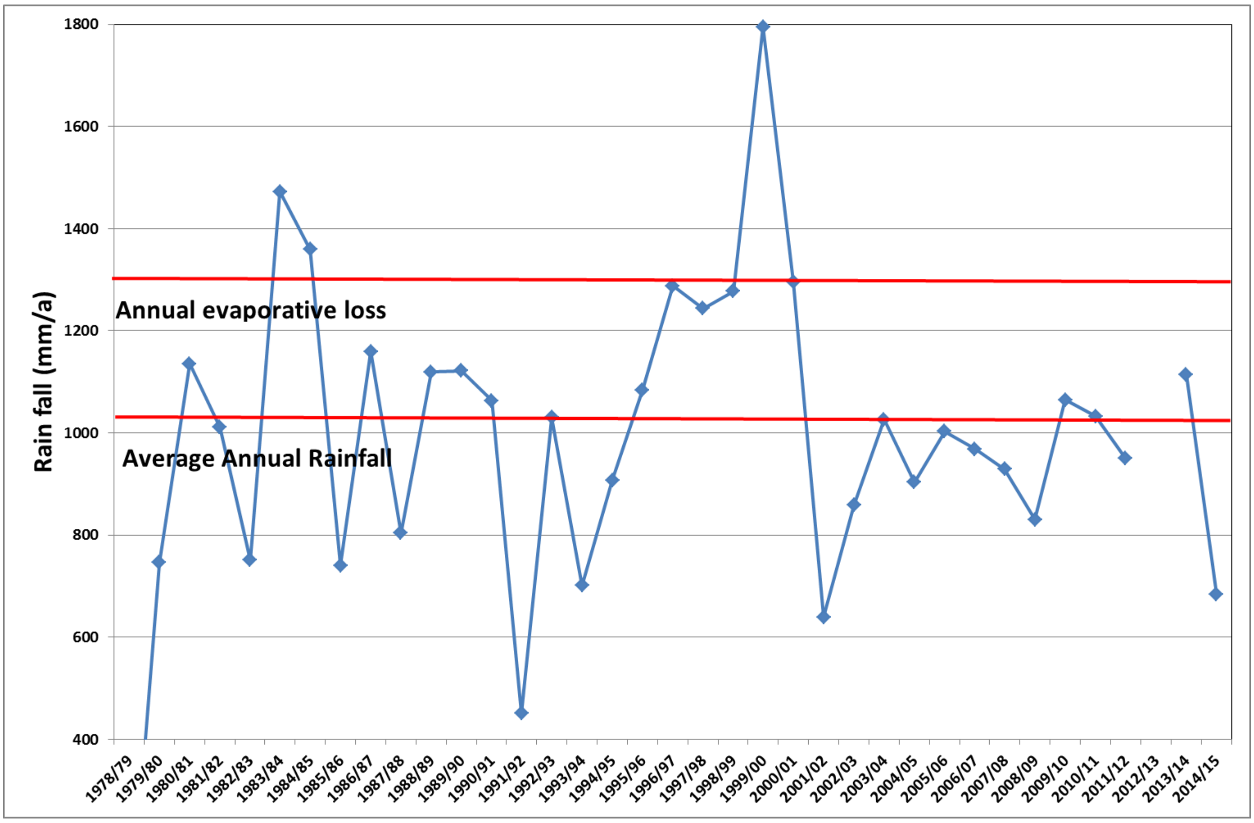


Figure B.10 Annual rainfall in the Kosi Estuarine Lake System in comparison with evaporative losses.

A comparison of annual rainfall versus evaporative losses (Figure B.10) shows that evaporative losses far exceed rainfall on the surface area of the lake system. The analysis also indicates that since 2003 rainfall has not been significantly below the average for the region. This in combination with current high salinity measurements highlights the potential impact of forestry and abstraction on the system.

B.1.9. WATER LEVELS

The following observations can be drawn from the three long-term water level recorders (W7T004, W7T005, W7T003) in the system (Table B.1 to B.3 and Figures B.11 to B.17):

- The tidal amplitude at W7T004 (between the Estuary and Lake 1) is greater than at that of the recorder W7T005 in the connecting channel.
- On a daily cycle: springs =~20cm, neap = 0-5 cm.

Table B.1 A summary of average water level amplitude in the Kosi Estuarine Lake System.

Recoder nr	Location	Neap tide Amplitude	Spring tide Amplitude	Level diffrance between neap and springs
W7T004	Between the Estuary and Lake 1	0-5 cm	20 cm	60 - 50 cm
W7T005	Between Lake 2 and Lake 3. Mantu (channel 3)	0-5 cm	15 -20 cm	40 cm
W7T003	KZN wildlife site	-		5 cm rise and fall in the neap - spring cycle

- W7T004 shows larger tidal amplitude than W7T005 which is in Channel 3, with the low tides lower and high tides higher than thise measured at W&T005 i.e. the tides are less truncated/ damped by the channels.
- W7T003 shows very little tidal sensitivity; on average only about 5 cm rise and fall in the neap - spring cycle is observed. This effect is also masked by wind generated waves. Under the influence of wind generated waves significant short-term (days/hours) variation can be observed (in the order of 10 cm) at the water level recorder W7T005 in Lake 3. Personal observations also show wind generated waves up to a 1.5 m in the centre of the lake.
- W7T004 and W7T005 show little sensitivity to increase in rainfall and associated runoff/groundwater input, while W7T003 (Lake 3) shows a response to high rainfall events. This is attributed to the large surface area and significant perimeter of this lake with only a relatively small outflow channel.
- The W7T003 (Lake 3) showed some sensitivity to the wet/dry cycle with water levels generally lower during the winter period, e.g. 30 cm difference observed between March and September 2005.
- The strong tidal flows over the spring-neap cycle (two weekly cycle) keeps the mouth nearly permanently open.
- In some years there water levels show some sensitivity to mouth configuration, when the mouth channel is constricted the low tides are more elevated.
- The Kosi Lake stsytem was not closed in 2013 as indicated by the Groundwater report.

Table B.2 Observations on the relative increase in water levels after a major rain event.

Date	Rainfall (mm)	Increase in relative water levels (m)
05/02/1999	287.6	0.47-0.908
19/02/2001	109.4	0.74-1.083
25/01/2004	81	0.509-0.795
15/06/2008	80	0.581-0.762
28/01/2009	123.4	0.527-0.787

Table B.3 Observations on the decline in water leves after a major rain event.

Date	Initial	After 1 month	After 2 months	After 3 months
05/02/1999	0.908	0.745	0.609	
19/02/2001	1.083	1.034	1.011	0.752
15/06/2008	0.762	0.718	0.65	0.644
28/02/2009	0.787	0.687	0.594	

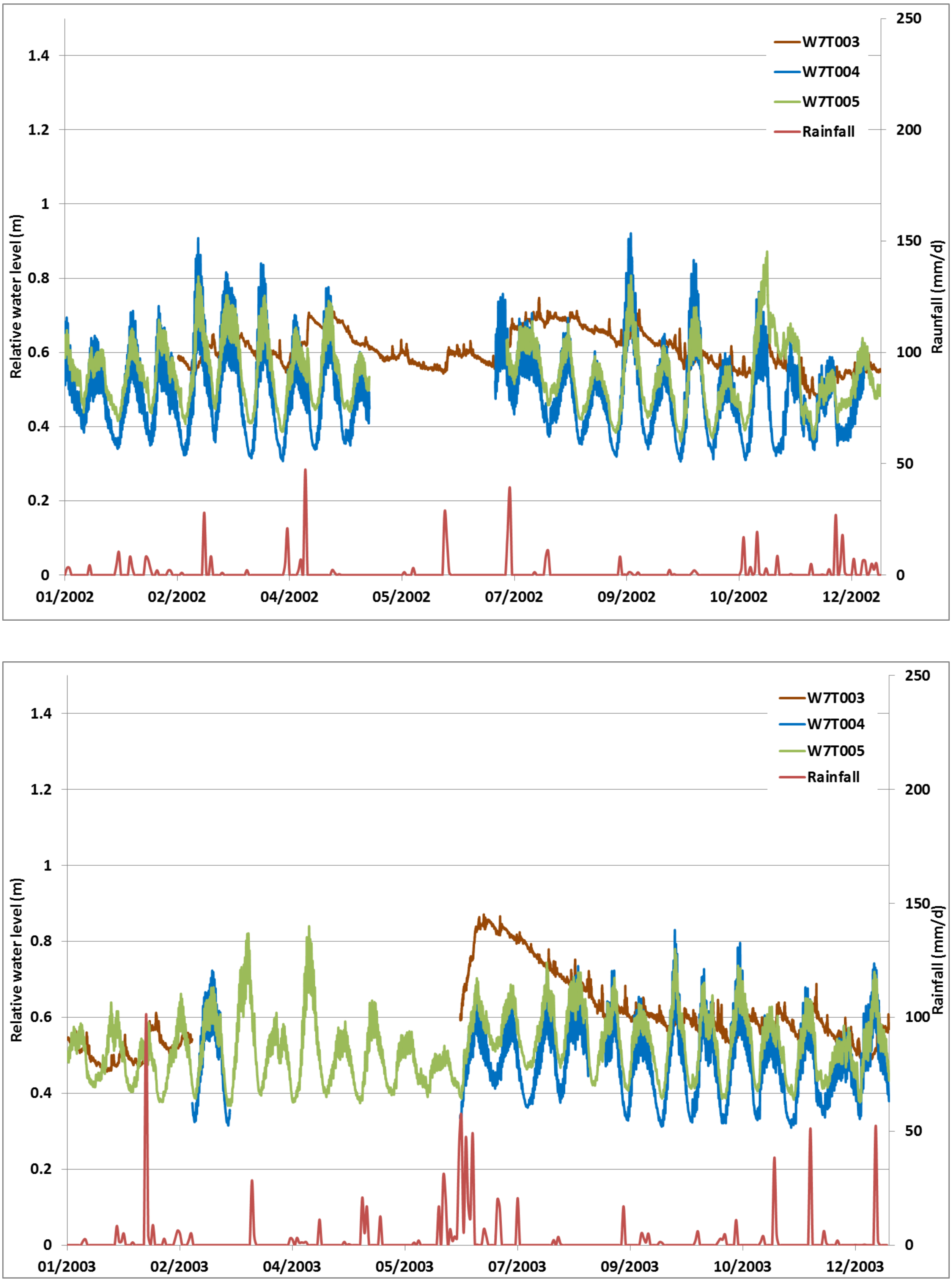
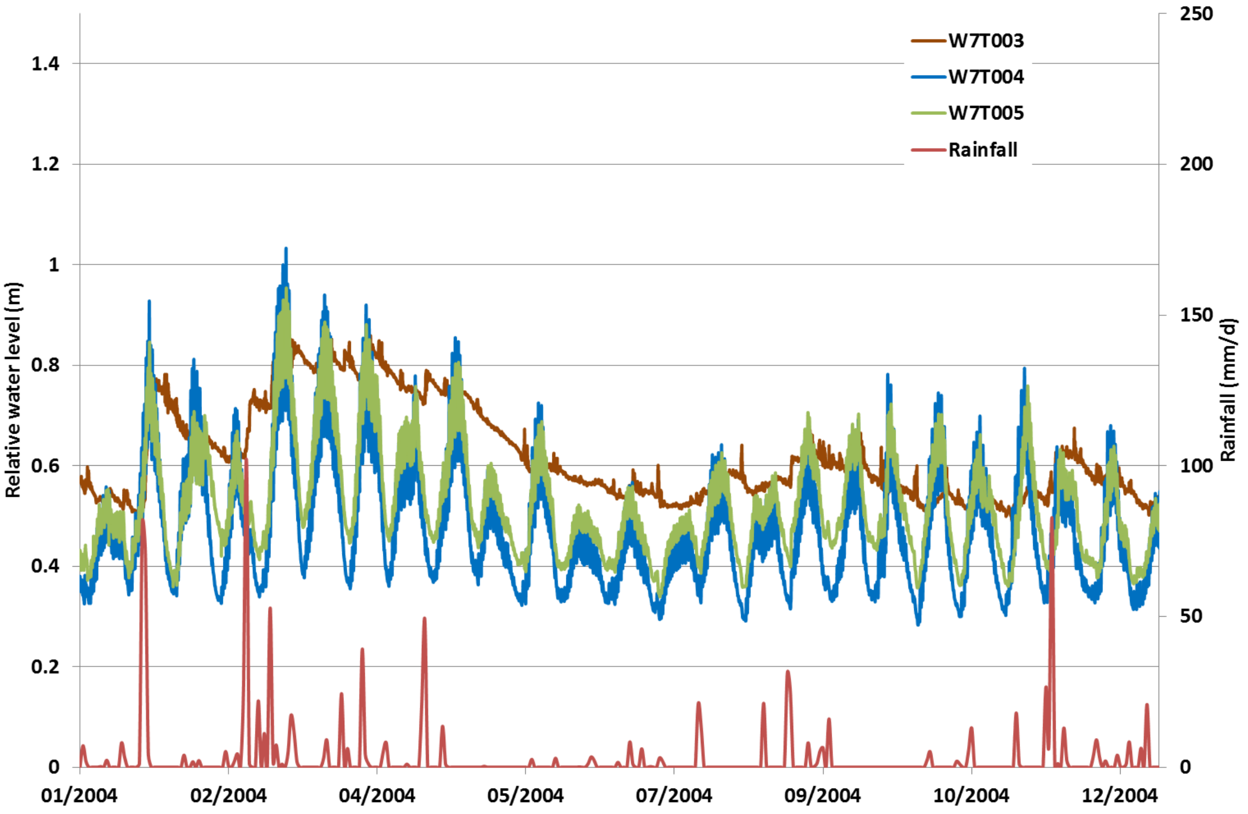


Figure B.11 Kosi Estuarine Lake System relative water level data (2002 to 2003)



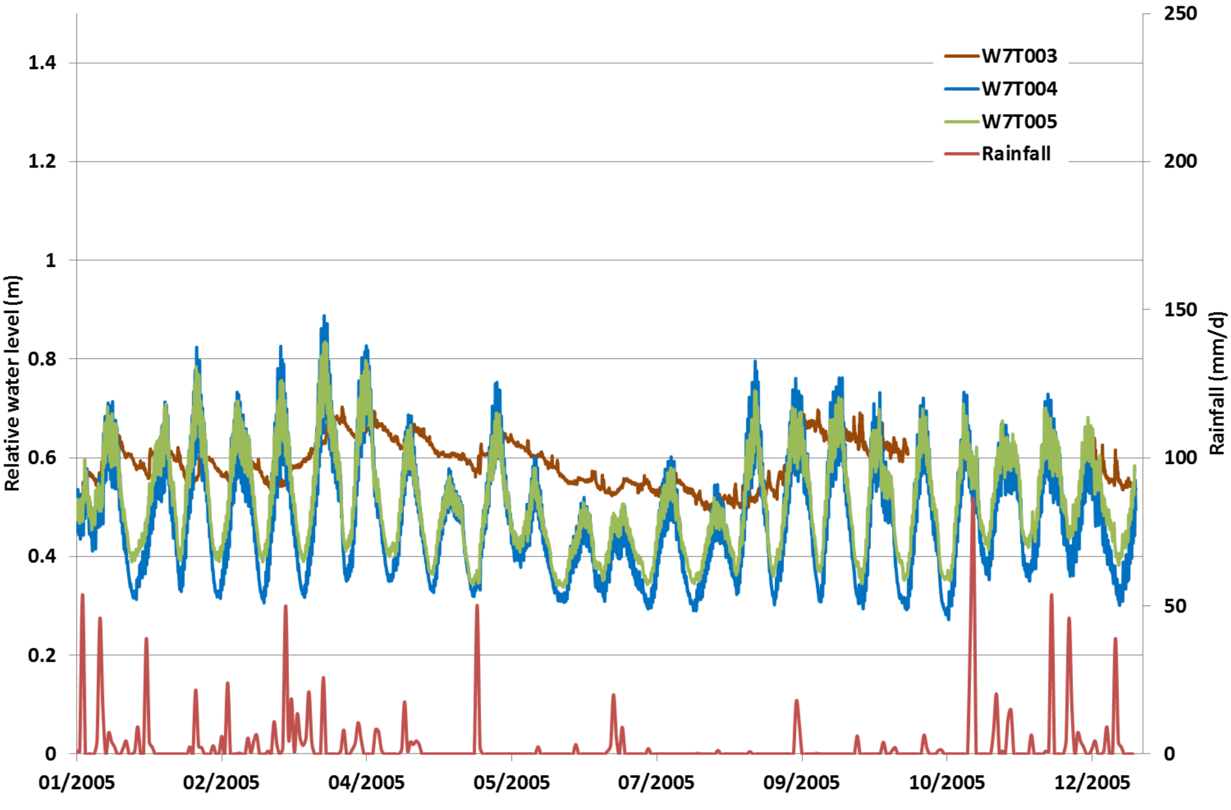
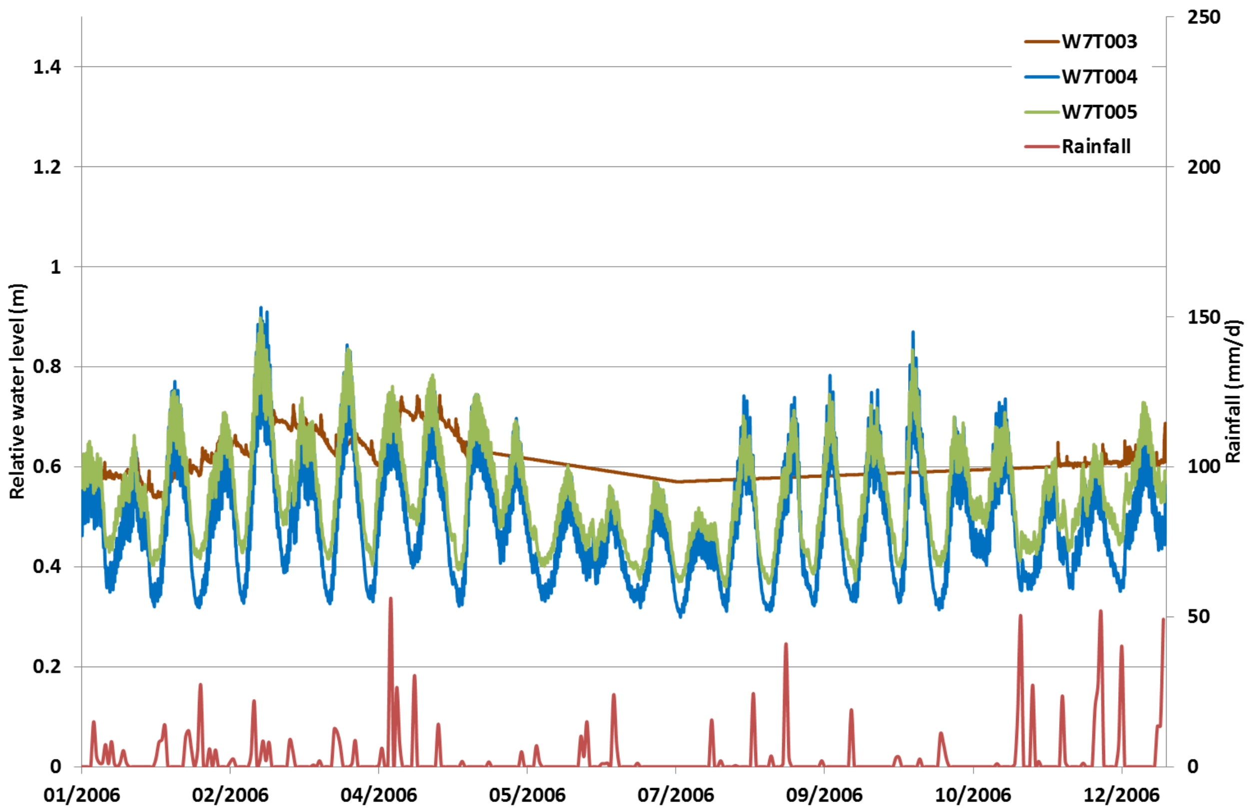


Figure B.12 Kosi Estuarine Lake System relative water level data (2004 to 2005)



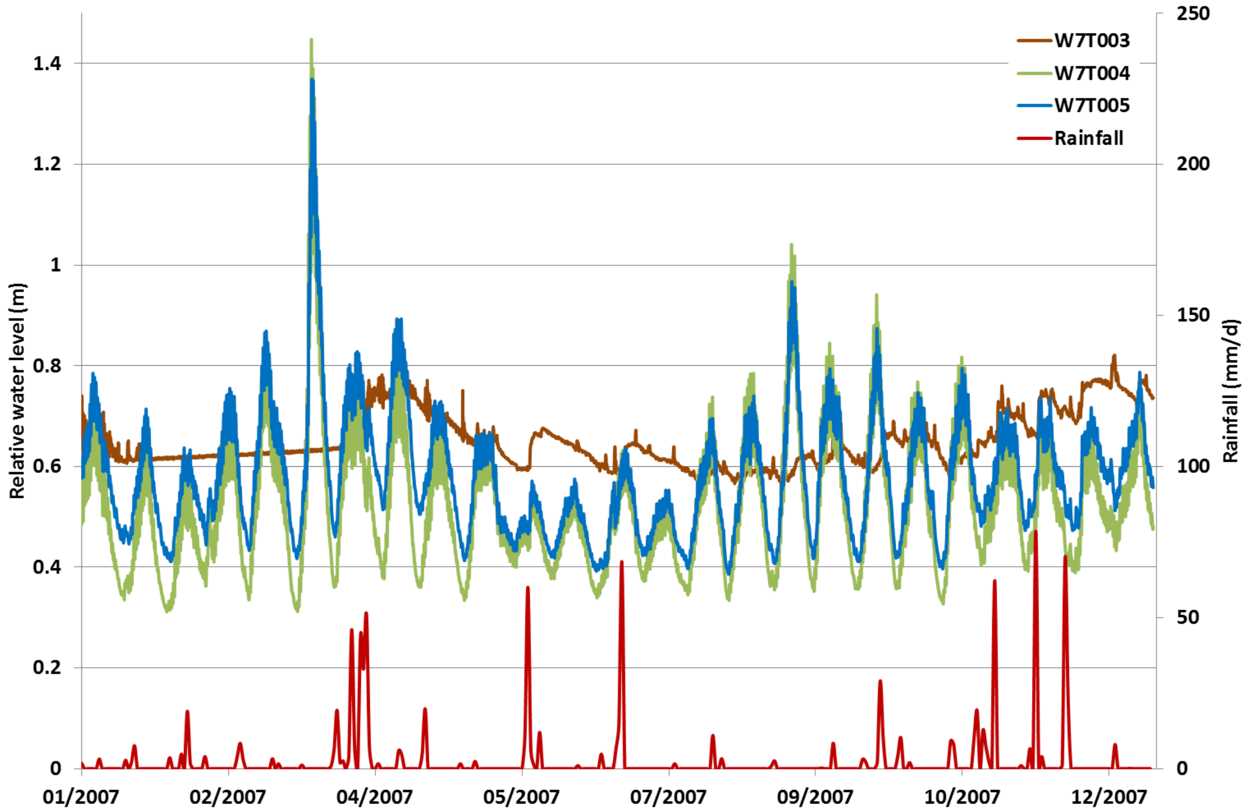
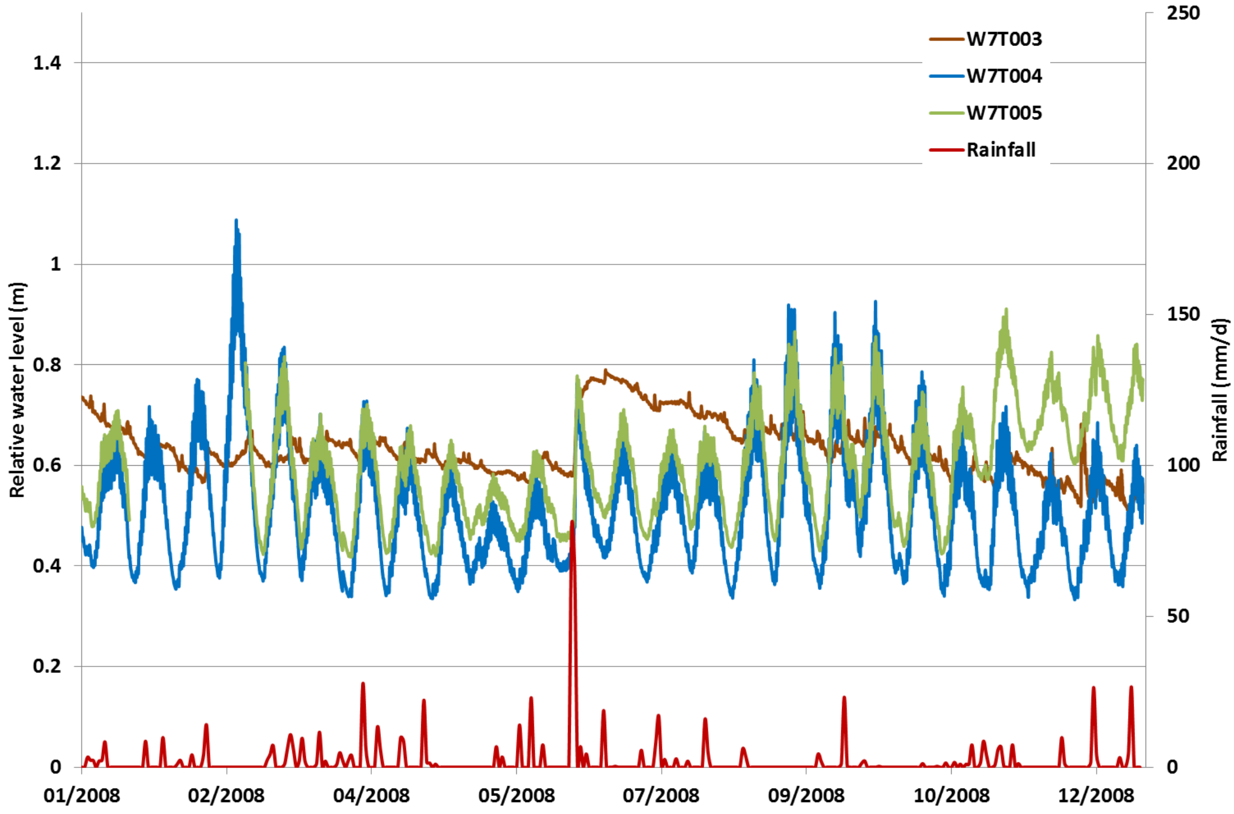


Figure B.13 Kosi Estuarine Lake System relative water level data (2006 to 2007)



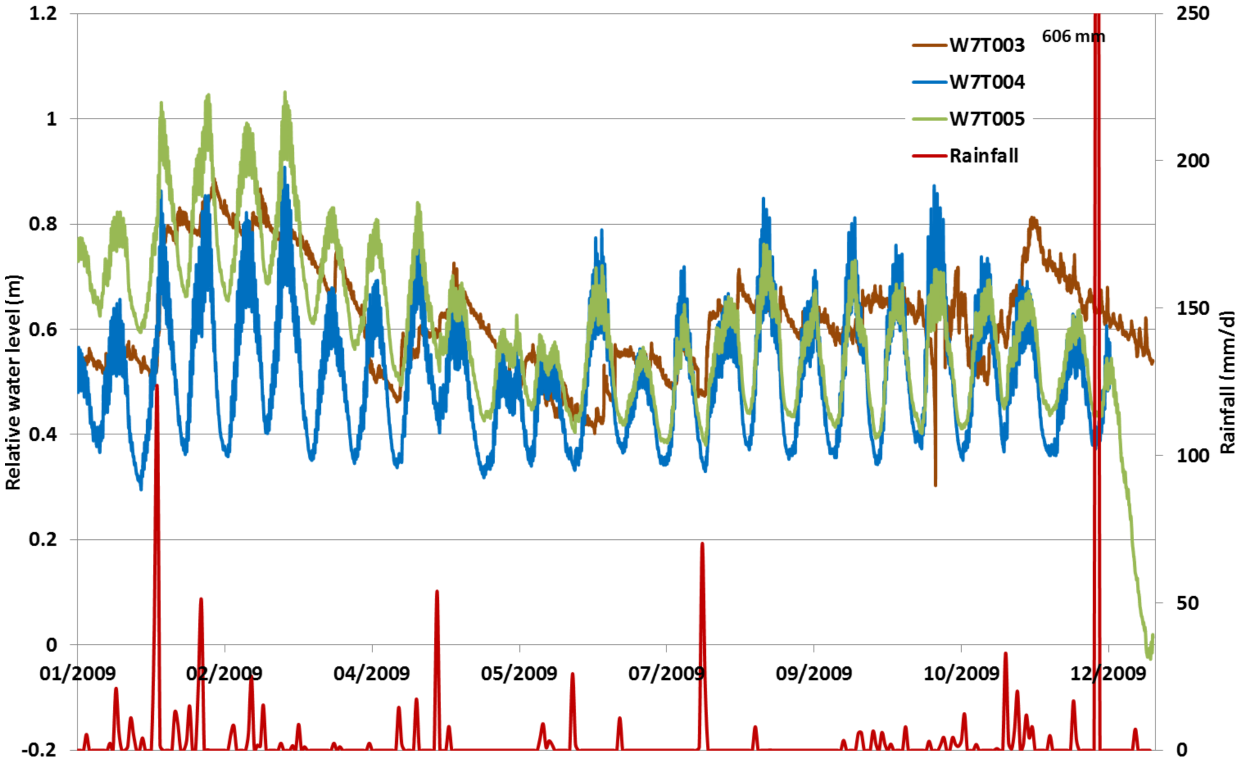


Figure B.14 Kosi Estuarine Lake System relative water level data (2008 to 2009)

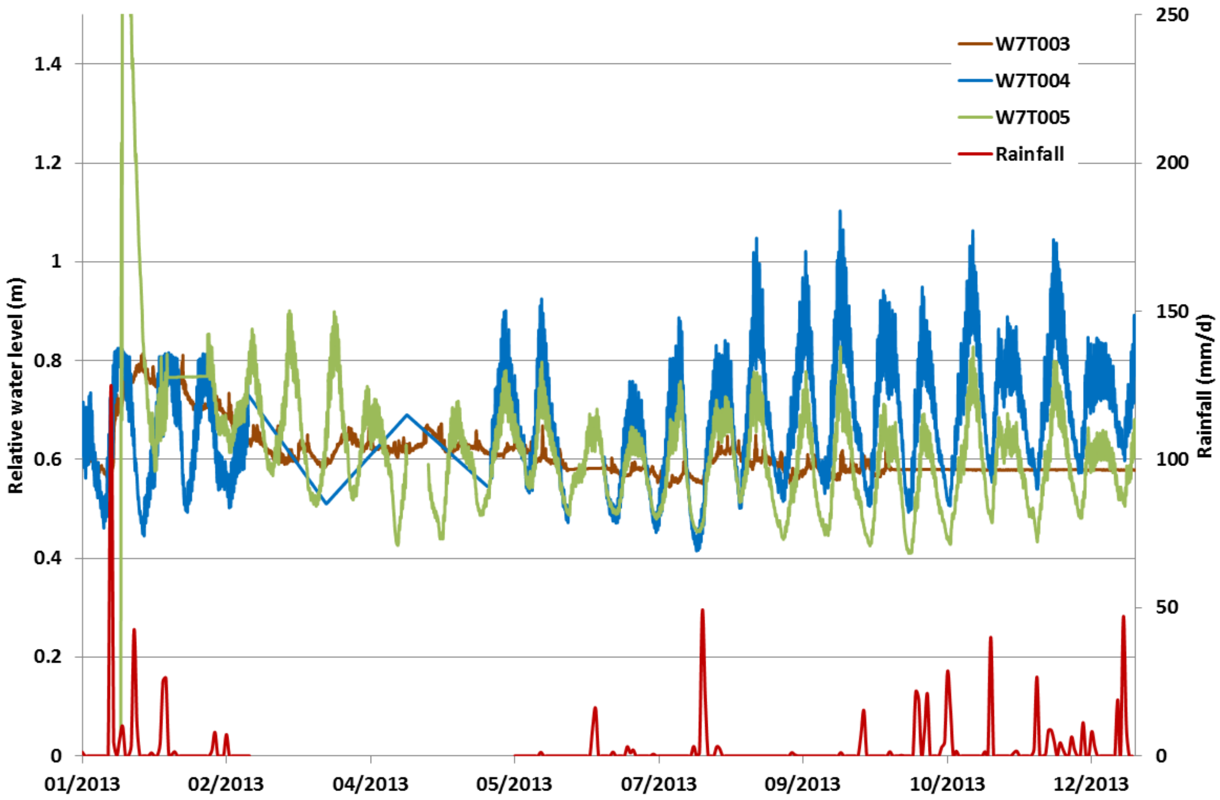


Figure B.15 Kosi Estuarine Lake System relative water level data (2013)

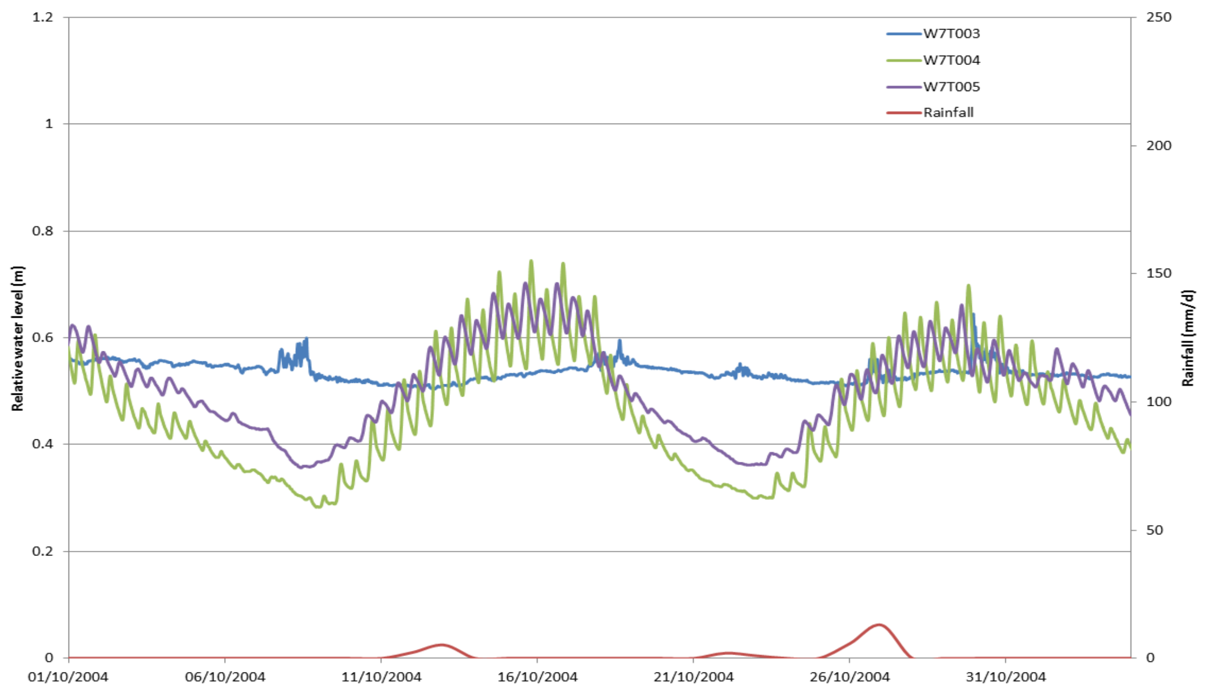


Figure B.16 Kosi Estuarine Lake System relative water level data for October 2004 showing water leves over spring neap cycle

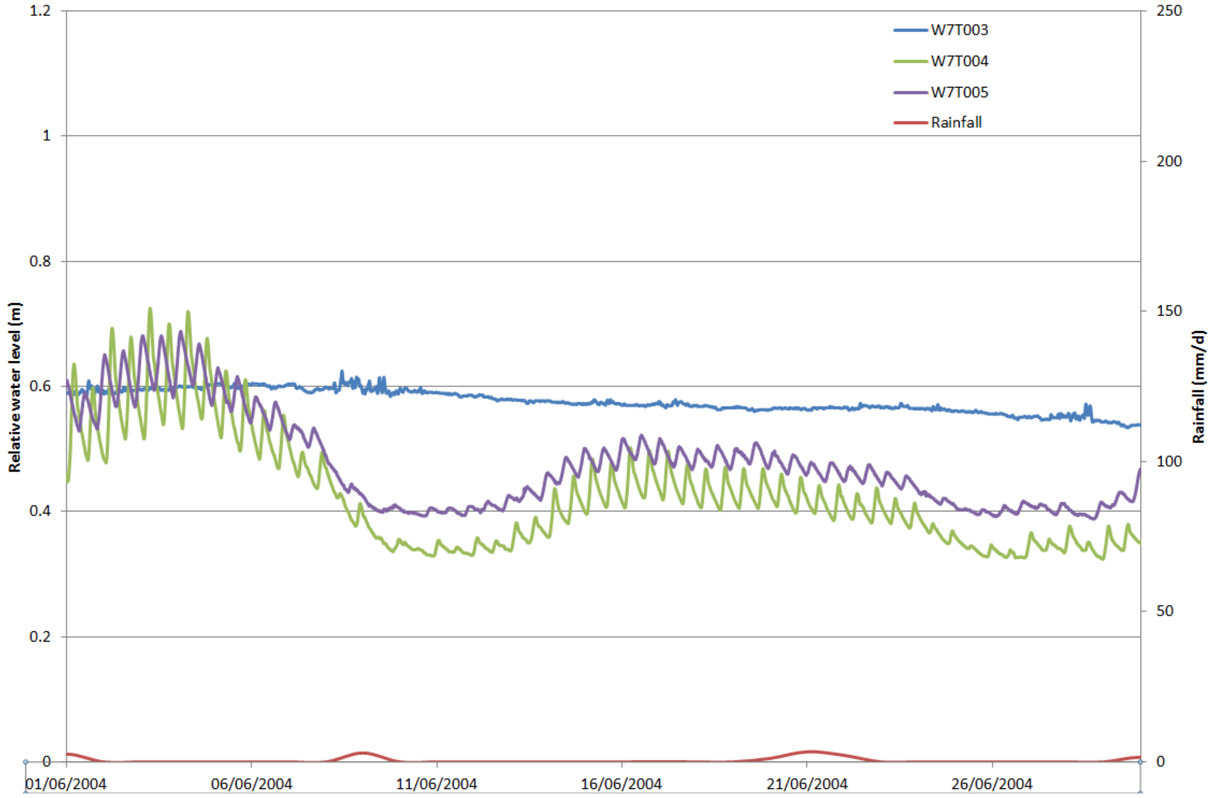


Figure B.17 Kosi Estuarine Lake System relative water level data for June 2004 showing decline in water level in neap cycle

Appendix C and D

Specialist Report Microalgae