





WP 10543
RDM/WMA16/04/CON/0813, Volume 3

RESERVE DETERMINATION STUDIES FOR THE SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE GOURITZ WATER MANAGEMENT AREA

Project Technical Report 8, Volume 3

Estuaries RDM Report – Intermediate Assessment, Volume 3
Goukou Estuary

February 2015

Department of Water and Sanitation
Chief Directorate: Water Ecosystems

Published by

Department of Water and Sanitation
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Republic of South Africa

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This report should be cited as:

Department of Water and Sanitation (DWS), 2015. *Reserve Determination Studies for Surface Water, Groundwater, Estuaries and Wetlands in the Gouritz Water Management Area:* Estuaries RDM Report – Intermediate Assessment, Volume 3 (Goukou Estuary). Prepared by the Council for Scientific and Industrial Research (CSIR) for Scherman Colloty and Associates cc. Report no. RDM/WMA16/04/CON/0813, Volume 3.

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APPROVAL

TITLE:	Reserve Determination Studies for Surface Water, Groundwater, Estuaries and Wetlands in the Gouritz Water Management Area: Estuaries RDM Report – Intermediate Assessment, Volume 3 (Goukou Estuary)
DATE:	February 2015
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REPORT NO:	RDM/WMA16/04/CON/0813, Volume 3
FORMAT:	MSWord and PDF
WEB ADDRESS:	http://www.dws.gov.za

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ACKNOWLEDGEMENTS

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REPORT SCHEDULE

Version	Date
First draft	February 2015
Final report	September 2015

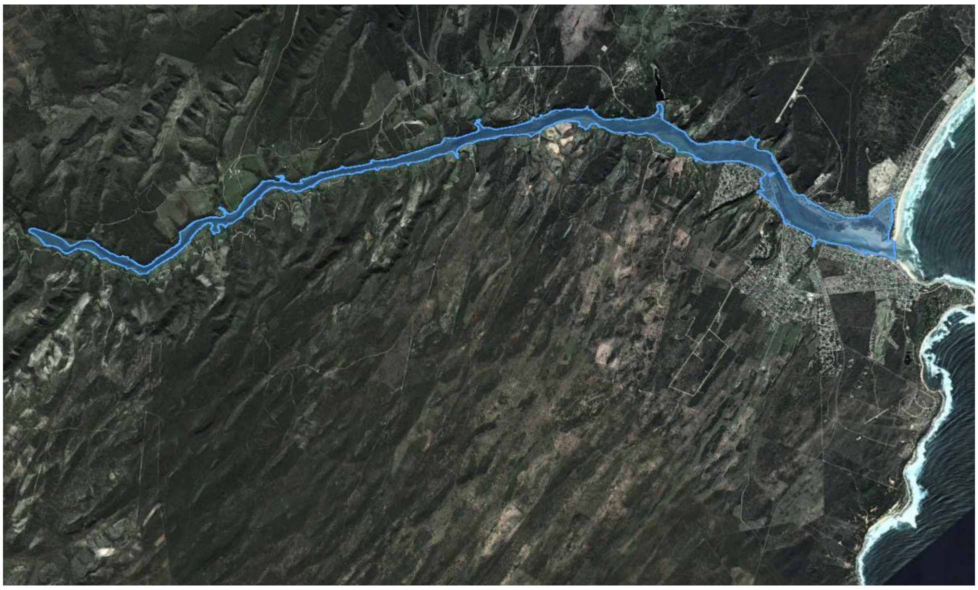
EXECUTIVE SUMMARY

GEOGRAPHICAL BOUNDARIES

The Goukou Estuary is located on the Indian Ocean seaboard, about 300 km east of Cape Town. The estuary covers approximately 250 ha, is 19 km in length, and is embedded in a deep valley.

The geographical boundaries of the estuary are defined as follows:

Downstream boundary:	*Estuary mouth 34°22'43.36"S, 21°25'22.19"E*
Upstream boundary:	*34°17'32.20"S, 21°18'29.03"E*
Lateral boundaries:	*5 m contour above Mean Sea Level (MSL) along each bank*



PRESENT ECOLOGICAL STATUS

The Estuarine Health Score for the Goukou Estuary is 69, thus a ***Present Ecological Status (PES)*** *of* ***Category C.***

Variable	*Weight*	*Score*
Hydrology	*25*	*54*
Hydrodynamics and mouth condition	*25*	*95*
Water quality	*25*	*75*
Physical habitat alteration	*25*	*65*
Habitat health score		***72***
Microalgae	*20*	*57*
Macrophytes	*20*	*68*
Invertebrates	*20*	*60*
Fish	*20*	*75*
Birds	*20*	*73*
Biotic health score		***67***
ESTUARY HEALTH SCORE Mean (Habitat health, Biological health)		***69***
PRESENT ECOLOGICAL STATUS (PES)		***C***

ECOLOGICAL IMPORTANCE

*The Goukou Estuary is rated as a **'Highly Important'** system. The system is part of the Stilbaai Marine Protected Area (MPA). The National Biodiversity Assessment 2011 (NBA 2011) (Van Niekerk and Turpie, et al., 2012) identified the estuary as an important nursery area for red data species and exploited fish stocks. Further, this estuary is very important conduit for eels which are a listed species under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).*

RECOMMENDED ECOLOGICAL CATEGORY

*The Goukou Estuary should at least be managed in a **Category A or at least a Best Attainable State (BAS)**. The motivation being that the estuary is highly important and part of a MPA. Considering the various flow and non-flow related factors that currently contributes to a PES of Category C, specialists agreed that several of the flow related and non-flow related impacts on the system are reversible, or at least partially reversible. However, it is unlikely to fully restore the ecological status of this estuary to a Category A, given the social and economic demand for water in the catchment, as well as extensive urban development along its banks. The Recommended Ecological Category (REC) for the Goukou Estuary, therefore, was set as a **Category B.***

RECOMMENDED ECOLOGICAL FLOW SCENARIO

***Present inflow, with restoring 50% of the base flow** (mean annual runoff [MAR] 101.69 million m^3) was selected as the recommended ecological flow scenario for the Goukou Estuary:*

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	23.4	30.8	27.2	16.6	16.7	24.2	30.3	17.9	8.1	10.1	34.9	29.1
99	19.5	23.6	16.6	12.3	13.2	16.3	29.0	14.9	7.5	9.8	26.8	15.7
90	11.2	9.3	4.8	3.5	6.4	7.6	8.6	7.4	5.3	5.1	6.6	7.0
80	5.8	7.3	3.4	2.5	3.3	5.7	6.0	5.0	3.5	3.4	5.4	5.2
70	4.4	4.8	2.1	1.3	2.2	3.9	3.8	3.6	2.9	2.6	3.8	4.0
60	3.5	3.4	1.4	0.8	1.0	3.3	3.0	3.0	2.2	2.3	3.5	3.2
50	2.8	2.4	1.0	0.6	0.7	2.4	2.3	2.7	1.9	2.0	2.6	2.8
40	2.1	1.8	0.6	0.4	0.5	1.6	1.8	2.0	1.5	1.8	2.3	2.4
30	1.8	1.2	0.5	0.3	0.4	1.1	1.5	1.1	1.2	1.4	1.6	2.0
20	1.4	0.9	0.4	0.3	0.3	0.4	1.3	0.7	0.8	1.0	1.4	1.5
10	1.1	0.7	0.4	0.3	0.3	0.3	0.7	0.4	0.5	0.8	1.0	1.2
1	0.6	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.6	0.7
0.1	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.6	0.5

However, in order to improve the estuary from a present Category C, restoration of some base flow will not suffice. Additional intervention in terms of non-flow related impacts will be essential to improve the ecological health of the estuary to a Category B. As a minimum, the following non-flow related interventions must be undertaken:

- *Restore 50% of the flood plain and riparian habitat along length of estuary;*
- *Identify all fountains, spring and seeps and ensure adequate freshwater supply to riparian zone and estuary to facilitate connectivity between estuary and terrestrial environment (critical factor for the protection of eels);*
- *Control/reduce fishing effort through improving compliance monitoring of fishing activities and banning of night fishing;*
- *Prepare and implement guidelines on appropriate bank stabilisation along the estuary;*
- *Control boating activities on the estuary towards mitigating bank erosion (e.g. through proper zonation, establishment and enforcement of boating carrying capacity limits);*
- *Institute proper stormwater management in future development planning (e.g. management of runoff from hardened surfaces and associated pollution);*
- *Upgrade and maintain sewage infrastructure (e.g. restore broken pipes and install back-up pumps for pump station in close proximity of the estuary);*
- *Ensure that the water quality and volumes discharged through the Riversdal Wastewater treatment works (WWTW) meet permit requirements as issued under the National Water Act (No 36 of 1998); and*
- *Prepare and implement guidelines on appropriate (nature-friendly) structures to secure access to the estuary.*

*The overall confidence of this study is **Medium**, derived from the medium confidence reflected in most of the abiotic and biotic components. In terms of the abiotic components, it was not possible to define and characterise the five abiotic states for this system with high/medium confidence, mainly because long-term river inflow records were not available at the head of the estuary. Data from the Duiwenhoks station (station H8H1) had to be used as proxy. Water quality data on river inflow were* *also not available for river inflow near the head of the estuary and conditions had to be extrapolated from further upstream (station H9H5) as well as using downstream data from the Duiwenhoks system (station H8H1). However, the Department of Agriculture, Forestry and Fisheries (DAFF) in conjunction with the Council for Scientific and Industrial Research (CSIR) collected salinity and other water quality parameters (i.e. temperature, pH, dissolved oxygen and turbidity) as part of a long-term monitoring programme in this estuary which enhanced confidence in the assessment of those parameters. Overall confidence in the abiotic components still came to medium, because specialists were able draw on experience from their collective research on other, related systems. Medium confidence in the macrophyte component is largely attributed to extensive, recent research conducted by the Nelson Mandela Metropolitan University on estuarine systems in the region. Medium confidence in the microalgae and invertebrate components is attributed to the availability of some historical data sets on this system, but mostly because specialists were able draw on experience from their collective research on other, related systems. Extensive data on the fish component collected by DAFF as part of their long-term monitoring programmes in estuaries significantly contributed to the medium (even high) confidence in this component. Historical data on the bird component was also available from the Coordinated Waterbird Counts (CWAC) programme. The character of the Goukou Estuary also allowed specialists to draw on experience from their collective research on other, related systems, warranting a medium confidence in the biotic components.*

ECOLOGICAL SPECIFICATIONS

*The following Ecological Specifications (EcoSpecs) and associated Thresholds of Potential Concern (TPCs) were identified as representative of a **Category B** for the **Goukou Estuary**:*

Component	***EcoSpecs***	***Thresholds of Potential Concern***
Hydrology	*Maintain flow regime as per recommended ecological flow* *Ensure the persistence of freshwater seepage sites in the lower and middle reaches of the estuary.*	*River inflow:* ▪ *< 0.3 m^3/s for more than 1 month a year* ▪ *< 1.0 m^3/s for more than 3 months a year* ▪ *Maintain water levels in fountains (determine trough baseline study)*
Hydrodynamics	▪ *Maintain connectivity with marine environment* ▪ *Maintain connectivity with terrestrial environment through the presence of fountains and seeps*	▪ *Average tidal amplitude < 20% of present observed data from the water level recorder in the estuary near the mouth during low flows (summer)* ▪ *Loss of wet riparian zones*

Component	EcoSpecs	Thresholds of Potential Concern
Sediment	▪ *Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) for biota* ▪ *No significant changes in sediment grain size and organic matter distribution patterns for biota* ▪ *No significant change in average sediment composition and characteristics* ▪ *No significant change in average bathymetry*	▪ *Average sediment composition in any survey (% fractions) along estuary change from that of the Present State (2014 baseline, to be measured) by 30%* ▪ *Average organic fraction in sediment along length of estuary > 5%* ▪ *Average bathymetry along main channel in the middle and lower reaches (10 km upstream) change by 30% in any survey from that of the Present State (2015 baseline, to be measured) (system expected to significantly fluctuate in terms of bathymetry between flood)* ▪ *Average bathymetry along main channel in the upper reaches (above 10 km from the mouth – above Zone C) change by 10% in any survey from that of the Present State (2015 baseline, to be measured)*
Water quality	*Salinity distribution not to cause exceedance of TPCs for biota (see below)*	▪ *Salinity > 0 at head of estuary* ▪ *Average salinity in Zone D > 5* ▪ *Average salinity in Zone C > 20* ▪ *Average salinity 9.5 km upstream from mouth > 20 more than 3 months of the year* ▪ *Salinity in interstitial water at seep sites > 20* ▪ *Salinity > 40 in saltmarsh sediments (linked to decrease in moisture and drying of floodplain habitat)*
	System variables (pH, dissolved oxygen and turbidity) not to cause exceedance of TPCs for biota (see below)	*River inflow:* ▪ *6.0 < pH > 8.0 (black water system)* ▪ *Dissolved oxyxgen (DO) < 5 mg/ℓ* ▪ *Suspended solids >5 mg/ℓ (low flow)* *Estuary:* ▪ *Average turbidity >10 NTU (low flow)* ▪ *Average 6.0 < pH > 8.5 (increasing with increase in salinity)* ▪ *Average DO < 5 mg/ℓ*

Component	EcoSpecs	Thresholds of Potential Concern
	Inorganic nutrient concentrations (NO_3-N, NH_3-N and PO_4-P) not to cause in exceedance of TPCs for macrophytes and microalgae (see below)	*River inflow:* ▪ *NO_x-N >150 µg/ℓ over 2 consecutive months* ▪ *NH_3-N > 20 µg/ℓ over 2 consecutive months* ▪ *PO_4-P > 20 µg/ℓ over 2 consecutive months* *Estuary (except during upwelling or floods):* ▪ *Average NO_x-N > 150 µg/ℓ single concentration > 200 µg/ℓ* ▪ *Average NH_3-N > 20 µg/ℓ during survey, single concentration > 100 µg/ℓ* ▪ *Average PO_4-P > 20 µg/ℓ during survey, single concentration > 50 µg/ℓ*
	Presence of toxic substances (e.g. trace metals and pesticides/herbicides) not to cause exceedance of TPCs for biota (see below)	*River inflow:* ▪ *Trace metals (to be confirmed)* ▪ *Pesticides/herbicides (to be confirmed)* *Estuary* ▪ *Concentrations in water column exceed target values as per South African Water Quality Guidelines for coastal marine waters (DWAF, 1995)* ▪ *Concentrations in sediment exceed target values as per WIO Region guidelines (UNEP/Nairobi Convention Secretariat and CSIR, 2009)*
Microalgae	▪ *Maintain a low median phytoplankton biomass* ▪ *Maintain a high median intertidal benthic microalgal biomass* ▪ *Prevent formation of localised phytoplankton blooms*	▪ *Median phytoplankton chlorophyll a (minimum 5 sites) exceeds 3.5 µg/ℓ* ▪ *Median intertidal benthic chlorophyll a (minimum 5 sites) exceeds 42 mg/m^2* ▪ *Site specific chlorophyll a concentration exceeds 20 µg/ℓ and cell density exceeds 10 000 cells/ℓ*

Component	EcoSpecs	Thresholds of Potential Concern
Macrophytes	▪ *Maintain the distribution of macrophyte habitats, particularly the submerged macrophytes, salt marsh, reeds and sedges* ▪ *Maintain pockets of reeds in lower and middle reaches (linked to freshwater seepage sites)* ▪ *Maintain the reed and sedge stands in the upper reaches of the estuary* ▪ *Rehabilitate 20% of the floodplain habitat by removing agriculture and invasive plants* ▪ *Maintain the integrity of the riparian zone*	▪ *Greater than 20% change in the area covered by salt marsh, reeds and sedges (2014 survey). Loss of submerged macrophytes (e.g. Stukenia pectinata, Zostera capensis) over a three year period* ▪ *Decrease in cover of reeds at the freshwater seepage sites in the lower and middle reaches of the estuary (linked to salinity in interstitial water > 20 for three months)* ▪ *Increase in bare areas in the salt marsh (linked to a decrease in moisture and increase in salinity in sediment – i.e. drying of floodplain habitat)* ▪ *Loss and die-back of reeds fringing the estuary in the upper reaches (linked to salinity being > 20 for three months)* ▪ *Invasive plants (e.g. Acacia cyclops, prickly pear) cover > 5% of total floodplain area* ▪ *Unvegetated, cleared areas along the banks caused by human disturbance*
Invertebrates	▪ *Maintain rich populations of the mudprawn Upogebia africana on mudbanks in the middle estuary (Zones A and B)* ▪ *Maintain rich invertebrate communities associated with the REI zone in the upper estuary (zooplankton and benthos)*	▪ *Mudprawn density should not deviate from average baseline levels (as determined in the eight visits undertaken quarterly in the first two years) by more than 25% in each season.* ▪ *The dominant species in the zone (zooplankton and benthos) should not deviate from average baseline levels (as determined in the eight visits undertaken quarterly in the first two years) by more than 40% in each season*

Component	EcoSpecs	Thresholds of Potential Concern
Fish	*Fish assemblage should comprise the 5 estuarine association categories in similar proportions (diversity and abundance) to that under the reference (see 2015 EWR report). Numerically assemblage should comprise:* ▪ *Ia estuarine residents (50-80% of total abundance)* ▪ *Ib marine and estuarine breeders (10-20%)* ▪ *IIa obligate estuarine-dependent (10-20%)* ▪ *IIb estuarine associated species (5-15%)* ▪ *IIc marine opportunists (20-80%)* ▪ *III marine vagrants (not more than 5%)* ▪ *IV indigenous fish (1-5%)* ▪ *V catadromous species (1-5%)* *Category Ia species should contain viable populations of at least 4 species (including G.aestuaria, Hyporamphus capensis, Omobranchus woodii).* *Category IIa obligate dependents should be well represented by large exploited species especially A. japonicus, L. lithognathus, P. commersonii, Lichia amia.* *REI species dominated by both Myxus capensis and G. aestuaria.*	▪ *Ia estuarine residents < 50%* ▪ *Ib marine and estuarine breeders < 10%* ▪ *IIa obligate estuarine-dependent < 10%* ▪ *IIb estuarine associated species < 5%* ▪ *IIc marine opportunists <20%* ▪ *III marine vagrants > 5%* ▪ *IV indigenous fish < 1%* ▪ *V catadromous species < 1% (also linked to presence of freshwater seepage areas)* ▪ *Ia represented only by G. aestuaria.* ▪ *IIa exploited species in very low numbers or absent* ▪ *REI species represented only by G. aestuaria, Myxus capensis absent*
Birds	*The estuary should contain a diverse avifaunal community that includes representatives of all the original taxonomic groups (see 2015 EWR report). Tern roosts should be seen at the estuary on a regular basis. Apart from gulls, terns and regionally increasing species such as Egyptian Goose, the estuary should generally support more than 200 birds*	▪ *Numbers of birds other than gulls, terns and regionally increasing species fall below 120 for three consecutive counts* ▪ *Numbers of waterbird species drop below 15 for three consecutive counts*

BASELINE AND LONG-TERM MONITORING PROGRAMMES

The following additional baseline surveys are required to improve the confidence of the EWR study (priority components are highlighted):

Component	**Action**	**Temporal scale (frequency and when)**	**Spatial scale (Stations)**
Hydrodynamics	*Measure freshwater inflow into the estuary*	*Continuous*	*Near head of estuary (H9H5 to far upstream, new station is required)*
	Aerial photographs of estuary (spring low tide)	*Baseline*	*Entire estuary*
Sediment dynamics	*Monitoring berm height using appropriate technologies*	*Quarterly*	*Mouth*
	Bathymetric surveys: Series of cross section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detail in mouth including berm (every 100 m). Vertical accuracy at least 5 cm.	*Once-off*	*Entire estuary*
	Collect sediment grab samples (at cross section profiles) for analysis of particle size distribution (and ideally origin, i.e. microscopic observations)	*Once-off*	*Entire estuary*
Water quality	*River inflow: Conductivity, temperature, suspended solids, pH, inorganic nutrients (N, P and Si) and organic content (TP and Kjeldahl N) in river inflow*	*Monthly, continuous*	*Near head of estuary (station H9H5 to far upstream, new station is required)*
	River inflow: Pesticides/herbicide and metal accumulation	*Once-off*	*Near head of estuary (station H9H5 to far upstream, new station is required)*
	Collect surface and bottom water samples for inorganic nutrients (and organic nutrient) and suspended solid analysis, together the in situ salinity, temperature, pH, dissolved oxygen and turbidity profiles	*Quarterly, preferably over two years*	*Entire estuary (10-15 stations)*
	Measure pesticides/herbicides and metal accumulation in sediments (for metals investigate establishment of distribution models – see Watling and Newman, 2007)	*Once off*	*Entire estuary, including depositional areas (i.e. muddy areas)*

Component	Action	Temporal scale (frequency and when)	Spatial scale (Stations)
Microalgae	▪ *Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae* ▪ *Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. spectrophotometer, HPLC, fluoroprobe* ▪ *Intertidal and subtidal benthic chlorophyll-a measurements (4 replicates each) using a recognised technique, e.g. sediment corer or fluoroprobe*	*Quarterly, preferably over two years*	*Along length of estuary minimum five stations*
Invertebrates	▪ *Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh) along the estuary at five sites* ▪ *Collect grab samples (five replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each samples to be sieved through 500 um)* ▪ *Collect sled samples (day) at same zooplankton sites for hyper benthos (190 um)* ▪ *Intertidal invertebrate hole counts using 0.25 m^2 grid (five replicates per site)* ▪ *Establish the species concerned using a prawn pump (Zones A and B)* ▪ *Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton)* ▪ *Three replicate hole counts of Upogebia africana at three intertidal sites in Zone B*	*Quarterly, preferably over two years*	*Minimum of five sites along length of estuary.* *For intertidal counts – minimum of five sites*

The recommended monitoring programme, to test for compliance with TPCs is as follows (priority components are highlighted):

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (Stations)
Hydrodynamics	*Measure freshwater inflow into the estuary*	*Continuous*	*Near head of estuary (station H9H5 to far upstream, new station is required)*
	Aerial photographs of estuary (spring low tide)	*Every three years*	*Entire estuary*
Sediment dynamics	*Monitoring berm height using appropriate technologies*	*Quarterly*	*Mouth*

Component	***Monitoring action***	***Temporal scale (frequency and when)***	***Spatial scale (Stations)***
	Bathymetric surveys: Series of cross section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detail in mouth including berm (every 100 m). Vertical accuracy at least 5 cm	*Every three years (and after large resetting event)*	*Entire estuary*
	Collect sediment grab samples (at cross section profiles) for analysis of particle size distribution (and ideally origin, i.e. microscopic observations)	*Every three years*	*Entire estuary*
Water quality	*River inflow: Conductivity, temperature, suspended solids, pH, inorganic nutrients (N, P and Si) and organic content (TP and Kjeldahl N) in river inflow*	*Monthly, continuous*	*Near head of estuary (H9H5 to far upstream, new station is required)*
	River inflow: Pesticides/herbicide and metal contamination	*Seasonally, or when contamination is expected*	*Near head of estuary (H9H5 to far upstream, new station is required)*
	Collect in situ continuous salinity data with mini Conductivity-Temperature-Depth (CTD) probe at a depth of about 1 m	*Continuous*	*Three sites – 5 km, 10 km from the mouth head and near head of estuary*
	Record longitudinal in situ salinity and temperature pH, DO, turbidity profiles	*Seasonally, every year*	*Entire estuary (17 stations)*
	Collect surface and bottom water samples for inorganic nutrients (and organic nutrient) and suspended solid analysis, together the in situ salinity, temperature, pH, dissolved oxygen and turbidity profiles	*Every three years (high flow and low flow) or when significant change in WQ expected*	*Entire estuary (10-17 stations)*
	Measure pesticides/herbicides and metal accumulation in sediments (for metals investigate establishment of distribution models – see Newman and Watling, 2007)	*Every 3 – 6 years*	*Entire estuary, including depositional areas (i.e. muddy areas)*
Microalgae	▪ *Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae* ▪ *Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. spectrophotometer, HPLC, fluoroprobe* ▪ *Intertidal and subtidal benthic chlorophyll-a measurements (four replicates each) using a recognised technique, e.g. sediment corer or fluoroprobe*	*Low flow surveys every three years*	*Along length of estuary minimum five stations*

Component	**Monitoring action**	**Temporal scale (frequency and when)**	**Spatial scale (Stations)**
Macrophytes	▪ *Ground-truthed maps to update the map produced for 2013 and to check the areas covered by the different macrophyte habitats.* ▪ *Record boundaries of macrophyte habitats and total number of macrophyte species in the field* ▪ *Assess extent of invasive species within the 5 m contour line* ▪ *Check for loss of reed and sedge area in the middle / upper reaches. Check for increase in bare areas in salt marsh habitat from mapping* ▪ *Measure macrophyte and sediment characteristics along transects in the main salt marsh areas. Percentage plant cover measured in duplicate 1 m^2 quadrats along transects and an elevation gradient from the water to the terrestrial habitat* ▪ *Duplicate sediment samples collected in three zones along each transect to represent the lower intertidal, upper intertidal and supratidal salt marsh. Analysed in the laboratory for sediment moisture, organic content, electrical conductivity, pH and redox potential. In the field measure depth to water table and ground water salinity*	*Summer survey every three years*	*Entire estuary for mapping (transects located in the middle and lower reaches)*
Invertebrates	▪ *Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh) along the estuary at five sites* ▪ *Collect grab samples (5 replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each samples to be sieved through 500 um)* ▪ *Collect sled samples (day) at same zooplankton sites for hyper benthos (190 um)* ▪ *Intertidal invertebrate hole counts using 0.25 m^2 grid (five replicates per site)* ▪ *Establish the species concerned using a prawn pump (Zones A and B)* ▪ *Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton)* ▪ *Three replicate hole counts of Upogebia africana at three intertidal sites in Zone B*	*Every two years in mid-summer*	*Minimum of five sites along length of estuary.* *For intertidal counts – minimum of five sites.*
Fish	*Record species and abundance of fish, based on seine net and gill net sampling*	*Summer and winter survey every three years*	*Entire estuary (17 stations)*

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (Stations)
Birds	*Undertake counts of all non-passerine waterbirds, identified to species level*	*Annual winter and summer surveys*	*Entire estuary (seven sections – see **Figure F.6**)*

The recommended interventions and implementation of the monitoring programme should be undertaken in collaboration with various responsible departments in Department of Water and Sanitation (DWS), as well as other national and provincial departments and institutions responsible for estuarine resource management. These include DAFF, Department of Environmental Affairs (DEA: Oceans and Coasts), South African National Biodiversity Institute (SANBI), CapeNature, as well as relevant municipal authorities. It is recommended that the estuarine management planning process and the associated institutional structures (as required under the Integrated Coastal Management Act, 2008) be used as mechanisms through which to facilitate the implementation these interventions.

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ACRONYMS AND ABBREVIATIONS

BAS	Best Attainable State
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CSIR	Centre of Scientific and Industrial Research
CTD	Conductivity-Temperature-Depth
CWAC	Coordinated Waterbird Counts
DAFF	Department of Agrculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphate
DO	Dissolved Oxygen
DRS	Dissolved Reactive Silicate
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Ecological Category / Electrical Conductivity
EcoSpecs	Ecological Specifications
EFZ	Estuary Functional Zone
EHI	Estuarine Health Index
EIS	Estuarine Importance Score
EWR	Ecological Water Requirement
GPS	Global Positioning System
GRDS	Gouritz Reserve Determination Study
H	High
L	Low
M	Medium
MAR	Mean Annual Runoff
MPB	Microphytobenthos
MSL	Mean Sea Level
NMMU	Nelson Mandela Metropolitan University
NBA 2011	National Biodiversity Assessment 2011
NTU	Nephelometric Turbidity Units
NWA	National Water Act (1998)
PES	Present Ecological Status
RDM	Resource Directed Measures
REC	Recommended Ecological Category
REI	River Estuary Interface
SC&A	Scherman Colloty & Associates
SANBI	South African National Biodiversity Institute
TPC	Threshold of Potential Concern
UNEP	United Nations Environmental Programme
VL	Very Low
WIO	Western Indian Ocean
WMA	Water Management Area
WQ	Water Quality
WRC	Water Research Commission
WRYM	Water Resource Yield Model
%ILE	Percentile

1 INTRODUCTION

1.1 ECOLOGICAL WATER REQUIREMENT METHOD FOR ESTUARIES

Methods to determine the Environmental Water Requirement (EWR) of estuaries were established soon after the promulgation of the National Water Act (No. 36 of 1998) (NWA). The so-called "Preliminary Reserve Method" involves setting a Recommended Ecological Category (REC) (i.e. desired state), recommended Ecological Reserve (i.e. flow allocation to achieve the desired state) and Ecological Specifications (EcoSpecs for a resource on the basis of its present health status and its ecological importance. The method follows a generic methodology which can be carried out at different levels (e.g. Rapid, Intermediate or Comprehensive). The official method for estuaries (Version 2) is documented in DWA (2008). Currently a Version 3 of the method is in preparation as part of a Water Research Commission (WRC) study (Turpie *et al.*, in prep.). Pending the official approval of Version 3 by the Department of Water and Sanitation (DWS), Version 2 is still applied in this study (DWAF, 2008), but considers obvious improvements proposed in Version 3. Currently, the official suite of "Preliminary Reserve Methods" for estuaries does not include a Desktop assessment method. However, a Desktop approach for assessing estuary health in data-poor environments was recently applied successfully in the National Biodiversity Assessment 2011 (NBA 2011) (Van Niekerk and Turpie, 2012). This method has since been refined in a WRC study (Van Niekerk *et al.*, 2014) and was also applied in this Gouritz Reserve Determination Study (GRDS), (WMA) study, where considered appropriate.

> **For management and improved governance reasons, South Africa's 19 water management areas have been consolidated into nine (9) WMAs. The Gouritz WMA (previously WMA16) now forms part of the Breede WMA (WMA8) and is known as the Breede-Gouritz WMA. It will be governed by the Breede-Gouritz Catchment Management Agency (CMA).**

Within the time and budgetary constraints it was not possible to conduct the preliminary reserve determination studies on the estuaries of the Gouritz Water Management Area (WMA) at a high confidence. Instead a "best attainable" approach was adopted to assess as many estuaries as possible within the available budgetary framework. In selecting the level of Reserve (i.e. Intermediate, Rapid or Desktop) for various estuaries, systems were prioritised in terms of the degree to which they were already water stressed or had major future abstraction pressures. Also, their protected status or desired protected status (NBA 2011) (Van Niekerk and Turpie, 2012) was taken into account. Using this rating system, the Goukou, Gouritz and Duiwenhoks estuaries showed highest priority (best attainable: Intermediate level) followed by the Klein Brak and Wilderness estuaries (best attainable: Rapid level). The Hartenbos, Blinde, Piesang, Groot (Wes) and Bloukrans estuaries clustered as the lowest rated systems (best attainable: Desktop assessment). This report presents the **Intermediate level assessment on the Goukou Estuary**, including a field measurement programme and specialist reports.

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

Step 1: Initiate study by defining the study area, project team and level of study (confirmed in the GRDS **Inception Report**; DWA, 2013).

Step 2: Delineate the geographical boundaries of the resource units (confirmed in the GRDS **Delineation Report**; DWA, 2014).

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 (see **Section 5**).

The Estuary Health Index (EHI) score, in turn, corresponds to an Ecological Category that describes the health using six categories, ranging from natural (A) to critically modified (F) (**Table 1.1**). The A to F scale represents a continuum, where the boundaries between categories are conceptual points along the continuum. To reflect this, straddling categories (+/- 3 from the category scoring range) were therefore introduced in this study, denoted by A/B, B/C, C/D, and so on.

Table 1.1 Translation of EHI scores into ecological categories

EHI score	PES	General description
91 – 100	A	**Unmodified**, or approximates natural condition; the natural abiotic template should not be modified. The characteristics of the resource should be determined by unmodifed natural disturbance regimes. There should be no human induced risks to the abiotic and biotic maintenance of the resource. The supply capacity of the resource will not be used.
76 – 90	B	**Largely natural with few modifications.** A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged. Only a small risk of modifyng the natural abiotic template and exceeding the resource base should not be allowed. Although the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a very limited number of localities may be slightly higher than expected under natural conditions, the resilience and adaptability of biota must not be compromised. The impact of acute disturbances must be totally mitigated by the presence of sufficient refuge areas.
61 – 75	C	**Moderately modified.** A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the wellbeing and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least partly be mitigated by the presence of sufficient refuge areas.

EHI score	PES	General description
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 **Section 6**).

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) (see **Section 6**)
An estuary cannot be allocated an REC below a category “D”. Therefore systems with a PES in categories ‘E’ or ‘F’ needs to be managed towards achieving at least a REC of “D”.

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

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

Step 6: **EcoSpecs** for the recommended REC, as well as **additional baseline and long-term monitoring requirements** to improve the confidence of the EWR and to test compliance with EcoSpecs.

1.2 DEFINITION OF CONFIDENCE LEVELS

The level of available historical data in combination with the level of effort expended during the assessment determines the level of confidence of the study. Criteria for the confidence limits attached to statements in this study are:

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

In the case of a Desktop assessment study the confidence levels generally fall in the "very low" to "low" categories.

1.3 SPECIALIST TEAM

The following specialists comprised the core Goukou Estuary study team:

Specialist	Affiliation	Area of responsibility
Dr S Taljaard	CSIR, Stellenbosch	Project coordinator/Water quality
Ms L van Niekerk	CSIR, Stellenbosch	Hydrodynamics
Mr A K Theron	CSIR, Stellenbosch	Sediment dynamics, abiotic morphology
Mr P Huizinga	Private Consultant	Hydrodynamics (advisory role)
Dr G Snow	Nelson Mandela Metropolitan University	Microalgae
Prof J Adams	Nelson Mandela Metropolitan University	Macrophytes
Prof T Wooldridge	Nelson Mandela Metropolitan University	Invertebrates
Dr S Lamberth	DAFF	Fish
Dr J Turpie	Anchor Environmental Consultants	Birds

Contributions were also received from:

- Chantel Peterson (CSIR) – hydrodynamic component;
- Nuette Gordon (NMMU) – macrophyte component;
- Demitri Veldkornet (NMMU) – macrophyte component;
- Nompumelelo Thwala (NMMU/National Research Foundation) – invertebrate component; and
- Jean du Plessis (CapeNature) – fish component.

1.4 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 dependant on the **quality of the simulated hydrology**. The overall confidence in the hydrology supplied is of a medium level (60-80).
- A detailed flood analysis was not conducted as it is not a requirement at an Intermediate level assessment. The simulated runoff data were used to estimate flood conditions.
- For the abiotic components, it was not possible to define and characterise the five abiotic states for this system with high/medium confidence, mainly because long-term river inflow records were not available at the head of the estuary. River inflow at DWS gauging station H8H1

(Duiwenhoks) was uses to approximate the base flow to the estuary and to provide context to historical observations and measurements. Water quality data on river inflow were also not available for river inflow near the head of the estuary and conditions also had to be extrapolated from stations further upstream (H9H5), as well as from the Duiwenhoks (H8H1). However, the DAFF, in conjunction with the CSIR collected salinity and other water quality parameters (i.e. temperature, pH, dissolved oxygen and turbidity) as part of a long-term monitoring programme in this estuary which enhanced confidence in the assessment of those parameters. Data on the sediment dynamics were especially limited, but such data is typically not considered a critical requirement for Intermediate level assessments. Because specialists were able to draw on experience from their collective research on other, related systems, the data available for this study were considered sufficient for an Intermediate level assessment.

- For the biotic components, additional data for the macrophyte component are largely attributed to extensive, recent research conducted by the NMMU on estuarine systems in the region, while the CWAC programme provided additional data on birds. Extensive data on the fish component collected by the DAFF as part of their long-term monitoring programmes in estuaries significantly contributed to the medium (even high) confidence in this component. Limited historical data on the microalgae and invertebrates where available on this sytem. However, specialists were able to draw on experience from their collective research on other, related systems, to provide information sufficient for an Intermediate level assessment.
- The seeps and fountains along the Goukou Estuary are important supporting habitat for its estuarine biota, e.g. eels. However, very little information was available on the connection between the estuary and these seeps, as well as their water requirements. Interpretation on the function of these was therefore based on the literature and personal observations of local environmental managers.
- An Intermediate level assessment is suitable for individual licensing in relatively unstressed catchments, but a comprehensive level assessment is required for individual licensing for large impacts in any catchment (e.g. dams), as well as small or large impacts in very important and/or sensitive catchments (DWAF, 2008).

1.5 STRUCTURE OF THIS REPORT

The report is structured as follows:

Section 1 provides an overview of EWR methods, confidence of the study and study team.

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

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

Section 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 understanding of the present situation and estimation of the Reference Condition. The health state of each component is computed using the EHI.

Section 5 describes the overall state of health (or PES) 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.

Section 6 combines the EHI score with the Estuarine Importance Score (EIS) for the system to determine the REC.

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

Section 8 concludes with recommendations on the ecological water requirements for the estuary, as well as EcoSpecs. Finally, additional baseline and long-term monitoring requirements to improve the confidence of the EWR assessment and to test compliance with EcoSpecs are provided.

Appendices include:

- A: Abiotic specialist report
- B: Microalgae specialist report
- C: Macrophyte specialist report
- D: Invertebrate specialist report
- E: Fish specialist report
- F: Bird specialist report
- G: Comments and response register

2 BACKGROUND INFORMATION

2.1 CATCHMENT CHARACTERISTICS

The catchment and tributaries of the Goukou River fall under the jurisdiction of the Hessequa Municipality and is illustrated in **Figure 2.1**. Reported catchment areas of the Goukou River range between 1 188 km^2 and 1 550 km^2. The length of the river, from source to sea is 64 km. There are five major tributaries draining into the Goukou River – excluding minor streams. These are the Soetmelks, Naroo, Brak, Vet and Kruis rivers (Carter and Brownlie, 1990).

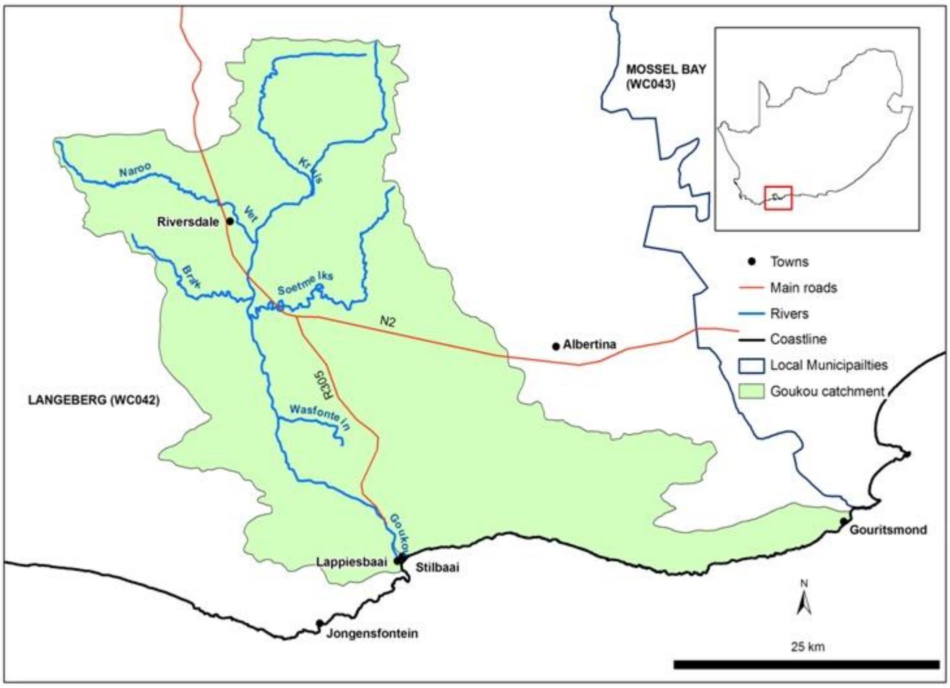


Figure 2.1 The catchment and tributaries of the Goukou River

The major geographical features of the Goukou catchment are presented in **Figure 2.2**. The Goukou River originates in the Langeberg Mountains of the Cape Fold Belt formed of the Table Mountain Sandstone of the mid-Palaeozoic Cape supergroup. The Goukou River passes through 10 km of highly erosive Cretaceous sedimentary rocks of the Enon formations followed by about 40 km of Palaeozoic Bokkeveld shales (Carter and Brownlie, 1990).

The Goukou River enters the coastal zone in gently sloping surroundings of Tertiary aeolianites (or dune rocks) and coastal sand, with a few outcrops of Table Mountain Sandstone, e.g. Morris Point. (Carter and Brownlie, 1990).

The Goukou River lies within a climatic region which receives rain almost uniformly spread throughout all seasons with peaks in autumn and spring. The mean annual precipitation, see **Figure 2.3**, for the overall catchment is 482 mm, while that of the upper catchment is 634 mm (Carter and Brownlie, 1990).

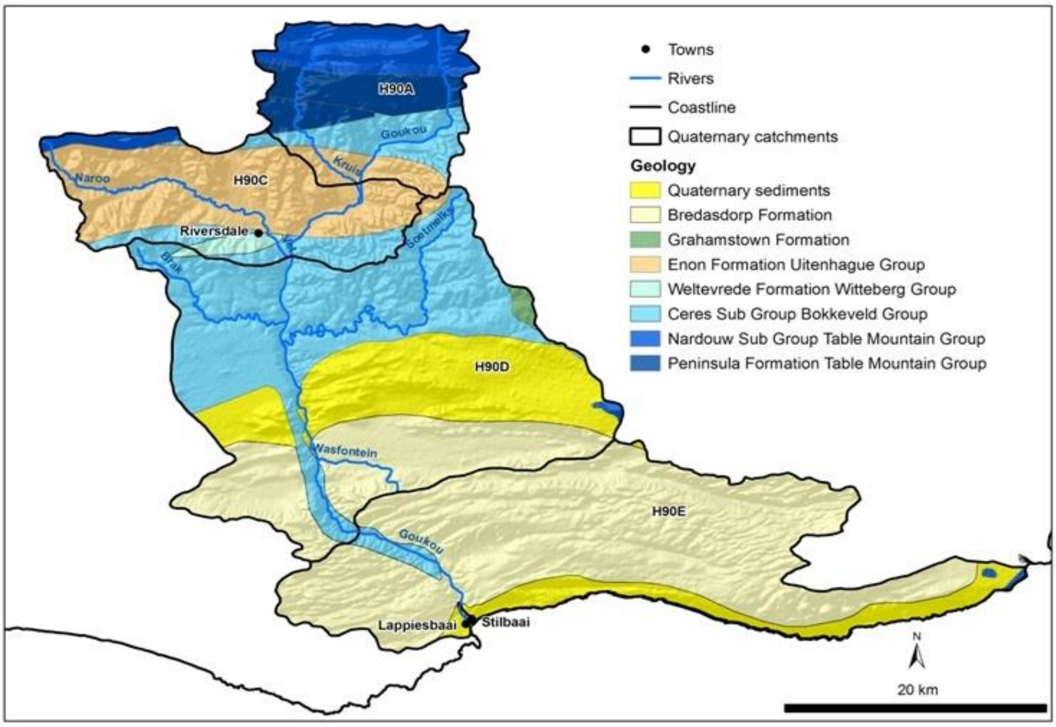


Figure 2.2 Major geological and geomorphological features of the Goukou catchment

Winds are predominantly westerly and south-westerly, especially during winter and spring with an average daily maximum velocity of 54 km/h. Although less frequent, easterly and south-easterly winds occur at stronger average daily maximum velocities of approximately 65 km/h. The latter winds play an important role in aeolian sand transport, specifically as these winds occur during the summer-autumn period when sands are dry (Carter and Brownlie, 1990).

Average temperature in the areas is approximately 26°C in summer and 16°C in winter, with extreme temperatures reaching 42°C and 32°C, respectively. During winter (July) average daily minimum temperatures are on average 7°C, while these temperatures increase to 15°C during summer (January) (Carter and Brownlie, 1990).

The only large dam in the Goukou catchment is the Korentepoort Dam with a capacity of 8.3 million cubic metres and is situated on the Vet River northwest of Riversdale. The dam was constructed during 1963-1965 to supply water to the Korente-Vet River Irrigation canal as well as water for the town of Riversdale (Carter and Brownlie, 1990).

The dominant land-use types in the catchment are (**Figure 2.4**):

- About 38% (green) cultivated, commercial dryland;
- About 29% (beige) thicket, bush clumps and high fynbos; and
- About 26% (light brown) scrubland and low fynbos.

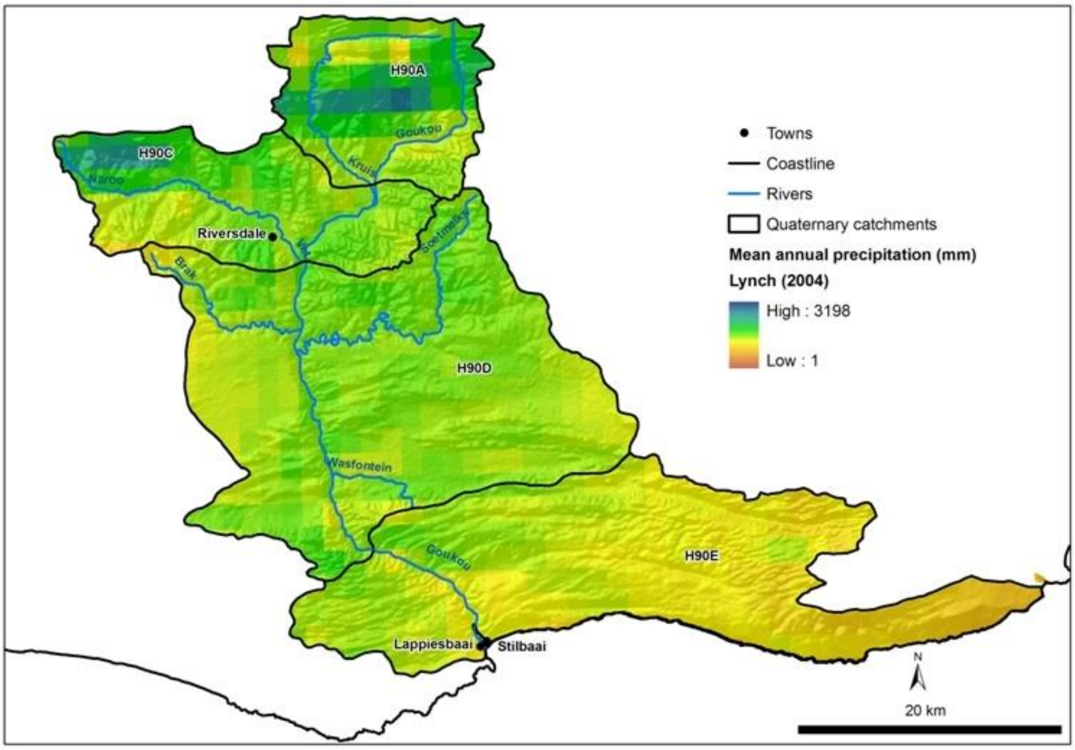


Figure 2.3 Rainfall distribution in the Goukou catchment

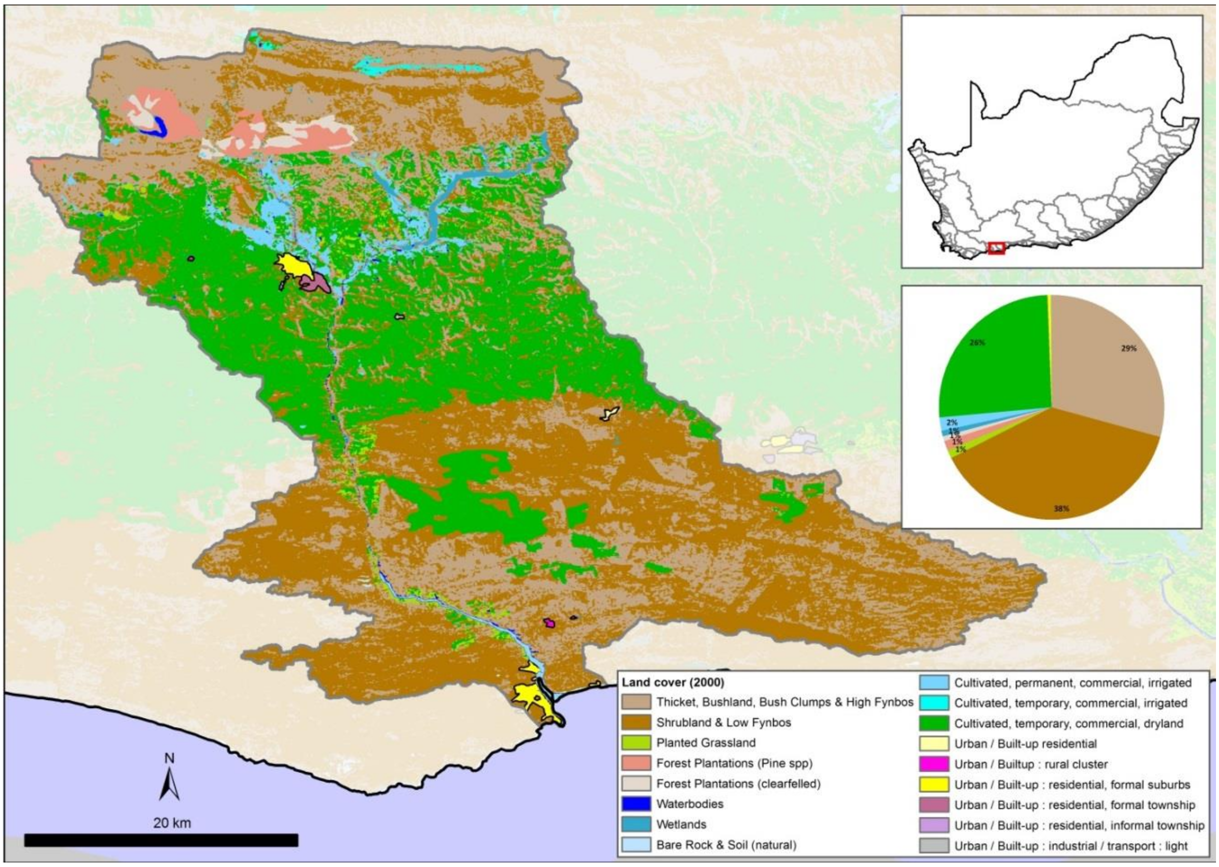


Figure 2.4 Dominant land-use practices in the Goukou catchment

2.2 HUMAN ACTIVITIES AFFECTING THE ESTUARY (PRESSURES)

Human activities affecting the estuary relating to flow modification and non-flow related pressures are briefly summarised in **Tables 2.1** and **2.2**, respectively.

Table 2.1 Pressures related to flow modification

Activity	Present	Description of impact
Water abstraction and dams (including farm dams)	✓	Korentepoort Dam with a capacity of 8.3 million cubic metres
Augmentation/Inter-basin transfer schemes		
Infestation by invasive alien plants	✓	Reduction of base flow, invasion of indigenous habitat

Table 2.2 Pressures, other than modification of river inflow presently affecting estuary

Activity	Present	Description of impact
Agricultural and pastoral run-off containing fertilisers, pesticides and herbicides	✓	Potential water quality degradation as a result of return flows due to increased nutrients etc.
Municipal waste (including sewage disposal)/infrastructure problems	✓	Riversdale WWTW (upstream)
Bridge(s)	✓	Main bridge to Stilbaai crosses the estuary at about 2.5 km from the mouth
Bank stabilisation and destabilisation	✓	Affect sediment dynamics in estuary
Road, riparian and instream infrastructure	✓	Affect sediment dynamics in estuary and cause destruction of natural habitat
Low-lying developments	✓	Affecting flood plain areas
Migration barrier in river		
Recreational fishing	✓	Exploitation of fish species affecting health of fish
Commercial/Subsistence fishing		
Illegal fishing (Poaching)	✓	Exploitation of fish species affecting health of fish
Bait collection	✓	Exploitation of invertebrate species affecting invertebrate health
Grazing and trampling of salt mashes	✓	Destruction of flood plain vegetation and possible erosion problems
Translocated or alien fauna and flora	✓	Affect natural populations detrimentally
Recreational disturbance of waterbirds	✓	Affect roosting and feeding patterns of birds, consequently affecting health of birds

3 DELINEATION OF ESTUARY

3.1 GEOGRAPHICAL BOUNDARIES

The Goukou Estuary is located on the Indian Ocean seaboard, about 300 km east of Cape Town. The estuary covers approximately 250 ha, is 19 km in length, and is embedded in a deep valley.

The geographical boundaries of the estuary are defined as follows **(Figure 3.1)**:

Downstream boundary:	Estuary mouth 34°22'43.36"S, 21°25'22.19"E
Upstream boundary:	34°17'32.20"S, 21°18'29.03"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

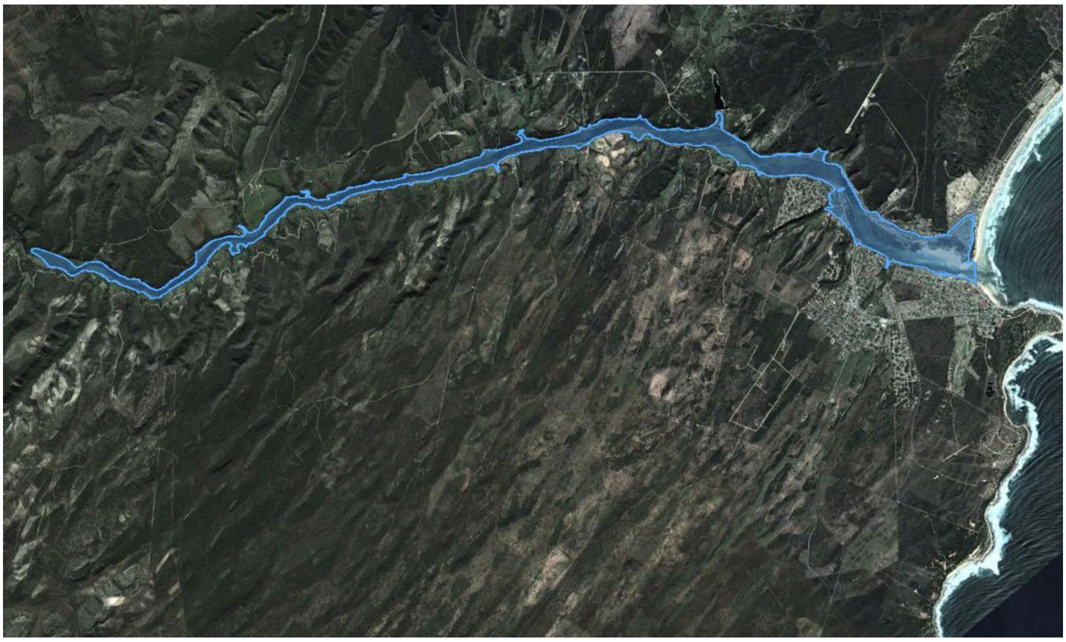


Figure 3.1. Geographical boundaries of the Goukou Estuary

3.2 ZONING OF THE GOUKOU ESTUARY

Figure 3.2 depicts the various zones in the Goukou Estuary, as for the purposes of this assessment. **Table 3.1** lists key features of the Goukou Estuary zonation that are used to determine the zonation and weighting of scores.

Table 3.1 Key features of the Goukou Estuary zonation

	Zone A	Zone B	Zone C	Zone D
Area (ha)	36.9	40.4	28.5	41.5
Average depth (m)	1.5 – 2.0	2.0 – 3.0	1.0	2.0 – 3.0

In addition to Zone A to D identified above, there are also **freshwater micro-habitats** distributed along the length of the estuary, stretching from above the Estuary Functional Zone (EFZ) to the intertidal area. These freshwater micro-habitats are dependent on the input of numerous fountains and seeps (see **Figure 4.3**).

Figure 3.2 Zonation in the Goukou Estuary

The zonation for the Goukou Estuary is schematically depicted as follows:

Zone A	Zone B	Zone C	Zone D
Freshwater micro-habitat			

3.3 TYPICAL ABIOTIC STATES OF THE GOUKOU ESTUARY

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

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

State	Flow range (m^3/s)	Description
State 1	< 0.3	Marine dominated, no REI
State 2	0.3 - 1	Full salinity gradient
State 3	1 - 5	Partial salinity gradient
State 4	5 - 15	Limited salinity penetration
State 5	> 15	Freshwater dominated

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 visually highlight the occurrence of the various abiotic states between different scenarios. In addition simulated runoff summary tables of the occurrence of different flows at increments of the 10%ile are listed separately to provide a quick comprehensive overview. A summary of the typical physical and water quality characteristics of different abiotic states in the Goukou Estuary is provided in **Section 4**. For a more detailed on the underlying data and assumptions, refer to Abiotic Specialist Report (**Appendix A**).

4 ECOLOGICAL BASELINE AND HEALTH ASSESSMENT

4.1 HYDROLOGY

4.1.1 Baseline description

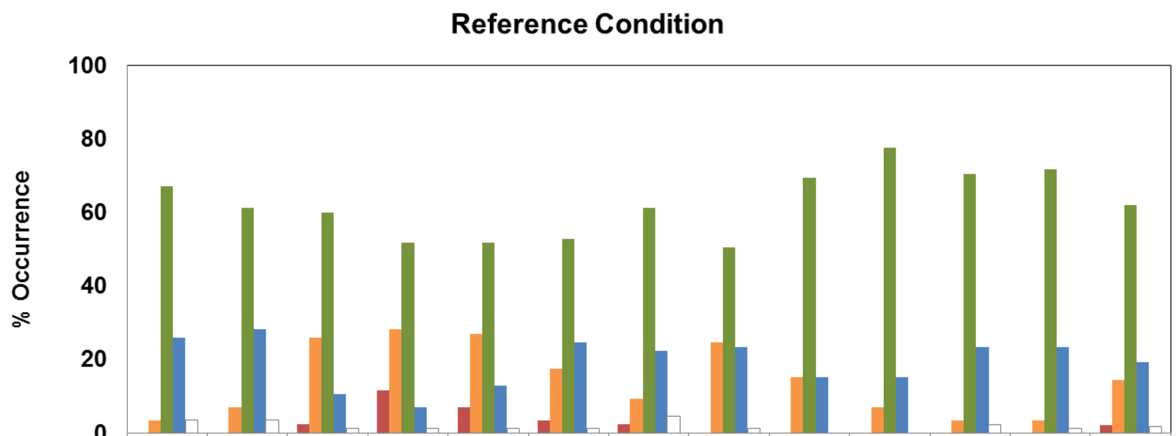
According to the hydrological data provided for this study, the present day mean annual runoff (MAR) into the Goukou Estuary is 91.73 million m^3. This is a decrease of 21% compared to the natural MAR of 115.95 million m^3. The occurrences of flow distributions (mean monthly flows in m^3/s) for the Reference Condition and Present State of the Goukou Estuary, derived from the 85-year simulated data set, are provided in **Tables 4.1** and **4.2**. The full 85-year series of simulated monthly runoff data for the Present State and Reference Condition is provided in Table 4.3 and Table 4.4. A graphic representation of the occurrence of the various abiotic states for the Reference Condition and Present State is presented in **Figures 4.1** and **4.2**

Table 4.1 Summary of the monthly flow (in m^3/s) distribution under the Reference Condition (refer to Table 3.2 for colour coding of abiotic states)

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	24.3	31.3	28.0	16.7	17.0	24.7	31.4	18.0	8.9	11.1	36.0	30.0
99	20.0	23.7	17.0	12.5	13.4	16.4	30.0	14.9	8.4	10.6	27.9	16.2
90	11.8	9.5	5.1	4.1	6.7	7.7	9.4	8.3	6.0	5.8	7.5	7.8
80	6.6	7.4	4.1	3.1	4.0	5.5	7.0	5.7	4.1	4.1	6.1	5.8
70	4.9	5.1	2.8	2.1	2.9	4.1	4.2	4.1	3.5	3.0	4.4	4.7
60	3.8	3.8	2.3	1.6	2.0	3.6	3.4	3.5	2.7	2.8	3.9	3.7
50	3.2	3.2	1.9	1.3	1.5	2.8	2.6	3.1	2.3	2.4	3.2	3.1
40	2.6	2.3	1.3	1.0	1.3	2.0	2.1	2.3	1.9	2.2	2.7	2.8
30	2.2	1.9	1.0	0.6	0.9	1.5	1.7	1.6	1.6	1.8	2.0	2.4
20	1.9	1.5	0.7	0.5	0.6	0.9	1.4	0.9	1.2	1.4	1.8	1.9
10	1.5	1.2	0.5	0.3	0.4	0.6	0.9	0.7	0.8	1.2	1.4	1.4
1	0.8	0.7	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.7	0.8	0.8
0.1	0.8	0.6	0.2	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.7	0.6

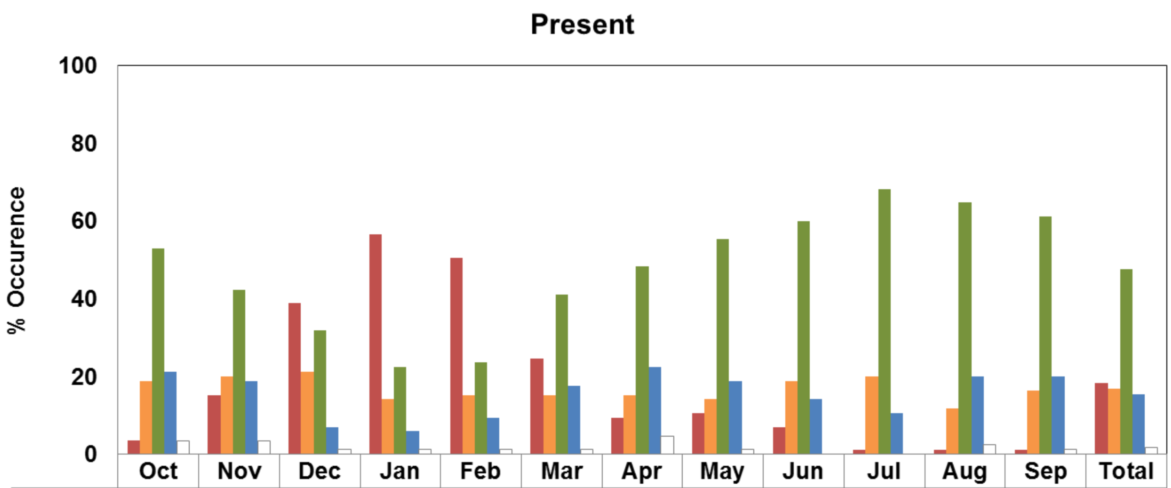
Table 4.2 Summary of the monthly flow (in m^3/s) distribution under the Present State (refer to Table 3.2 for colour coding of abiotic states)

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	23.3	29.7	27.1	15.9	15.9	23.1	30.3	16.9	8.1	10.1	34.9	29.1
99	18.7	22.4	15.9	11.7	12.4	15.3	29.0	14.0	7.5	9.8	26.8	15.3
90	10.9	8.4	4.1	2.9	5.5	6.7	8.6	7.4	5.3	5.1	6.6	7.0
80	5.8	6.4	2.9	1.9	2.7	4.6	6.0	5.0	3.5	3.4	5.4	5.1
70	4.0	4.0	1.6	0.9	1.5	3.2	3.7	3.5	2.9	2.5	3.8	3.9
60	2.9	2.7	1.0	0.4	0.6	2.7	2.9	2.9	2.2	2.2	3.2	3.1
50	2.2	1.9	0.6	0.2	0.3	1.8	2.0	2.4	1.9	2.0	2.5	2.5
40	1.6	1.2	0.3	0.1	0.1	1.1	1.5	1.8	1.5	1.8	2.2	2.1
30	1.3	0.7	0.2	0.0	0.0	0.6	1.2	1.1	1.2	1.4	1.6	1.8
20	0.9	0.4	0.1	0.0	0.0	0.1	0.9	0.5	0.8	1.0	1.3	1.3
10	0.6	0.2	0.1	0.0	0.0	0.0	0.4	0.3	0.4	0.8	0.9	0.7
1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.3
0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.1



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	2	12	7	4	2	0	0	0	0	0	2
State 2	4	7	26	28	27	18	9	25	15	7	4	4	14
State 3	67	61	60	52	52	53	61	51	69	78	71	72	62
State 4	26	28	11	7	13	25	22	24	15	15	24	24	19
State 5	4	4	1	1	1	1	5	1	0	0	2	1	2

Figure 4.1 Occurrence of various abiotic states under the Reference Condition (refer to Table 3.2 for colour coding of abiotic states)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	4	15	39	56	51	25	9	11	7	1	1	1	18
State 2	19	20	21	14	15	15	15	14	19	20	12	16	17
State 3	53	42	32	22	24	41	48	55	60	68	65	61	48
State 4	21	19	7	6	9	18	22	19	14	11	20	20	15
State 5	4	4	1	1	1	1	5	1	0	0	2	1	2

Figure 4.2 Occurrence of the various abiotic states under the Present State (refer to Table 3.2 for colour coding of abiotic states)

Table 4.3 Simulated monthly flows (in m³/s) for the Reference Condition (refer to Table 3.2 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	2.1	1.5	5.2	1.7	8.2	4.1	8.4	3.4	6.2	3.9	4.1	3.6
1921	1.7	0.7	2.7	7.3	2.8	6.9	3.0	1.5	1.4	2.8	2.1	1.3
1922	2.0	4.4	1.3	0.8	0.6	0.2	6.3	7.0	5.1	2.7	1.9	1.1
1923	3.3	4.6	1.2	0.5	1.3	0.7	0.7	0.7	1.8	1.3	6.6	2.8
1924	1.2	2.5	1.4	0.6	0.3	4.0	1.7	0.6	2.7	1.8	1.5	3.8
1925	3.6	2.5	0.9	0.8	0.5	1.2	2.1	1.0	1.1	3.1	3.0	2.8
1926	8.7	5.2	1.0	0.2	1.5	1.7	1.3	2.7	1.6	0.8	3.1	1.6
1927	0.8	2.6	1.2	0.6	0.4	8.1	2.7	0.8	1.1	0.9	2.3	4.1
1928	1.9	32.2	14.7	1.9	1.5	2.0	1.6	3.0	2.3	7.2	6.1	3.2
1929	2.2	0.9	1.8	1.0	17.4	7.8	2.1	4.4	2.6	1.4	2.4	2.1
1930	4.9	1.9	0.4	1.1	0.6	7.5	11.0	3.5	1.2	5.3	3.4	3.1
1931	8.9	3.2	10.5	3.6	5.1	2.4	0.6	0.8	1.7	1.9	1.4	31.6
1932	11.3	2.2	0.7	0.2	1.3	2.0	0.9	3.5	2.1	1.3	7.3	3.1
1933	0.8	7.8	2.3	3.8	4.0	6.8	2.2	0.5	0.3	4.6	4.8	2.8
1934	24.8	13.9	2.3	0.3	0.4	1.9	2.2	8.0	6.8	3.3	2.0	4.7
1935	3.0	4.9	2.3	0.6	1.4	0.9	0.4	3.2	1.4	2.5	1.6	4.7
1936	3.4	18.1	8.1	1.9	0.5	6.4	2.2	0.4	0.8	1.9	1.2	2.9
1937	1.3	2.3	4.5	2.4	0.6	3.7	3.8	1.5	1.3	1.9	1.5	2.4
1938	3.9	8.5	3.4	1.3	4.2	10.3	3.9	1.0	0.5	3.1	12.4	5.9
1939	2.4	1.9	0.6	1.6	12.6	5.4	3.9	1.8	1.3	1.1	0.7	2.6
1940	1.5	6.6	1.9	1.6	0.9	0.5	7.9	3.4	3.7	2.5	2.7	3.3
1941	6.0	3.2	1.5	3.0	1.2	2.0	1.9	2.8	2.0	1.3	1.3	2.0
1942	2.3	1.2	3.2	9.5	4.0	1.6	1.3	0.6	0.4	0.4	1.6	8.4
1943	3.6	9.2	3.5	0.5	0.2	3.8	1.8	5.4	3.3	3.0	3.6	7.3
1944	5.3	1.6	0.3	0.2	0.2	0.3	0.7	7.3	6.0	3.0	4.3	3.9
1945	7.6	2.7	0.5	0.3	0.7	12.1	4.1	0.6	0.7	1.5	1.8	1.4
1946	1.6	1.3	0.4	0.1	1.6	12.5	5.7	3.4	2.3	5.0	2.4	3.6
1947	3.2	3.2	0.9	3.2	1.2	5.0	6.3	2.0	1.0	1.3	0.9	2.4
1948	13.3	5.0	0.7	1.7	0.8	0.2	1.7	3.5	1.6	1.1	1.0	1.2
1949	0.9	12.4	3.6	0.4	0.2	0.2	2.1	1.8	0.8	2.4	2.7	2.3
1950	6.2	8.7	2.6	11.6	4.5	3.3	1.5	2.0	3.1	7.5	4.2	7.8
1951	3.3	0.8	0.2	1.7	1.7	0.6	1.4	0.9	0.9	1.2	3.0	11.0
1952	4.7	7.3	3.0	1.2	2.0	0.7	2.3	1.0	1.9	8.0	4.3	6.1
1953	6.8	5.3	1.3	0.2	0.2	2.0	7.0	11.5	4.9	3.2	12.6	5.4
1954	1.6	2.8	0.9	3.1	11.5	3.0	0.8	0.8	1.4	2.3	3.2	3.8
1955	2.7	2.2	0.7	0.5	0.6	4.1	2.3	8.8	3.8	2.4	3.0	2.5
1956	6.1	2.2	5.0	1.5	3.6	2.6	1.4	4.1	9.0	5.0	5.8	8.8
1957	5.0	1.5	0.3	0.2	0.3	5.3	3.4	18.3	7.7	1.9	7.0	3.7
1958	3.0	1.6	0.8	4.1	7.0	7.0	11.0	7.7	3.0	10.5	8.5	4.1
1959	9.3	3.4	0.6	1.4	1.0	3.7	2.6	3.5	3.7	2.9	1.9	2.9
1960	1.9	4.2	4.4	3.9	2.0	2.4	2.1	3.5	2.1	2.9	4.0	3.7
1961	5.2	2.4	0.5	1.3	3.1	5.1	4.3	1.8	1.7	1.4	26.1	9.1
1962	9.0	9.0	2.2	2.2	0.8	7.4	3.9	3.3	1.6	3.1	1.9	0.9
1963	2.9	2.3	4.6	3.4	2.2	4.0	1.7	0.9	7.0	3.0	4.8	7.9
1964	4.6	3.7	1.1	0.6	2.5	3.5	3.0	5.3	2.5	2.0	2.4	1.4
1965	12.4	10.6	4.1	2.6	0.8	1.4	1.8	6.1	2.8	1.3	9.3	7.5
1966	2.5	0.7	0.3	0.4	2.1	5.5	31.6	14.3	5.7	5.5	4.4	5.8
1967	2.6	3.5	1.1	0.2	0.2	1.5	2.4	4.3	7.5	2.8	6.5	4.1
1968	2.2	5.5	1.5	0.4	1.2	1.0	1.5	0.9	5.0	2.6	2.8	2.0
1969	1.4	0.7	0.2	1.2	3.1	0.9	0.2	0.3	0.9	1.3	5.3	2.2
1970	2.8	1.2	2.0	0.9	6.3	5.7	8.9	7.1	4.1	11.1	11.4	4.7
1971	2.4	5.8	1.9	0.6	3.9	3.2	4.0	3.9	2.5	2.5	6.3	6.5
1972	2.2	2.3	1.1	0.5	0.3	0.5	1.9	1.6	3.0	2.9	3.4	2.8
1973	1.6	2.0	2.4	4.8	7.4	6.6	1.9	8.5	3.6	1.1	6.4	4.6
1974	2.3	2.2	0.6	1.5	0.7	0.7	0.9	2.7	3.5	3.9	7.6	8.6
1975	3.3	3.8	1.9	1.0	4.1	4.8	3.8	4.0	8.3	5.9	3.3	3.2
1976	12.2	7.9	2.8	0.7	8.7	3.7	3.4	13.3	6.2	2.7	2.9	3.4
1977	3.0	4.9	2.4	0.7	0.3	0.8	3.3	1.6	2.6	2.9	4.2	3.1
1978	3.3	1.9	3.0	1.6	4.4	1.4	0.3	3.6	2.1	8.3	7.3	6.0
1979	4.7	1.9	2.5	2.5	1.4	0.6	1.2	0.7	2.8	1.5	2.0	3.0
1980	3.5	11.8	4.1	17.2	12.1	10.9	20.4	11.0	3.9	3.8	12.0	5.6
1981	2.0	1.3	4.5	1.4	1.7	2.9	29.7	9.0	3.5	4.5	4.2	9.5
1982	4.8	1.6	0.9	0.3	1.8	0.7	1.3	4.4	5.7	6.2	3.2	7.3
1983	4.0	5.1	1.8	0.6	1.4	3.8	1.8	0.9	0.8	2.5	1.5	0.8
1984	2.9	1.4	1.0	8.7	7.4	1.8	5.0	2.0	2.7	8.6	3.8	1.4
1985	12.4	8.4	4.9	1.3	1.4	1.4	1.4	0.7	0.5	0.9	37.0	13.2
1986	6.6	3.3	0.8	0.3	0.4	0.7	10.5	3.7	2.3	1.8	4.4	5.6
1987	2.3	0.6	1.9	0.7	0.4	2.3	7.3	2.7	2.9	2.3	3.2	2.4
1988	2.3	1.2	2.9	2.4	1.3	2.9	9.6	3.1	1.6	1.5	2.2	1.6
1989	13.6	9.1	1.8	0.3	2.0	1.3	12.1	5.6	6.0	2.8	1.7	1.5
1990	2.0	1.4	1.8	2.7	3.7	1.2	0.4	0.8	0.9	1.2	0.9	0.6
1991	19.0	6.0	1.9	1.3	2.2	2.1	1.4	1.4	4.1	4.7	3.0	2.5
1992	12.9	9.6	2.3	0.6	0.8	0.5	16.8	7.6	2.5	2.2	2.6	4.8
1993	2.2	1.1	6.2	2.2	2.9	3.0	3.3	1.9	1.8	2.2	7.1	4.0
1994	3.9	1.4	9.1	3.2	3.4	4.6	5.9	6.1	2.6	1.6	1.8	2.7
1995	1.8	13.0	14.4	4.1	0.9	2.6	1.2	0.5	0.4	2.4	1.2	1.9
1996	8.8	22.1	6.2	0.5	1.4	3.6	2.9	4.8	3.4	5.7	5.5	2.6
1997	1.4	1.6	0.6	1.5	1.7	7.8	7.3	4.1	2.0	2.2	1.9	1.4
1998	1.0	3.8	4.2	3.1	5.2	4.1	3.1	1.8	1.1	1.7	1.4	2.4
1999	4.4	1.5	0.7	5.5	2.5	14.7	4.7	4.0	1.8	0.9	1.0	1.0
2000	1.9	4.3	2.7	0.9	0.4	1.8	6.9	2.5	0.8	0.7	5.0	3.0
2001	1.7	3.4	1.1	1.7	1.8	0.5	1.7	2.9	2.1	2.4	4.6	4.8
2002	1.8	1.2	1.7	1.6	0.9	25.7	9.3	9.0	4.2	1.9	3.3	1.9
2003	5.1	1.8	0.5	1.7	2.9	1.6	6.8	2.9	1.9	2.4	1.7	1.9
2004	16.2	5.3	29.3	11.3	1.6	2.8	8.0	5.1	4.4	2.0	2.0	1.5

Table 4.4 Simulated monthly flows (in m^3/s) for the Present State (refer to Table 3.2 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	1.3	0.6	4.2	0.5	7.3	3.2	7.7	2.9	5.6	3.4	3.6	3.0
1921	0.7	0.1	1.5	6.4	1.4	6.2	2.4	1.1	1.0	2.3	1.6	0.6
1922	1.2	3.4	0.2	0.0	0.0	0.0	5.1	6.2	4.3	2.2	1.4	0.4
1923	2.5	3.6	0.2	0.0	0.0	0.0	0.1	0.3	1.3	0.9	5.7	2.0
1924	0.3	1.5	0.2	0.0	0.0	3.0	1.1	0.2	2.2	1.3	1.0	3.1
1925	2.7	1.4	0.1	0.0	0.0	0.2	1.6	0.5	0.7	2.5	2.4	2.2
1926	7.9	4.0	0.2	0.0	0.1	0.8	0.9	2.1	1.2	0.4	2.5	0.8
1927	0.1	1.5	0.1	0.0	0.0	6.8	2.0	0.4	0.8	0.5	1.8	3.4
1928	0.8	30.5	13.5	0.6	0.3	1.2	1.2	2.4	1.8	6.4	5.3	2.5
1929	1.3	0.2	0.6	0.1	16.2	6.9	1.6	3.8	2.2	1.0	1.9	1.4
1930	4.1	0.7	0.0	0.0	0.0	6.4	10.1	2.8	0.8	4.7	2.9	2.6
1931	8.1	1.9	9.8	2.3	4.0	1.5	0.1	0.3	1.3	1.4	0.9	30.6
1932	10.2	1.0	0.1	0.0	0.1	1.0	0.4	2.9	1.7	0.9	6.5	2.2
1933	0.3	6.7	1.0	2.9	2.8	6.0	1.5	0.1	0.0	3.8	4.1	2.1
1934	23.8	12.8	0.9	0.0	0.0	0.9	1.7	7.1	6.0	2.8	1.4	4.1
1935	2.1	4.0	1.1	0.0	0.1	0.1	0.0	2.4	1.0	2.0	1.1	4.0
1936	2.4	17.0	6.9	0.8	0.0	5.5	1.5	0.1	0.4	1.4	0.6	2.4
1937	0.3	1.3	3.5	1.3	0.0	2.7	3.3	1.1	0.9	1.4	1.1	1.8
1938	3.1	7.5	2.2	0.2	3.1	9.5	3.3	0.5	0.2	2.6	11.4	5.1
1939	1.4	0.9	0.1	0.4	11.6	4.5	3.5	1.2	1.0	0.8	0.3	2.0
1940	0.5	5.6	0.6	0.6	0.1	0.0	6.9	2.8	3.1	2.0	2.2	2.7
1941	5.2	2.0	0.4	2.0	0.1	1.1	1.5	2.3	1.5	0.9	0.8	1.5
1942	1.5	0.2	2.0	8.6	2.6	0.7	0.9	0.2	0.1	0.1	1.2	7.4
1943	2.5	8.3	2.2	0.1	0.0	2.7	1.3	4.7	2.7	2.5	3.0	6.4
1944	4.3	0.6	0.1	0.0	0.0	0.0	0.1	6.1	5.2	2.5	3.6	3.2
1945	6.7	1.4	0.1	0.0	0.0	10.8	3.4	0.2	0.3	1.1	1.4	0.8
1946	0.8	0.3	0.0	0.0	0.3	11.2	5.0	2.8	1.8	4.3	1.7	3.0
1947	2.4	2.2	0.1	2.0	0.2	4.1	5.6	1.4	0.7	1.0	0.4	1.9
1948	12.4	3.8	0.2	0.5	0.0	0.0	1.1	3.0	1.1	0.8	0.6	0.6
1949	0.1	11.3	2.1	0.0	0.0	0.0	1.4	1.3	0.3	1.9	2.2	1.7
1950	5.4	7.6	1.3	10.8	3.1	2.6	0.9	1.6	2.5	6.7	3.5	7.0
1951	2.2	0.3	0.0	0.5	0.4	0.0	0.8	0.5	0.5	0.8	2.5	9.9
1952	3.6	6.3	1.8	0.2	0.8	0.0	1.7	0.5	1.4	7.2	3.7	5.3
1953	5.9	4.2	0.4	0.0	0.0	0.9	6.1	10.5	4.3	2.7	11.7	4.6
1954	0.9	1.7	0.2	1.9	10.5	1.9	0.3	0.4	1.0	1.9	2.6	3.2
1955	1.8	1.1	0.1	0.0	0.0	3.0	1.8	7.9	3.2	2.0	2.5	1.9
1956	5.2	0.9	4.1	0.3	2.4	1.8	1.0	3.5	8.1	4.4	5.1	8.0
1957	4.1	0.6	0.1	0.0	0.0	4.1	2.9	17.3	7.1	1.4	6.4	2.9
1958	2.2	0.4	0.2	2.9	5.9	6.1	10.1	7.0	2.4	9.8	7.7	3.4
1959	8.5	2.0	0.2	0.3	0.2	2.7	2.1	2.9	3.1	2.4	1.4	2.3
1960	0.9	3.3	3.3	2.8	0.7	1.6	1.6	3.0	1.7	2.4	3.4	3.0
1961	4.3	1.3	0.1	0.2	1.9	4.3	3.7	1.3	1.3	1.0	25.1	8.0
1962	8.3	8.0	0.8	1.2	0.1	6.5	3.3	2.7	1.2	2.6	1.4	0.3
1963	1.9	1.2	3.6	2.3	1.0	3.3	1.2	0.5	6.2	2.4	4.1	7.0
1964	3.7	2.7	0.3	0.0	1.1	2.8	2.5	4.6	2.0	1.6	1.9	0.7
1965	11.5	9.6	2.9	1.6	0.0	0.5	1.4	5.4	2.3	0.9	8.5	6.7
1966	1.4	0.2	0.0	0.0	0.6	4.5	30.5	13.4	5.1	4.8	3.9	5.1
1967	1.6	2.5	0.2	0.0	0.0	0.5	1.8	3.6	6.6	2.1	5.8	3.3
1968	1.3	4.5	0.3	0.0	0.1	0.1	1.0	0.5	4.3	2.1	2.3	1.3
1969	0.5	0.1	0.0	0.0	1.8	0.0	0.0	0.0	0.4	0.8	4.4	1.2
1970	2.0	0.2	0.8	0.0	5.0	4.8	8.1	6.3	3.4	10.1	10.4	3.9
1971	1.5	4.9	0.6	0.1	2.6	2.4	3.5	3.3	2.0	2.0	5.5	5.7
1972	1.0	1.4	0.1	0.0	0.0	0.0	1.2	1.1	2.4	2.3	2.8	2.1
1973	0.7	0.9	1.3	3.8	6.2	5.8	1.2	7.7	3.1	0.6	5.8	3.9
1974	1.4	1.1	0.1	0.3	0.0	0.0	0.3	2.2	2.9	3.2	6.6	7.6
1975	2.1	2.8	0.8	0.1	2.9	4.0	3.2	3.4	7.4	5.2	2.8	2.6
1976	11.4	6.7	1.7	0.1	7.5	2.7	3.0	12.4	5.5	2.2	2.4	2.9
1977	2.1	3.9	1.2	0.1	0.0	0.1	2.5	1.1	2.2	2.4	3.6	2.4
1978	2.4	0.8	1.9	0.4	3.3	0.4	0.0	2.8	1.6	7.4	6.4	5.2
1979	3.8	0.7	1.4	1.5	0.2	0.0	0.7	0.3	2.2	1.0	1.5	2.4
1980	2.7	10.8	2.8	16.4	10.9	10.1	19.5	10.1	3.5	3.3	11.2	4.9
1981	1.1	0.5	3.3	0.3	0.4	2.1	28.7	8.3	3.1	3.9	3.6	8.6
1982	3.8	0.5	0.2	0.0	0.3	0.1	0.7	3.8	5.1	5.4	2.5	6.5
1983	3.0	4.1	0.6	0.1	0.1	2.9	1.2	0.5	0.5	2.0	1.0	0.3
1984	2.0	0.2	0.1	7.6	6.1	0.8	4.4	1.5	2.2	7.7	3.1	0.8
1985	11.4	7.3	3.7	0.3	0.2	0.4	1.0	0.2	0.2	0.5	35.8	12.3
1986	5.8	2.1	0.2	0.0	0.0	0.0	9.2	3.1	1.9	1.4	3.7	4.8
1987	1.2	0.1	0.6	0.0	0.0	1.2	6.5	2.2	2.3	1.8	2.7	1.7
1988	1.5	0.3	1.7	1.3	0.1	2.0	8.7	2.4	1.2	1.1	1.8	0.9
1989	12.6	7.9	0.5	0.0	0.5	0.4	11.2	4.9	5.3	2.2	1.3	0.9
1990	1.1	0.2	0.8	1.6	2.5	0.2	0.1	0.3	0.6	0.8	0.3	0.1
1991	17.7	4.5	0.8	0.2	1.0	1.3	0.9	1.0	3.5	4.0	2.4	1.8
1992	11.9	8.5	1.1	0.1	0.1	0.1	15.4	6.9	2.1	1.8	2.1	4.1
1993	1.1	0.2	5.1	0.9	1.7	2.1	2.8	1.4	1.4	1.7	6.3	3.2
1994	3.1	0.3	8.0	1.9	2.2	3.8	5.2	5.3	2.1	1.2	1.4	2.1
1995	0.8	12.1	13.5	2.8	0.1	1.6	0.6	0.1	0.1	1.8	0.6	1.3
1996	7.9	20.9	4.7	0.2	0.1	2.6	2.4	4.1	2.8	4.9	4.7	1.9
1997	0.6	0.4	0.1	0.2	0.3	7.0	6.5	3.5	1.5	1.8	1.4	0.7
1998	0.2	2.6	3.0	1.9	4.0	3.1	2.6	1.3	0.7	1.3	0.9	1.8
1999	3.5	0.2	0.0	4.2	1.1	13.6	4.0	3.3	1.3	0.6	0.6	0.4
2000	1.1	3.2	1.5	0.0	0.0	0.7	6.0	1.9	0.4	0.4	4.2	2.2
2001	0.7	2.3	0.1	0.5	0.5	0.0	1.0	2.3	1.6	1.9	3.9	4.0
2002	0.7	0.2	0.4	0.5	0.0	24.0	8.6	8.1	3.6	1.6	2.8	1.1
2003	4.3	0.4	0.1	0.4	1.6	0.7	6.0	2.3	1.4	1.9	1.1	1.3
2004	15.1	3.7	28.3	9.9	0.4	1.8	7.1	4.4	3.8	1.5	1.6	0.8

4.1.1.1 Low flows

River inflows did not decrease below 0.5 m^3/s for more than 5% of the time under the Reference condition thereby maintaining the REI zone in the upper reaches of the estuary. Under the Present State, flows below 0.5 m^3/s occur between 20 and 30% of the time **(Table 4.5).**

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

Percentile	Monthly flow (m^3/s)		% remaining
	Natural	Present	
30%	1.6	0.8	50.1
20%	1.2	0.3	28.5
10%	0.7	0.1	11.9
% Similarity in low flows			**30.2**

4.1.1.2 Flood regime

No large dams are present in the Goukou catchment. Any changes in the flood regime of the system would be mostly related to the Korente-Vet dam and numerous smaller farm dams, land-use change and associated catchment permeability. No flood analysis was done for this study, but an evaluation of the simulated monthly flow data shows that flood events occur relatively untransformed from Reference Condition to Present State, i.e. about a 5% change from Reference condition (**Table 4.6**).

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

Date	Monthly volume (million m^3/month)		% remaining
	Natural	Present	
Aug 1986	98.98	96.00	96.99
Nov 1928	83.43	78.95	94.63
Apr 1967	81.82	79.00	96.55
Sep 1932	81.82	79.36	97.00
Dec 2005	78.36	75.92	96.89
Apr 1982	77.05	74.49	96.68
Aug 1967	70.02	67.15	95.90
Mar 2003	68.73	64.30	93.55
Oct 1934	66.43	63.73	95.93
Nov 1996	57.26	54.11	94.49
Apr 1981	52.83	50.59	95.75
Oct 1991	50.98	47.40	92.98
May 1958	49.10	46.26	94.21

Date	Monthly volume (million m^3/month)		% remaining
	Natural	Present	
Nov 1936	46.89	44.01	93.86
Jan 1981	46.09	43.85	95.15
Apr 1993	43.50	39.79	91.46
Oct 2004	43.48	40.45	93.05
Feb 1930	42.54	39.64	93.19
Dec 1929	39.41	36.21	91.88
% Similarity in floods			**94.6**

4.1.1.3 Fountains and seeps

In addition to the direct river run-off to the Goukou Estuary, there are also numerous fountains and seeps that provide supporting freshwater habitats (in the form of fountains above and in the EFZ) and associated freshwater micro-habitats along the length of the estuary (**Figure 4.3**). The fountains and seeps increase soil moisture of the riparian zone (form a gradient from EFZ to water line) and reduce interstitial soil salinities. This allows for the establishment of brackish species of plants, such as reeds, and associated biota in areas where supratidal, intertidal and the water column salinity would normally exclude them.

At present there are significant pressures on these fountains and seeps, in the form of direct abstraction from fountain heads and small farm dam development. Very little formal records exit of the degree of pressure on this freshwater resource, but the reduction in freshwater input to the system is estimated at between 50% and 70% of the Reference Conditions (Jean De Villiers, CapeNature, pers comm.).

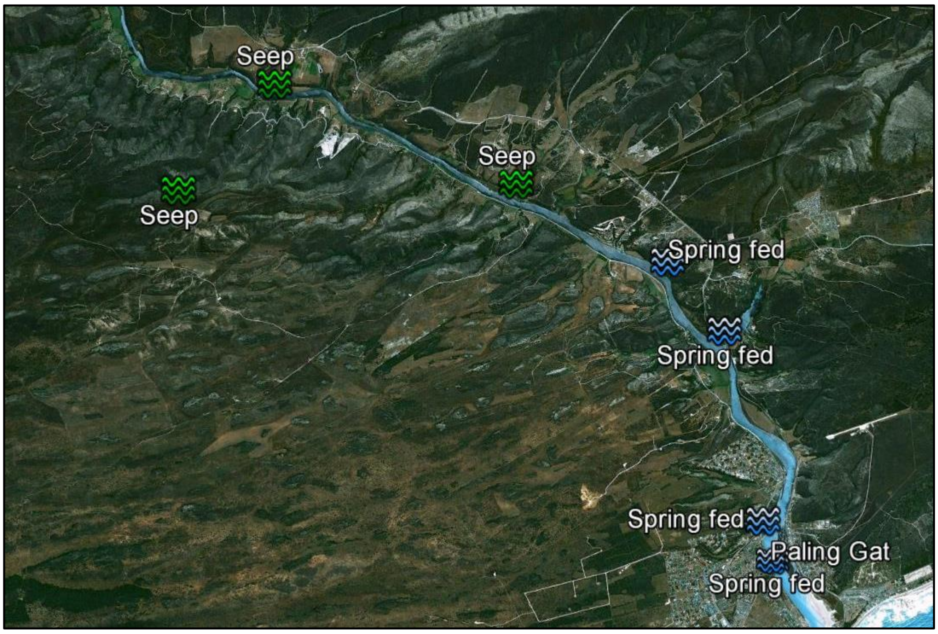


Figure 4.3 Position of some of the fountains and seeps that feed into the Goukou Estuary (Source: J de Villiers, CapeNature)

4.1.2 Hydrological health

Table 4.7 provides the present hydrological health scores of the Goukou Estuary.

Table 4.7 Present hydrological health scores

Variable	Summary of change	Weight	Score	Confidence
a. % Similarity in low flows	Significant increase in the low flow period and reduction in flow rate.	55	30	M
b. % Similarity in flood volumes	The simulated monthly flow data indicate that under Reference Conditions floods were about 5% higher than at present, depending on the size class.	35	95	M
c. % Similarity in freshwater input from fountains and seeps	Significant reduction in the input from fountains and seeps to micro habitats.	10	40	L
Hydrology score weighted mean (a to c)			**54**	**M**

4.2 PHYSICAL HABITAT

4.2.1 Baseline description

The Goukou River delivers a relatively low sediment load into the estuary, most of which is fine sediments that are largely washed out to sea. The significant agricultural activities in the catchment lead to increased land erosion and thus sediment yield to the estuary. From various accounts by observers, it would appear that there may be some progressive sedimentation of the middle and upper reaches of the estuary. These sediments would be of fluvial origin. There are unfortunately no suitable measurements or data available to prove these claims, or to conclusively disprove these perceptions.

Comparative surveys (Jan 1996 vs May 2004) at about the narrowest point in the mouth and 90 m upstream of the mouth shows little difference in the deepest point (almost at -2,5 m MSL). The mouth width in May 2004 appears somewhat narrower than that measured in Jan 1996. However, it should be kept in mind that the sandy eastern bank of the mouth is highly dynamic and constantly changing in response to tidal flows through the mouth, wave action and even wind action. In fact, the estuary mouth is unlikely to close due to sediment deposition. Regular river floods flush out the marine sediment that is deposited within the lower estuary. An additional factor that helps to ensure an open mouth is the occurrence of rocky shelves within the mouth area. These increase turbulence, which hinder the settling of sediment in this area. Thus, it would seem that the combination of a relatively large tidal prism, sufficient river flows and slightly reduced wave energy ensure the permanently open mouth. The wave energy is reduced by wave sheltering from Morris Point as well as the very flat seabed slope across the surf zone seaward of the mouth. The wide surf zone results in breaking of large waves far seaward of the mouth and high wave energy dissipation across the surf zone, which results in relatively lower energy and sediment transport at the mouth itself. Thus, if floods are not reduced (e.g. due to anthropogenic actions), the estuary mouth should not be in danger of closing. If there is a long-term net ingress of marine sediment (which is probable), then the only way for a long-term equilibrium to be maintained, is by means of large river floods which would on occasion flush out this sediment. In the lower part of the estuary, flow velocities and sediment transport potential during an about 1 in 10 year river flood were not even as high as during spring tides. It seems that a flood with a significantly greater return period would be required to affect large scale scouring of the sandbanks in the lower Goukou Estuary.

Besides river flow, the main hydraulic driver in the estuary is the ocean tide. A more than ample supply of marine sediment is present at the Goukou Estuary mouth, for potential transport into the estuary. Thus, the amount of marine sediment intrusion into the estuary is mainly dependent on the (nett) transport capacity of the ebb and flood tidal flows near the mouth, and not on the amount of sediment available outside of the mouth. During neap tides maximum velocities are low with very little transport, while both velocities and transport increase towards spring tides. In low river flow periods, the net sediment transport in the estuary relies on a subtle balance between dominant flood and ebb tide flows.

Comparisons of sediment sample grain size data from December 2013 with that of a previous sediment survey conducted in 2001 could not identify any distinct shift in the marine/riverine sediment balance.

Pertinent impacts on physical drivers and morphologic and sediment dynamics characteristics include (see **Appendix A** for further detail):

- Road, riparian and instream infrastructure
- Water abstraction from the river catchment
- Sediment input from the river catchment
- Alien vegetation in the supra-tidal zone
- Clearing of riparian vegetation, agricultural livestock grazing and trampling
- Power-boating and water-skiing.

4.2.2 Physical habitat health

Table 4.8 provides the present physical habitat health scores of the Goukou Estuary.

Table 4.8 Present physical habitat scores, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related factors

Variable		Summary of change	Score	Confidence
a	% similarity in supratidal area	Overall the supratidal geophysical habitat areas in all zones of the estuary (upper, middle & lower) have been moderately transformed from Reference Condition in terms of sediment & morphologic characteristics, and have in all zones locally been significantly changed, mainly by anthropogenic actions and developments, as summarised below: 1. In limited areas existing road infrastructure encroaches on both banks of the Goukou Estuary and floodplain; thus these habitat areas have been permanently lost. (-5) The	65	L/M

Variable		Summary of change	Score	Confidence
		road bridge (and abutments) between Stilbaai east and west has minimal influence on tidal flows and only limited direct impact on adjacent bank and supra-tidal habitat in terms of stabilisation and build-up of these areas. (-3) 2. Saltmarshes and natural riparian vegetation in the Goukou system have been, and continue to be, degraded or replaced by low-lying developments and infrastructure. They therefore directly encroach on parts of the supra-tidal habitat along the estuary, which also reduces the mitigating effect that natural vegetation provides against erosion due to wave attack (caused by wind action and boating) and flood scouring. (-5) 3. Invasive alien plant species have colonized some channel banks and floodplain areas. These may significantly hinder "natural" bank erosion during floods, allowing for compaction/consolidation of sediments and further establishment of "permanent" vegetation, with associated dampening of natural channel variability. (-5) 4. Alien vegetation on the spit on the eastern side of the mouth led to major accumulation of wind-blown sand and dune build up resulting in stabilisation of the spit and prevention of mouth breaching towards the eastern side or periodic flushing of sediment from the eastern side of the mouth during large floods. (-5) 5. Felled alien vegetation (from both the catchment and estuarine environment) that is not removed from floodplains litters the estuary banks in some places, and can reduce the flow onto and natural deposition of sediment on supra-tidal areas during floods. (-2) 6. The clearing of endemic riparian vegetation (e.g. to gain access for recreation) leaves the Goukou Estuary's banks vulnerable to intensified erosion. (-5) The burning of reeds and sedges for grazing purposes often poses a similar risk of intensified erosion. Saltmarshes and natural wetlands are also damaged by domestic animal grazing and trampling. This leads to direct habitat destruction, increased sediment input into the estuary and ultimately amplified bank erosion. (-5)		
b	% similarity in area of intertidal sand- and mudflats	Overall the intertidal geophysical habitat areas in all zones of the estuary (upper, middle & lower) are still relatively similar to Reference Condition in terms of sediment & morphologic characteristics, but have in all zones been significantly changed, mainly by anthropogenic actions and developments, as summarised below: 1. Instream infrastructure (e.g. jetties and slipways) interferes with the natural hydro & sediment-dynamics of the Goukou Estuary and sometimes causes localised bank erosion (typically directly adjacent to the structure) usually during	65	L/M

Variable		Summary of change	Score	Confidence
		river floods. Artificial bank stabilization (e.g. gabions, riprap, and concrete amour units such as Waterloffel blocks) has a similar effect and replaces natural habitat areas. (-5) 2. Vessel/boat induced waves (also "wake" waves) from speeding or deeper draught boats leads to increased potential for bank erosion exceeding the occasional natural erosion due to wind waves and tidal flows. (-5) 3. The decreased floods (~-5%) are likely to result in slightly increased fluvial sedimentation in the upper reaches of the estuary and slightly increased marine sediment ingress into the lower estuary (in terms of the average regime over decadal to longer term time scales). (-5) The small dams will preferentially trap a larger proportion of the coarser sediments, but have very low sediment trapping efficiency and capacity. (-5) 4. The significant agricultural activities in the catchment lead to increased land erosion and thus sediment yield (especially fines) to the estuary. (-5) 5. The effects of alien vegetation, felled vegetation and clearing of endemic vegetation partial impact within the intertidal area in the long term. (-10)		
c	% similarity in area of subtidal/submerged sand and mud substrates	Overall the subtidal geophysical habitat areas in all zones of the estuary (upper, middle & lower) are still relatively similar to Reference Condition in terms of sediment & morphologic characteristics, but have in all zones been significantly changed, mainly by anthropogenic actions and developments, as summarised below: 1. The effect points 1 to 8 in (b) above in the long-term also have a partial impact within the subtidal area. (-10 + -3) 2. The effects of points 9 & 10 in (b) above in the long-term also have a direct impact within the subtidal area. (-15)	72	L/M
d	% similarity in bathymetry (indirectly estuary water volume)	Overall the bathymetry in all zones of the estuary (upper, middle & lower) is probably still relatively similar to Reference Condition, but has in all zones been somewhat reduced, mainly by anthropogenic actions and developments, as summarised below: 1. Encroachment into the estuary by development, roads, infrastructure, etc. (-5) 2. The decreased floods are likely to result in slightly increased fluvial sedimentation in the upper reaches of the estuary and slightly increased marine sediment ingress into the lower estuary (in terms of the average regime over decadal to longer term time scales). (-5) 3. Stabilisation of the spit and prevention of mouth breaching towards the eastern side or periodic flushing of sediment from the eastern side of the mouth during large floods. (-2) 4. The significant agricultural activities in the catchment lead to increased land erosion and thus sediment yield	85	L

Variable		Summary of change	Score	Confidence
		(especially fines) to the estuary leading to relatively increased sedimentation on average. (-3)		
Physical habitat score (min a to d)			**65**	**L**
% of impact due to non-flow factors			86	
Adjusted score			95	L

4.3 HYDRODYNAMICS

4.3.1 Baseline description

A summary of the hydrodynamic characteristics in the Goukou Estuary for each of the abiotic states is presented in **Table 4.9**.

Table 4.9 Summary hydrodynamic characteristics of various abiotic states

Parameter	State 1: Marine dominated, no REI	State 2: Full gradient	State 3: Partial gradient	State 4: Limited gradient	State 5: Freshwater dominated
Flow range (m^3/s)	< 0.3	0.3-1.0	1.0-5.0	5.0-15.0	> 15.0
Mouth condition*	Open	Open	Open	Open	Open
Water level (m to MSL)	1.5	1.5	1.5	1.5	3.0 – 4.0 during Floods
Inundation	-	-	-	-	During floods
Tidal range	REF/PRES/SC1&2 1.55-0.5 SC3 1.50-0.5 SC4 1.45-0.5	1.75-0.5	1.75-0.5	1.75-0.5	2.0-0.5
Dominant circulation process	Tide	Tide	Tide	River and tide	River
Water column structure (ΔS)**	Well mixed	Well mixed	Stratified	Stratified	Stratified in lower estuary
	0 | 0 | 0 | 5	0 | 0 | 0 | 10	10 | 20 | 0 | 5	20 | 10 | 0 | 0	10 | 0 | 0 | 0

* Alien vegetation on the spit on the eastern side of the mouth led to major accumulation of wind-blown sand and dune build up resulting in stabilisation of the spit and prevention of mouth breaching towards the eastern side or periodic flushing of sediment from the eastern side of the mouth during large floods. It is possible that on the rare occasions when the mouth migrated further to the east and during low flow periods, that the mouth could then have become more constricted than at present (always on the western side). Possibly the mouth could even have closed on very rare occasions when located towards the eastern side.

**ΔS = difference between the salinity of the surface and bottom water

A summary of the key changes in hydrodynamic characteristics from Reference Condition to Present State is summarised in **Table 4.10.**

Table 4.10 Summary of the key changes in hydrodynamic characteristics from Reference Condition to Present State

Parameter	Change
Mouth condition	Virtually no change as it is a permanently open estuary (except for the possible small effects of the stabilised eastern sand spit at the mouth).
Water level (m to MSL)	Similar to Reference as there has only been a 5% reduction in floods.
Inundation	Small reduction in inundation as a result of the 5% reduction in floods.
Tidal range	Small reduction as a result of the increase in low flow conditions, from an average of 1.74 to 1.7 m as a result of the increase in the State 1 (have a reduced tidal amplitude. (Also possible small effect of the stabilised eastern sand spit at the mouth related to more constriction).
Dominant circulation process	Under the Reference Condition the tide dominated the circulation processes in the estuary process for about 79% of the time. This increased to 83% of the time under the Present State.
Retention	The high retention states (i.e. States 1 and 2) increased from 17% under the Reference Condition to about 35% under the Present State.
Connectivity with riparian area	The Goukou Estuary had a high degree of connectivity with the riparian areas in the form of permanently damp seeps and adjacent fountain habitat, that served, for example, as habitat for eels (Paling gat) and bathing areas for Cape Clawless Otters. Due to the damming and over-abstraction of the surrounding fountains and seeps, the direct riparian connectivity is estimated to be reduced by at least 50%.

4.3.2 Hydrodynamic health

Table 4.11 provides the present hydrodynamic and mouth condition health scores for the Goukou Estuary.

Table 4.11 Present hydrodynamic and mouth state scores, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

Variable		Summary of change	Weight	Score	Confidence
a.	% in mouth condition	Similar to Reference Condition	34	100	M
b.	% similarity in the water column structure	From Reference to Present there has been some loss of stratification in in the lower reaches (Zone A and B) and a slight increase in the upper reaches (Zone D) as a result of decreasing flow.	33	90	M
c	% similarity in water retention time	No data			
d.	% similarity in water level (using tidal amplitude and symmetry	Very similar to Reference.	33	99	M
Hydrodynamic score weighted mean (a to d)				**95**	**M**
% of impact due to non-flow factors				0	
Adjusted score				95	M

4.4 WATER QUALITY

4.4.1 Baseline description

A summary of the water quality characteristics for the various states, in each of the four zones, as well as freshwater micro-habitats for salinity) is presented in **Table 4.12**. This summary was derived from available information on the estuary as presented in the Abiotic Specialist Report (**Appendix A**). A summary of the typical characteristics in each of the Zones, under Reference Condition and Present State is presented in **Table 4.13**.

Table 4.12 Summary of water quality characteristics of different abiotic states (differences in state between Reference Condition and Present State and Future Scenarios – due to anthropogenic influences other than flow – are indicated) (colour coding does not have specific meaning and is only for illustrative purposes)

Parameter	State 1: Marine dominated, no REI	State 2: Full gradient	State 3: Partial gradient	State 4: Limited gradient	State 5: Freshwater dominated
Salinity	Estuary 35 | 32 | 30 | 25 Freshwater micro-habitat Reference: 5-15 Present/Future: 15-35	Estuary 35 | 25 | 15 | 10 Freshwater micro-habitat Reference: 5-15 Present/Future: 15-35	Estuary 30 | 20 | 10 | 0 Freshwater micro-habitat Reference: 5-15 Present/Future: 15-35	Estuary 20 | 10 | 5 | 0 Freshwater micro-habitat Reference: 5-15 Present/Future: 15-35	Estuary 5 | 0 | 0 | 0 Freshwater micro-habitat Reference: 5-15 Present/Future: 15-35
Temperature (^{o}C)	Summer 17- 25, lower temperature in lower reaches (States 1-3) when colder upwelled waters intrude during summer Winter 10 - 20				
pH	7 – 8.2 (usually lower in fresher waters compared with more saline waters)				
DO (mgl/ℓ)	Reference 8 | 8 | 8 | 6* Present/Future 8 | 6 | 6 | 4**	Reference 8 | 8 | 8 | 6* Present/Future 8 | 6 | 6 | 4**	Reference 8 | 8 | 8 | 8 Present/Future 8 | 6 | 6 | 6	Reference 8 | 8 | 8 | 8 Present/Future 8 | 8 | 6 | 6	Reference 8 | 8 | 8 | 8 Present/Future 8 | 8 | 8 | 8
Turbidity (NTU)	Reference 10 | 10 | 10 | 10 Present/Future 10 | 10 | 10 | 10	Reference 10 | 10 | 10 | 10 Present/Future 10 | 10 | 10 | 10	Reference 10 | 10 | 10 | 10 Present/Future 10 | 10 | 10 | 20	Reference 10 | 10 | 10 | 10 Present/Future 10 | 10 | 20 | 20	Reference 20 | 20 | 20 | 20 Present/Future 40 | 40 | 40 | 40
Dissolved inorganic nitrogen (DIN) (µg/ℓ)	Reference 50 | 50 | 50 | 50 Present/Future 50 | 100 | 200 | 100	Reference 50 | 50 | 50 | 50 Present/Future 50 | 100 | 200 | 200	Reference 50 | 50 | 50 | 50 Present/Future 50 | 100 | 200 | 200	Reference 50 | 50 | 50 | 50 Present/Future 100 | 100 | 200 | 200	Reference 100 | 100 | 100 | 100 Present/Future 300 | 300 | 300 | 300

Parameter	State 1: Marine dominated, no REI	State 2: Full gradient	State 3: Partial gradient	State 4: Limited gradient	State 5: Freshwater dominated
Dissolved inorganic phosphate (DIP) (μg/ℓ)	Reference: 10, 10, 10, 10 Present/Future: 10, 20, 20, 20	Reference: 10, 10, 10, 10 Present/Future: 10, 20, 20, 20	Reference: 10, 10, 10, 10 Present/Future: 10, 20, 20, 20	Reference: 10, 10, 10, 10 Present/Future: 20, 20, 20, 20	Reference: 20, 20, 20, 20 Present/Future: 40, 40, 40, 40
Dissolved reactive silicate (DRS) (μg/ℓ)	100, 100, 100, 300	100, 300, 800, 1000	100, 500, 1000, 2000	500, 1000, 2000, 2000	3000, 3000, 3000, 30000

* Depth average DO concentration in stratified water column, with bottom DO 2 mg/ℓ and surface 8 mg/ℓ

**Depth average DO concentration in stratified water column, with bottom DO 2 mg/ℓ and surface 6 mg/ℓ

Table 4.13 Summary of average changes in water quality from Reference Condition to Present State within each of the various zones (colour coding does not have specific meaning and is only for illustrative purposes)

Parameter	Summary of change	Zone	Reference	Present
Salinity	⇧ due to increase in low flow conditions, the loss of the wetlands in the catchments that would have moderated baseflow, loss of fountain and seep surface and subsurface flows	A (lower)	28	30
		B	19	21
		C	10	14
		D (upper)	5	9
		Micro-Habitat	15	30
DIN (µg/ℓ)	⇧ due to agricultural activity in the catchment, especially during high flows (e.g. States 4 and 5)	A (lower)	51	63
		B	51	104
		C	51	202
		D (upper)	51	184
DIP (µg/ℓ)	⇧ due to agricultural activity in the catchment, especially during high flows (e.g. States 4 and 5)	A (lower)	10	12
		B	10	20
		C	10	20
		D (upper)	10	20
Turbidity (NTU)	⇧ due to agricultural activity in the catchment, especially during high flows (e.g. States 4 and 5)	A (lower)	10	11
		B	10	11
		C	10	12
		D (upper)	10	17
DO (µg/ℓ)	⇩ due to increased nutrients (causing increased algal growth) and organic loading from agricultural activity in the catchment	A (lower)	8	8
		B	8	6
		C	8	6
		D (upper)	7*	5**
Toxic substances		80% similar to Reference		

* Bottom water 2 mg/ℓ for ~16% of the time ** Bottom water 2 mg/ℓ for ~35% of the time

4.4.2 Water quality health

The similarity in each parameter (e.g. dissolved oxygen) to Reference Condition was scored as follows:

- Define **zones** along the length of the estuary **(Z)** (e.g. Zones A, B, C and D)
- **Volume fraction** of each zone **(V)** (Salinity: A = 0.25; B = 0.30; C = 0.30, D=0.10, Freshwater Micro-habitat= 5) (Other: A = 0.25; B = 0.35; C = 0.30, D=0.10)
- Different **abiotic states (S)** (i.e. States 1 to 5)
- Define the **flow scenarios** (i.e. Reference, Present, Future scenarios)
- Determine the **% occurrence** of abiotic states for each scenario
- Define **water quality concentration range (C)** (e.g. 6 mg/ℓ; 4 mg/ℓ; 2 mg/ℓ)

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

- Calculate Average concentration for each Zone for Reference and Present/Future Scenarios, respectively
- Average Conc (Z_A) = $[(\{\sum\%$ occurrence of states in $C_1\} * C_1) + (\{\sum\%$ occurrence of states in $C_2\} * C_2) + (\{\sum\%$ 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: $\sum(\min(ref,pres))\ (\sum ref + \sum pres)/2)$

For the final scores, a weighted average of the similarity scores of different zones was computed using the volume fractions (**Table 4.14**).

Table 4.14 Present water quality scores, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

Variable		Summary of change	Weight	Score	Confidence
1	**Salinity in estuary**				
a	Estuary water column	⇧ due to increase in low flow conditions	95	88	M
b	Freshwater micro-habitat	⇧ due to reduction in flow from riparian fountains and seeps above and in EFZ	5	67	L
General salinity in estuary: weighted mean (a,b)			40	87	M
2	**General water quality in estuary**				
a	DIN/DIP concentrations	⇧ due to agricultural activities in catchment (and WWTW), as well as effects of urban runoff along banks (Zones B and C)		67	L
b	Turbidity	⇧ due to agricultural activities in catchment		93	M
c	Dissolved oxygen	⇩ due to agricultural activities in catchment (and WWTW), as well as effects of urban runoff along banks (Zones B and C)		90	M
d	Toxic substances	⇧ due to agricultural activities in catchment, as well as urban runoff in lower reaches		80	L
General water quality in estuary: min (a to d)			60	67	M
Water quality health score: weighted mean (1,2)				**75**	**L/M**
% of impact non-flow related				60	
Adjusted score				95	M

4.5 MICROALGAE

4.5.1 Overview

4.5.1.1 Main grouping and baseline description

The biomass of phytoplankton in the Goukou Estuary ranged from 1.5 to 21.9 µg/ℓ in December 2013, with a median of 5.92 µg/ℓ (Lemley, 2015); the highest concentration was located 11.5 km from the mouth in Zone C. This indicates a medium concentration when compared to other permanently open estuaries (Snow, 2008). The river flow has decreased by 21% from reference and there has been a slight increase in nutrients, particularly during high flows, supporting an increase in microalgal biomass. All measurements by Harrison (unpublished data) in winter 1994 were below detectable limits.

In the Goukou Estuary the flagellate group dominated (> 50% RA) the phytoplankton community in the middle to lower reaches (Zones 1 and 2), with chlorophytes (*Sphaerocystis* sp.) dominant throughout the middle to upper reaches (Zone D). The only exception was at 3.7 km, where blue-green algae (*Symplocastrum* sp.) were dominant (78% RA). It is worthwhile noting that the blue-green algae were confined to the incoming saline water (i.e. from the lower reaches) in the stratified section of the water column. Vertically averaged phytoplankton cell density was lowest in the middle reaches (Zone C; 7.7 km) and peaked in the upper reaches (Zone D; 15.5 km); 177 and 38034 cells ml^{-1} respectively. The middle to upper reaches (11.5 and 15.5 km) exceeded the suggested cell density threshold for bloom conditions (> 20 µg/ℓ).

Average benthic chlorophyll *a* in the Goukou Estuary ranged from 0 to 45.2 mg/m^2 and was significantly lower ($F = 28.25$; $P < 0.001$; df = 4) in the middle to upper reaches (Zone D; Sites 11.5 and 15.5 km) compared to the rest of the system. The average organic content of the sediment within the estuary (ranging from 0.3 to 5.9%) was significantly elevated ($H = 14.84$; $P < 0.05$; $n = 20$) in the lower reaches (Zone A; 0.3 km) compared to the mid to upper reaches (Zone D). No significant ($P > 0.05$) variations were observed between the subtidal and intertidal zones for any of the above parameters. The median intertidal chlorophyll *a* concentration was 24.0 mg m^{-2} in the Goukou Estuary, which is regarded as high (23 to 42 mg/m^2) based on the classification scheme of Snow (2008).

Based on the Masters study by Lemley (2015), the dominant benthic diatom species in the middle and upper reaches of the estuary were typically brackish and tolerant of pollution suggesting that the Goukou Estuary could be regarded as eutrophic. The benthic diatom species richness was 2.35 ± 0.15 and the evenness score 0.74 ± 0.04. These scores are relatively high when compared to other estuaries in the Gouritz WMA.

4.5.1.2 Description of factors influencing microalgae

Table 4.15 summarises the key responses of estuarine microalgae to changes in abiotic and other biotic components, while **Table 4.16** translates these into expected responses within each of the abiotic states (see **Table 3.2**).

Table 4.15 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various microalgae groupings

Variable	Grouping				
	Flagellates	Dinoflagellates	Diatoms	Chlorophytes	Cyanobacteria
Nutrients (N & P)	↑	↑	↓	↑	-
Herbicides	↓	↓	↓	↓	↓
Tidal flushing	↓	↓	↓	↓	↓
Turbidity	↓	↓	↓	↓	↓
Dissolved oxygen	-	-	-	-	↑
Stratification	-	↑	-	-	-

Variable	Grouping			
	Diatoms (Epipelic)	Diatoms (Episammic)	Cyanobacteria	Euglenophytes
Fines (silt & clay)	↑	↓	↑	↑
Organic loading	**-**	**-**	↑	↑
Nutrients (N & P)	↑	↑	↑	↑

Table 4.16 Summary of microalgae responses to different abiotic states

State	Response
Phytoplankton	
1	Very low river flow will result in estuary becoming nutrient depleted and dependent on mineralisation of nutrients from sediment to sustain productivity; only the shallow upper reaches are likely to have elevated chlorophyll *a* (unlikely to exceed 10 µg/ℓ) in response to nutrients in river water. The settling of particulate matter will result in a clear water column and only small phytoplankton cells will be present (diatoms and flagellates). Factors such as competition, herbivory and presence of herbicides will impact on phytoplankton biomass.
2	A full salinity gradient favours the development of a strong REI zone in the upper reaches of the estuary. The estuary, particularly the lower reaches, is likely to be well mixed limiting the dominance of dinoflagellates in the presence of nutrients. The water column should be dominated by flagellates and diatoms (elevated nutrients and high residence time will favour a low diatom:flagellate ratio), and blue-greens (particularly during warm summer months). Factors such as competition, herbivory and presence of herbicides will have an impact on phytoplankton biomass. Optimal residence time; chlorophyll *a* should be elevated and likely to reach bloom concentrations (> 20 µg/ℓ).
3	Partial salinity gradient favours the development of a relatively weak REI zone in the lower and middle reaches of the estuary. Elevated nutrients and stratified water column favour the presence of dinoflagellates. The water column should be dominated by flagellates and diatoms (the diatom:flagellate ratio would have been high in the Reference Condition but is likely to have decreased as a result of elevated nutrients). Residence time is relatively low so phytoplankton biomass is unlikely to exceed 15 µg/ℓ.
4	Low residence time and elevated turbidity override the effects of elevated nutrients; phytoplankton biomass is low (< 5 µg/ℓ) and freshwater species are favoured (e.g. chlorophytes and diatoms). Some intrusion of marine water, particularly during high tides introduces some marine species.

State	Response
Phytoplankton	
5	Very low residence time and extremely high turbidity override the effects of elevated nutrients; phytoplankton biomass is very low (< 3 µg/ℓ) and freshwater species are favoured (e.g. chlorophytes and diatoms)
Benthic microalgae	
1	Extremely low river flow. The benthic microalgae are largely dependent on mineralisation of organic material for nutrients (elevated biomass in regions of the estuary dominated by organic-rich fine muds). Elevated biomass in the organic-rich fines dominated by epipelic microalgae. Coarse sediment at mouth and head of the estuary dominated by episammic microalgae. Euglenophytes and blue-greens present in areas of elevated nutrients (e.g. seeps).
2	Ideal flow rate supporting the deposition of fines and organic material, and supplying water column nutrients. Elevated biomass in areas dominated by organic-rich fines; dominated by epipelic microalgae. Coarse sediment at mouth and head of the estuary dominated by episammic microalgae. Euglenophytes and blue-greens present in areas of elevated nutrients (e.g. seeps).
4	Strong currents that result in scouring of fine sediments and high turbidity override the effects of water column nutrients and sediment characteristics (i.e. presence of fines and organic matter); benthic microalgal biomass is low. Fine sediments scoured from estuary supporting subsequent growth of episammic microalgae on sand particles.
3	Elevated river flow will not support deposition of fine sediments and organic material limiting the growth of benthic microalgae (light not a limiting factor); estuary sediments dominated by episammic and epipelic microalgae (sand and mud environments respectively).
5	Very strong currents that result in scouring of the sediments and extremely high turbidity override the effects of water column nutrients and sediment characteristics (i.e. presence of fines and organic matter); benthic microalgal biomass is very low. Fine sediments scoured from estuary supporting subsequent growth of episammic microalgae on sand particles.

4.5.1.3 Reference Condition

Expected changes in microalgae from the Reference Condition to the Present State is summarised in **Table 4.17**.

Table 4.17 Summary of relative changes from Reference Condition to Present State

Key drivers	Change
Reduced river flow; shift from State 3 to 2 (increased residence time)	Increase in residence time, reduced sediment scouring, decrease in turbidity and sedimentation (particularly in Zone D) supports an increase in microalgal biomass.
Elevated nutrients	Supports microalgal growth and potential loss of pollution intolerant species.
Turbidity	A decrease in turbidity in response to reduced river flow supports microalgal growth.
Loss of stratification	Reduced relative abundance of dinoflagellates.
Reduced floods	Reduced import of coarse sediments supports a shift from episammic to epipelic microalgal species.

4.5.2 Microalgae health

The microalgae health scores for the Present State are presented in **Table 4.18**.

Table 4.18 Present microalgae health score, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

Variable	Summary of change	Score	Confidence
Phytoplankton			
a. Species richness	The mouth of the estuary closes rarely, if at all. There could have been a loss of pollution intolerant species.	95	L
b. Abundance	Nutrient concentrations have increased by ~32% (N & P are not limiting to microalgal growth). A localised chlorophyte bloom (*Sphaerocystis* sp.) in the upper reaches (11.5 km) suggests that flow from seeps contributes nutrients &/or freshwater phytoplankton. A reduction in flow has increased the average residence time of water in the estuary supporting elevated microalgal biomass (States 1 and 2 increased from 17% during reference to 35% at present). Using the scoring templates the predicted change in biomass associated with changes in States is 43%.	57	M
c. Community composition	The reduced river flow (21%) and elevated nutrients (32%) favour a decrease in the diatoms: flagellates ratio, and an increase in dinoflagellates, blue-greens and chlorophytes (53%*0.70); change largely restricted to Zones B, C & D (70%).	63	M
Benthic microalgae			
a. Species richness	The mouth of the estuary closes rarely, if at all. There could have been a loss of pollution intolerant species.	95	L
b. Abundance	The largest factors affecting benthic microalgae are related to catchment flow reductions (incl. flood volume), sediment input (lower coarse sediment) and elevated nutrients. Assuming a 42% increase in biomass related to reduction in river flow (21%), floods (5%) and nutrients (32%*0.5; benthic microalgae dependent on water column and mineralised nutrients).	58	M
c. Community composition	The small decrease in flood volume is likely to have increased sedimentation in the upper reaches, farm dams are likely to have removed some coarse sediment, and the intrusion of marine sediment into the estuary is likely to have increased. The change in community composition related to sediment type (5%) and elevated nutrients (32%*0.5; benthic microalgae dependent on water column and mineralised nutrients) is likely to be 21%.	79	M

Microalgae health score min (a to c)	**57**	**M**
% of impact non-flow related impacts	60	
Adjusted score	83	M

4.6 MACROPHYTES

4.6.1 Overview

4.6.1.1 Main grouping and baseline description

The important macrophyte habitats are the salt marsh, reeds and sedges and submerged macrophytes (**Table 4.19**). The field survey in December 2013 investigated the dominant species in the salt marshes from the mouth to the upper reaches of the estuary. The salt marsh at the mouth on the eastern bank had *Spartina maritima*, *Limonium linifolium*, *Sporobolus virginicus*, *Disphyma crassifolium, Bassia diffusa*, *Cotula coronopifolia* and *Samolus porosus*. Towards the mouth dune vegetation occurred closer to the water at high elevation with a marsh area behind this. The marsh area on the west bank below the mouth consisted mostly of the lower intertidal grass *Spartina maritima*. Above the bridge on the east bank the large marsh and floodplain area has been disturbed by farming. There was clear zonation from the lower intertidal to supratidal zone with 2 m *Spartina maritima*, 1 m *Cotula coronopifolia*, 2 m *Triglochin elongata*, 10 m *Samolus porosus* with *Cotula coronopifolia* and *Limonium linifolium*. The upper intertidal species *Bassia diffusa* was followed by *Sarcocornia pillansii, Disphyma crassifolium* and *Atriplex vestita* along an elevation gradient. The terrestrial habitat was defined by the grass, *Stenotaphrum secundatum*, and where it was drier *Acacia cyclops (*invasive rooikrans) and *Chrysanthemoides monilifera* were abundant.

During the December 2013 survey the beds of *Zostera capensis* found near the mouth were patchy possibly in response to the flooding prior to sampling which would have removed some biomass. However, pondweed *Stuckenia pectinata* occurred in Zone C; the middle-upper reaches of the estuary. This is of significance as this plant grows best at a salinity less than 20.

Freshwater seepage results in pockets of common reed *Phragmites australis* occurring at certain sites such as the launch site on the west bank in the lower reaches. The salt tolerant grass, *Spartina maritima,* grows in front of the reed. *Phragmites australis* which grows best at salinity less than 15 can survive when it is tidally inundated by seawater if its roots are in freshwater (Adams and Bate, 2002). Field studies in the Goukou Estuary showed that surface and interstitial salinity decreased from the water's edge inland which resulted in an increase in plant height. These sites of freshwater seepage create nodes of biodiversity. Van Niekerk *et al*. (2015) described these as freshwater micro-habitats dependent on the input of numerous fountains and seeps.

Veldkornet (unpublished data) studied the distribution and connectivity of estuarine macrophytes and sampled across the salt marsh – terrestrial habitats in the Goukou Estuary and found a specific group of species associated with the fringe habitat. The salt marsh and the terrestrial vegetation had the greatest number of species (18) across all five transects. The fringe had the lowest species richness of ten. In the lower reaches the 'terrestrial' vegetation consisted of strandveld and *Chrysanthemoides monilifera* (bitou bush) was dominant. Transects in the upper reaches of the estuary had thicket vegetation with *Aloe pluridens*, *Sideroxylon inerm*, and *Searsia pterota*. Invasive species (*Acacia cyclops*, *Acacia longifolia* and *Opuntia ficus indica*) occurred in the terrestrial zone. There was a steep decrease in sediment electrical conductivity from the lower intertidal salt marsh to the terrestrial vegetation. The sediment organic content was higher in the terrestrial vegetation compared to the fringe and salt marsh habitats. The salt marsh as expected (sediment moisture content 33-41%) was wetter compared to the fringe and terrestrial habitats (26% and 10.5% respectively).

Table 4.19 Summary of estuarine habitat area in the Goukou Estuary

Habitat type	Defining features, typical/dominant species	2014 area (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	206
Sand and mud banks	Intertidal zone consists of sand/mud banks that are regularly flooded by freshwater inflows. This habitat provides a possible area for microphytobenthos to inhabit.	35
Macroalgae	Macroalgae would be attached as epiphytes to intertidal vegetation. They would also occur attached to rocky substrates.	0
Submerged macrophytes	Plants that are rooted in both soft subtidal and low intertidal substrata and whose leaves and stems are completely submerged for most states of the tide. Species recorded for the Goukou Estuary include *Zostera capensis.* Pondweed, *Stuckenia pectinata,* which is indicative of brackish conditions, was found during the field survey in November 2013.	5
Salt marsh	The following species have been recorded: *Poecilolepis ficoidea, Bassia diffusa, Cotula coronopifolia, Disphyma crassifolium, Limonium linifolium, Samolus porosus, Sarcocornia natalensis, Sarcocornia pillansii, Spartina maritima, Sporobolus virginicus Triglochin striata, buchenaui* and *Triglochin elongata.*	57
Reeds and sedges	The following species have been recorded, and belong to the families Cyperaceae, Juncaceae & Poaceae: *Juncus kraussii*, *Phragmites australis* and *Schoenoplectus scirpoideus*.	21
Floodplain	This is a mostly grassy area which occurs within the 5 m contour line. Also includes dune vegetation at the mouth and riparian vegetation along the middle and upper reaches of the estuary. Most of the area is degraded (89 ha).	126
Total estuarine area		**372**

4.6.1.2 Description of factors influencing macrophytes

Table 4.20 summarises the key responses of estuarine macrophytes to changes in abiotic and other biotic components, while **Table 4.21** translates these into expected responses within each of the abiotic states.

Table 4.20 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various macrophyte groupings

Process	Macrophytes
Mouth condition	Open mouth conditions creates intertidal habitat. There are large areas of intertidal salt marsh on both banks of the estuary, especially on the eastern bank below the road bridge.
Flow velocities (e.g. tidal velocities or river inflow velocities)	Strong tidal flows can limit the establishment of submerged macrophytes in the lower reaches of the estuary.
Total volume and/or estimated volume of different salinity ranges	The longitudinal salinity gradient promotes species richness, different macrophyte habitats are distributed along the length of the estuary, for example salt marsh in the lower reaches and reeds and sedges in the upper reaches.
Floods	Large floods are important in flushing out salts from the salt marsh area and preventing the encroachment of reeds and sedges into the main river channel. Floods are attenuated by the various impoundments in the catchment area.
Salinity	Base flow is sufficient to maintain longitudinal salinity gradients from the mouth to head of the estuary. Different macrophytes are distributed along the longitudinal gradient in the Goukou Estuary.
Turbidity	Increase sediment load within the water column results in a reduction in the photic zone and will limit submerged macrophyte establishment and distribution, as well as phytoplankton production.
Dissolved oxygen	The estuary is well oxygenated.
Nutrients	Increased nutrient inputs would increase macrophyte growth particularly in areas of freshwater seepage (i.e. reeds and sedges). Inputs from septic tanks would stimulate reed growth.
Sediment characteristics (including sedimentation)	Stabilization of sand banks and dunes at the mouth has allowed a large dune / marsh area to develop.
Other biotic components	Grazing and trampling has occurred in certain sections of salt marsh. Invasive plants occur in the riparian zone.

Table 4.21 Summary of macrophyte responses to different abiotic states

<table>
<tr><th>State</th><th>Description</th><th>Response</th></tr>
<tr><td>State 1</td><td>Marine dominated, no REI</td><td rowspan="2">Favourable for growth of salt marsh but persistent conditions would cause die-back of reeds & sedges (salinity of 20 for greater than three months) as well as pondweed, Stukenia pectinata (salinity of 20 for greater than three months).</td></tr>
<tr><td>State 2</td><td>Full salinity gradient</td></tr>
<tr><td>State 3</td><td>Partial salinity gradient</td><td rowspan="2">Favourable for growth of all macrophytes that are distributed along a salinity gradient up the length of the estuary.</td></tr>
<tr><td>State 4</td><td>Limited salinity penetration</td></tr>
<tr><td>State 5</td><td>Freshwater dominated</td><td>Submerged macrophytes and macroalgae lost due to high flow. Very important in inundating salt marshes and reducing salinity. Water level can increase to 3-4 m during floods. Large flood events would remove fringing reeds and sedges.</td></tr>
</table>

4.6.1.3 Reference Condition

A summary of the relative changes in macrophytes in the Goukou Estuary from Reference Condition to Present State is summarised in **Table 4.22**.

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

Key drivers	Change
⇩ River flow ⇧ salinity	⇩ Reed & sedge growth as well as pondweed in upper reaches ⇩ Salt marsh due to salinization and formation of bare areas
⇧ Agriculture, development, disturbance & invasive plants	⇩ Floodplain and salt marsh habitat
⇧ Stabilisation of dunes at mouth	⇧ Salt marsh
TOTAL CHANGE	⇩ Reed & sedges ⇩ Pondweed ~Salt marsh ⇩ Floodplain habitat

4.6.2 Macrophyte health

The health of the macrophytes was assessed in terms of species richness, abundance and community composition. Change in species richness was measured as the loss in the average species richness expected during a sampling event, excluding species thought to not have occurred under Reference conditions. Abundance was measured as the change in area cover of macrophyte habitats. The following was used to measure abundance:

% similarity = 100*present area cover / reference area cover.

Floodplain agriculture (19 ha) and development (70 ha) has disturbed 89 ha of habitat. It is estimated that reeds and sedges covered 30 ha compared to 21 ha for present conditions. This includes loss of micro-habitats at freshwater seepage sites. There has been a decrease in area due to an increase in low flow conditions and salinity. Although salt marsh area increased in cover in the lower reaches of the estuary there would have been an overall loss of this sensitive habitat as a result of removal by development. Invasive plants would not have been present in the reference state but now cover approximately 2 ha. Pondweed (*Stukenia pectinata*) would have covered larger areas in the upper reaches of the estuary under natural conditions compared to present day due to lower salinity.

In total, estuarine habitat covered 505 ha but now covers 366 ha with a 72% similarity in abundance compared to Reference Conditions. There has been a loss of floodplain, salt marsh and reed and sedge habitat. Approximately 40 % of the changes are due to flow related impacts and 60% due to non-flow related impacts (**Table 4.23**).

Change in community composition was assessed using a similarity index which is based on estimates of the area cover of each macrophyte habitat in the reference and Present State. (Czekanowski's similarity index: ∑(min(ref,pres) / (∑ref + ∑pres)/2). The macrophytes are 68% similar to what they were under Reference Conditions (**Table 4.24**).

Table 4.23 Estimate of the area (ha) covered by the different macrophyte habitats for reference and present (2013) conditions

Habitat	Reference	Present (2013)
Floodplain agriculture & development	0	89
Floodplain natural	126	37
Salt marsh	60	57
Reeds & sedges	30	21
Submerged macrophytes (pondweed)	10	5
Mud & sandbanks	73	35
Open water surface area	206	206
Total area	**505**	**366**

Table 4.24 Area covered by macrophyte habitats and calculation of the similarity in community composition for the Goukou Estuary

Habitat	Reference	Present (2013)	Minimum
Floodplain natural	126	37	37
Salt marsh	60	57	57
Reeds & sedges	30	21	21
Submerged macrophytes (pondweed)	10	5	5
Invasive plants	0	5	0
Total area	**226**	**125**	**125**
% similarity Sum min / (sum ref + present) /2	**125/(351/2)**		**68%**

The macrophyte health score for the Present State is presented in **Table 4.25**.

Table 4.25 Present macrophyte health score, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

Variable	Summary of change	Score	Confidence
a. Species richness	Low baseflow and increase in salinity have reduced macrophyte species richness. Development, disturbance and loss of salt marsh and floodplain habitat would also result in loss of species.	80	M
b. Abundance	There has been substantial loss of floodplain habitat due to development and agriculture. Reeds and sedges have lower abundance. There has been some loss of salt marsh area as well as submerged macrophytes. Loss of habitat due to invasive plants.	72	M

Variable	Summary of change	Score	Confidence
c. Community composition	Degraded floodplain has replaced supratidal salt marsh and floodplain areas. Invasive plants are common in the riparian areas and have altered the community composition. There has been loss of reeds, sedges and submerged macrophytes (pondweed)	68	M
Macrophyte health score min (a to c)		**68**	**M**
% of impact non-flow related impacts		60	
Adjusted score		87	M

4.7 INVERTEBRATES

4.7.1 Overview

4.7.1.1 Main grouping and baseline description

Four major invertebrate groups (Mesozooplankton, hyperbenthos, subtidal macrozoobenthos and the intertidal macrozoobenthos) are identified for the purposes of reserve determination studies in estuaries. Unfortunately, documented information on invertebrates from the Goukou Estuary is limited. In the Situation Assessment Report on the Goukou Estuary, the CSIR (2011) noted 19 taxa of plankton. These data were originally collected by Grindley in 1969 and described in Carter and Brownlee (1990). Detail is limited and only non-quantitative descriptive information is provided.

More recent zooplankton collections in the Goukou Estuary are described in Montoya-Maya and Strydom (2009) and include data in a broader study of south coast estuaries. At the time of Montoya-Maya and Strydom’s study (2009) the estuary was freshwater deprived and predominantly euhaline (Salinity 30.0-35.9) throughout. While the species composition is similar to the information provided in Carter and Brownlee (1990), abundance levels were higher. Copepod species included the genus *Acartia,* with abundance exceeding 5000 ind.m^{-3} of water. Two estuarine mysid species *Gastrosaccus brevifissura* and *Mesopodopsis wooldridgei* were also present in the estuary (although numbers did not exceed 100 ind.m^{-3} and are considered low by comparison with other south coast estuaries).

In the December 2013 field study, fifteen hyperbenthic taxa were recorded. Abundance levels were also low compared to other temperate estuaries and are probably a reflection of oligohaline conditions that dominated over much of the estuary at the time. Floods were experienced a few weeks previously and populations were in a recovery phase. Amphipods (*Copophium triaenonyx* and *Grandidierella lignorum*) were the most common taxa and their distributions along the estuary reflect tolerance to low salinity conditions (Wooldridge and Deyzel 2009, Masikane *et al.* 2014). Although mysid shrimps are often the most abundant taxa in the hyperbenthos, numbers in the Goukou were orders of magnitude lower compared to other temperate estuaries probably as a consequence of low salinity conditions at the time of sampling.

The study by Carter and Brownlie (1990) identified 24 macrobenthic taxa, although some are associated with hard substrata near the mouth. Again, information is non-quantitative and descriptive. The report also noted the presence of bloodworm (*Arenicola lovenii*) described as locally common in coarse sand, mud prawns (*Upogebia africana*) in the intertidal at densities up to 20 ind.m^{-2}, sand prawns (*Callichirus kraussi*) in low numbers and pansy shells (*Echinodiscus bisperforatus*) in the lower estuary.

In December 2013 during the field investigation, salinity was < 5 throughout much of the estuary. A total of 17 species belonging to 10 different taxonomic groups was recorded. The mysid shrimp *Gastrosaccus brevifissura* occurred at all sites and numerically dominated the benthic community. Although *Gastrosaccus brevifissura* has limited physiological ability to adapt to lower salinities (Marshall *et al.,* 2003) compared to other estuarine mysids, it is well adapted to regulate its spatial distribution along the estuary (Schlacher and Wooldridge, 1994), even under conditions of relatively strong water flow. This strategy probably aided population recovery following the flood that occurred before the sampling programme commenced.

The low species richness and abundance levels recorded in the current study were probably indicative of loss of organisms due to the flood that passed through the estuary weeks previously.

Ceratonereis keiskama and *Grandidierella lignorum* were fairly abundant in samples and were amoung the few estuarine taxa usually associated with upper estuarine sites where oligohaline conditions prevail (Schlacher and Wooldridge, 1996).

4.7.1.2 Description of factors influencing invertebrates

Table 4.26 summarises response of invertebrates to specific abiotic drivers in the estuary.

Table 4.26 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various invertebrate groupings

Variable	Response of the zooplankton and hyperbenthos
Mouth state	Mouth closure will reduce species richness, since marine species will disappear from the estuary. A closed mouth may also lead to extinction of some species from the estuary.
Turbidity	Under severe turbid conditions, some zooplankton species such as mysid shrimps are no longer able to capture prey successfully (visual predators).
Salinity	A full salinity gradient will increase species richness and enables zonation patterns to develop within communities. Biomass also increases, particularly in the REI. If salinity falls too low (closed mouth for extended periods and salinity falls below 5-10 throughout the estuary), the communities will shift towards a more oligiohaline mix of species. The opposite occurs if salinity values exceed 10 throughout the estuary – the oligohaline community disappears or it is present in the extreme upper limit of the estuary only. If salinity remains euhaline throughout, many zooplankters remain at low levels of abundance.

Variable	Response of the zooplankton and hyperbenthos
Freshwater seeps	The presence of freshwater seeps along the length of the estuary will create nodes or micro-habitats where euryhaline and oligohaline invertebrates become permanently established. Communities associated with seeps (intertidal and subtidal) are therefore different from adjacent areas dominated by euryhaline species at least part of the time. These nodes also provide centres of radiation from which colonization of the main estuary occurs as salinity decreases in the adjacent water body.
Floods	Floods will flush populations from the estuary, particularly zooplankton – recovery in some cases will be relatively slow. Sediment characteristics change locally and this impacts community structure.
Tidal currents	Strong tidal currents change sediment structures and this leads to changes in species composition, particularly in the benthos. Zooplankters are also affected, with some flushed from the estuary.
REI Zone	The development of the REI zone will increase biomass, particularly among the euryhaline copepods. Benthic species such as some amphipods also increase in abundance – also linked to less competition from other species that prefer higher salinity levels.
Phytoplankton biomass	An increase in phytoplankton biomass leads to an increase in density of many invertebrate populations – food availability.
Changes in the fringing vegetation cover	Hyperbenthic species such as the carid shrimp *Palaemon capensis* utilizes stands of fringing vegetation as a habitat. A decrease in fringing macrophyte biomass will lead to a concomitant decrease in carid biomass.
Variable	**Benthic response (subtidal and intertidal)**
Mouth state	Some species such as the mudprawn *Upogebia africana* require a marine phase of development – recruitment to the population ceases should the mouth close during the breeding season. After about three years of mouth closure, mudprawn populations become locally extinct. Numerous species are affected in a similar way, and include most of the estuarine crabs.
Salinity	A full salinity gradient will increase species richness and enable zonation patterns to develop within the benthic community. Low salinity zones are particularly favourable for amphipod species such as *Corophium triaenonyx* and *Grandidierella lignorum*.
Freshwater seeps	The presence of freshwater seeps along the length of the estuary will create nodes or micro-habitats where euryhaline and oligohaline invertebrates become permanently established. Communities associated with seeps (intertidal and subtidal) are therefore different from adjacent areas dominated by euhaline species at least part of the time. These nodes also provide centres of radiation from which colonization of the main estuary occurs as salinity decreases in the adjacent water body.
Oxygen	A decrease in oxygen concentration (below 50% of surface values) will result in the disappearance of many of the benthic species.
Floods	Some populations, particularly in unconsolidated sediments will be flushed from the estuary.
Estuary becomes shallower	Benthic species that favour deeper areas become exposed to shallow-water predators – e.g. molluscs.

Variable	Response of the zooplankton and hyperbenthos
Organic content of the sediment	High organic content of the sediment favours species that are associated with the surface layers particularly.
Changes in sediment characteristics	Benthic species distribution will change in accordance with the shift of habitat preference.
Expansion or decrease coverage of subtidal macrophyte beds	Biomass of benthic populations particularly will increase significantly should submerged macrophytes become more expansive. The reverse pattern holds true at times of macrophyte disappearance. The change in macrophyte coverage will also lead to shifts in the macrobenthic species mix.

The abiotic state of the estuary impacts invertebrates in different ways and is summarised in **Table 4.27**.

Table 4.27 Summary of invertebrate responses to different abiotic states

Abiotic state	Response
State 1: Marine dominated, no REI	Marine dominance will lead to a significant change in zooplankton species distribution and biomass. In Zones 1 – 3, salinity values remain above 30 and the zooplankton community will be characterized by relatively high species richness, but low biomass. In Zone 4, zooplankton will be similar to the other zones, although species richness will be slightly less (salinity ca 25). Although typical estuarine species are present, biomass will remain persistently low. No REI community will establish itself and species associated with oligohaline conditions will be absent. Zonation patterns will not develop and community variability will also decease since freshwater inflow is persistently low. Community composition will also change, with species favouring higher salinity values extending up-estuary. Low biomass will also persist because of low phytoplankton biomass, particularly in summer. Fringing vegetation along the estuary will also decrease, leading to loss of habitat for hyperbenthic species such as carid shrimps. Benthic species favouring unvegetated sediments will decrease (e,g., amphipods). In the upper reaches of the estuary (Zone 4), low oxygen concentrations (below 50% surface saturation) in bottom waters will impact the benthic community particularly in a negative way – species will disappear. Higher salinity values in the upper estuary will also lead to a decrease in the habitat available to amphipod species (particularly *Corophium triaenonyx and Grandidierella lignorum*) that dominate habitats influenced by low salinity conditions. Other species are likely to begin dominating the estuarine benthic community and this change will impact higher trophic levels. No oligohaline community will be present under State 1.

Abiotic state	Response
State 2: Full salinity gradient	A full salinity gradient will maximize for species richness and biomass – the latter also supported by an increase in primary production. The presence of the REI will favour zooplankton biomass. If submerged macrophyte cover decreases, this will favour burrowing forms in the benthos. Occasional low oxygen concentrations however (< 50% of surface saturation), will impact communities in Zone 4 in a negative way and lead to declining abundance levels. The oligohaline community will also only develop in the uppermost parts of the estuary. Stratification also increases in Zone 4, and this will begin to influence vertical distribution of planktonic organisms.
State 3: Partial salinity gradient	The stronger inflow of freshwater under this state will be particularly beneficial for invertebrates and high biomass will characterize the estuary. Species richness will remain high. Although the marine associated community will be present near the mouth, the oligohaline community will become well established in the estuary. Populations will also shift downstream in accordance with salinity tolerance levels Strong vertical stratification now develops in Zones 1 and 2, and this will impact the vertical distribution of invertebrates in the water column. Euryhaline species will still move across the boundary layer, but species linked to euhaline conditions will colonise the lower water column.
States 4 and 5: Limited salinity penetration; and Freshwater dominated	As salinity penetration decreases progressively from States 4 to 5, there will be a concomitant decrease in species richness as species favouring higher salinity values (> 28) disappear from the estuary. Populations will shift downstream in accordance with salinity tolerance levels. Euryhaline zooplankton communities will be more at risk from flushing effects and as populations are forced nearer the mouth. Flushing will be exacerbated as tidal current increase in velocity nearer the mouth. Because of decreasing residence time of water in the estuary, some populations (zooplankton particularly) will not be able to complete their respective life cycles as larvae or eggs are flushed to sea. The net result is that oligohaline forms will dominate the whole estuary under State 5. Among benthic species, polychaetes such as Cratonereis keiskama and amphipods that include *Grandidierella lignorum*, *Melita zeylanica* and *Corophium triaenonyx* will dominate much of the estuarine community numerically.

4.7.1.3 Reference Condition

Expected changes between the reference state and Present State with reference to the invertebrate community are shown in **Table 4.28**.

Table 4.28 Summary of relative changes in invertebrates from Reference Condition to Present State

Key drivers	Change
Increased marine dominance upstream	A twenty-one percent reduction in MAR has resulted in marine dominance increasing during all months of the year. The marine dominated state now persists for longer (20 – 30% of the time, compared to < 5% of the time under reference), particularly during summer. In terms of the zooplankton, variability at the community level will increase, as the REI develops and disappears during the year. Under the Reference Condition, the REI was persistent most of the time. The full salinity gradient present under the natural state also ensured a species-rich community characterized by high biomass associated with the euryhaline group. Under the Present State, salinity remains high in Zones 3 and 4 and the oligohaline community disappears for months at a time, particularly during summer. The net result for the zooplankton is reduced biomass (also lower phytoplankton biomass) and weaker zonation of species along the estuary. Increasing marine dominance has also led to a reduction in reed and sedge biomass as the boundary of the fringing vegetation shrinks upstream. The habitat available to carid shrimps for example, will decrease in response to a decreasing habitat. The carid shrimp *Palaemon capensis* is a species that favours fringing vegetation in low-salinity habitats. The intertidal area inhabited by the mudprawn *Upogebia africana* has decreased, mostly due to modification of the intertidal zone (e.g. bank stabilization). Low salinity estuarine zones favoured by the benthic amphipods *Corophium triaenonyx* and *Grandidierella lignorum* have decreased. Although both species have a wide salinity tolerance range, they colonize low salinity estuarine areas very successfully. The repeated pattern of high amphipod biomass in low salinity estuarine areas indicates a preference for this zone.
Decreased subtidal macrophyte biomass	Decreased coverage by submerged macrophytes will cause a loss of invertebrate species that utilise such habitats. Examples are bivalve molluscs - *Exosphaeroma hylocoetes* and Anthurid isopods. Species mix in the benthic community will therefore include a lesser proportion of invertebrates that attach themselves to the macrophytes.
Oxygen concentration	The development of low oxygen concentrations in the deeper upper parts of the estuary will lead to the disappearance of benthic populations particularly as concentrations decrease below 50%. This occurs as a consequence of marine dominance.

Key drivers	Change
Freshwater abstraction from seeps	The reduction in freshwater inflow associated with seeps along the length of the estuary will reduce species richness and biomass associated with these micro-habitats (euryhaline and oligohaline species). This occurs as the nodal size shrinks and as salinity in the patch increases. The communities associated with seeps (intertidal and subtidal) are different from adjacent areas dominated by euhaline species at least part of the time. These nodes also provide centres of radiation from which colonization of the main estuary occurs as salinity decreases in the adjacent water body.

4.7.2 Invertebrate health

The invertebrate health scores for the Present State are presented in **Table 4.29**.

Table 4.29 Present invertebrate health score, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

Variable	Summary of change	Score	Confidence
Zooplankton			
a. Species richness	Species richness has not changed, based on a time frame of one year.	100	M
b. Abundance	Abundance has decreased, particularly due to the persistence of State 1 (increased marine dominance). Although relative, high abundance is linked to the euryhaline community that decreases as average salinity increases and phytoplankton production decreases. The absence of low salinity values in the upper estuary for much of the time also results in reduced biomass of the oligohaline component. Because of the shrinking of micro-habitats (Freshwater seeps) abundance of the community associated with the seeps reduces.	65	M
c. Community composition	There has been a shift towards less variability in community composition within the annual cycle. The mix of species along the estuary has also changed, because of increasing average salinity values upstream. Under present conditions, the presence of a functional REI and oligohaline zone only appears in the uppermost reaches of the estuary for a relatively short time or not at all during the annual cycle.	65	M
Hyperbenthos			
a. Species richness	Species richness has not changed, based on a time frame of one year	100	M

Variable	Summary of change	Score	Confidence
b. Abundance	Abundance has decreased, particularly due to the persistence of State 1 (increased marine dominance). Although relative, high abundance is linked to the euryhaline community that decreases as average salinity increases and phytoplankton production decreases. The absence of low salinity values in the upper estuary for much of the time also results in reduced biomass of the oligohaline component. Because of the shrinking of micro-habitats (Freshwater seeps) abundance of the community associated with the seeps reduces.	65	M
c. Community composition	There has been a shift towards less variability in community composition within the annual cycle. The mix of species along the estuary has also changed, because of increasing average salinity values upstream. Under present conditions, the presence of a functional REI and oligohaline zone only appears in the uppermost reaches of the estuary for a relatively short time or not at all during the annual cycle. The shift in macrophyte and fringing vegetation coverage also results in a change in community composition.	60	M
Benthos			
a. Species richness	Species richness has not changed, based on a time frame of one year	100	M
b. Abundance	Subtidal abundance has decreased, particularly in Zones 3 and 4 because of a significant increase in salinity on average compared to the natural state. Key groups associated with a low salinity zone are tanaeids and amphipods that favour low salinity conditions (*Apseudes digitalis*, *Corophium triaenonyx* and *Grandidierella lignorum*). The aperiodic development of reduced oxygen concentrations in deeper sections of the upper estuary will also lead to a decline in benthic abundance particularly. Intertidal invertebrates have decreased because of loss of habitat (Bank stabilization, modified intertidal marsh areas etc.)	60	M
c. Community composition	There has been a shift towards reduced variability within benthic populations. Thus the mix of species along the estuary changes in favour of those linked to euhaline species. Species along the estuary gradient and associated with oligohaline conditions disappear for much of the time. Species mix will also change as abiotic drivers such as low oxygen concentrations develop, particularly in deeper areas.	60	M
Invertebrate score min (a to c)		**60**	**M**
% of impact non-flow related		10	
Adjusted score		64	M

4.8 FISH

4.8.1 Overview

4.8.1.1 Main grouping and baseline description

A total of 78 species from 40 families have been recorded in the Goukou Estuary. Records have been accumulated by sampling, recreational recorded catches and species observations by CapeNature (dive and baseline records).

Category Ia estuarine breeders are represented by five species estuarine-roundherring *Gilchristella aestuaria*, Cape halfbeak *Hyporhamphus capensis*, kappie blenny *Omobranchus woodi*, checked goby *Redigobius dewaali* and possibly the Knysna seahorse *Hippocampus capensis*. These species spend their entire life-cycles in estuaries and represented 57.1% of the total catch sample. *Gilchristella aestuaria* was overwhelmingly the most abundant in this category with 57% of the total sample and the remainder of the species in Category Ia contributing 0.1%.

Seven category Ib species, Cape silverside *Atherina breviceps*, prison goby *Caffrogobius gilchristi*, barehead goby *Caffrogobius nudiceps*, sandgoby *Psammogobius knysnaensis* and longsnout pipefish *Syngnathus temminckii* have marine and estuarine breeding populations. This category comprised of 11.8% of the total sample size. The Gobiidae family (four species) was the most abundant group in this category with a 9.16% contribution.

Obligate estuarine-dependent species (category IIa) were represented by leervis *Lichia amia*, spotted grunter *Pomadasys commersonii*, cape moony *Monodactylus falciformis*, dusky kob *Argyrosomus japonicus* and white steenbras *Lithognathus lithognathus* and comprised a total of 11.1% of the total sample size. These species have to spend at least their first year of life in estuaries. Freshwater mullet *Myxus capensis* and flathead mullet *Mugil cephalus* fall into category IIa as well but venture far into freshwater and may therefore also be categorised as facultative catadromous (Vb) species.

Partially estuarine-dependent category IIb species whose juveniles are usually more abundant in estuaries were represented by barbel *Galeichthyes feliceps*, groovy mullet *Liza dumerilii*, striped mullet *Liza tricuspidens*, Cape sole *Heteromycteris capensis* and blackhand sole *Solea bleekeri.* Category IIc species whose juveniles tend to be more abundant in the surf-zone, were represented by southern mullet *Liza richardsonii*, elf *Pomatomus saltatrix* and blacktail *Diplodus sargus*. This was reflected in the total sample size with category IIb comprising 16.1% and IIc 3.3% of the total sample size. Of these, *L. richardsonii* is the most versatile and opportunistic, able to take advantage of prime conditions in the estuarine and marine environment. This species was then also encountered throughout the entire length of the system with a total of 13% contribution to the total sample size as the second most abundant species.

Thirty-one estuarine-independent marine species, e.g. spot damsel *Abudefduf sordidus*, wildeperd Diplodus cervinus, blaasop Amblyrhynchotes honckenii and trumpet-fish *Aulostomus chinensis* have been recorded in the Goukou. The proportion of marine species (40%) is high compared to other permanently open systems in the region and may be partly due to the greater marine influence in the present day. Their abundance in the estuary at present is low, however, with only 0.3% of the total sample size.

Freshwater fish (category IV) are represented by the indigenous and regionally endemic Cape kurper *Sandelia capensis*, Eastern Cape redfin *Pseudobarbus afer* and cape galaxias *Galaxias zebratus* as well as the introduced or translocated smallmouth bass *Micropterus dolomieu*, Mozambique tilapia *Oreochromis mossambicus* and banded tilapia *Tilapia sparrmanii*. Longfin eel *Anguilla mossambica* is the only catadromous species reported from the system but the occurrence of at least two other *Anguillid* species should not be discounted as they occur in other catchments in the region.

4.8.1.2 Description of factors influencing fish

A summary of the effect of abiotic characteristics and processes, as well as other biotic components (variables) on various fish groupings is presented in **Table 4.30**, while a summary of fish responses to various abiotic states is presented in **Table 4.31**.

Table 4.30 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various fish groupings

Variables	Ia. Estuarine residents (breed only in estuaries)	Ib. Estuarine residents (breed in estuaries and the sea)	IIa. Estuary dependent marine species	IIb and c. Estuary associated species	III. Marine migrants	IV and V. Freshwater species
Mouth condition	Goukou permanently open.1a and 1b predominantly in lower and middle reaches.		In permanently open systems, abundance and richness of marine migrant communities dependent on flow-related recruitment cues rather than whether the estuary is accessible or not.			Freshwater species confined to the headwaters of the estuary especially during low flow and absence of REI zone
Retention times of water masses	Food (zooplankton) abundance for all groups increases with increased retention times.					
Flow velocities (e.g. tidal velocities or river inflow velocities)	Resident species move upstream when flow velocities increase		Migrant species exploit tidal currents when migrating into or out of the estuary or when feeding and following the tidal 'front' up the estuary. Eddies accumulate food and provide refugia for both adult and juvenile fish			Freshwater species can get washed into the estuary by strong river currents

Variables	Ia. Estuarine residents (breed only in estuaries)	Ib. Estuarine residents (breed in estuaries and the sea)	IIa. Estuary dependent marine species	IIb and c. Estuary associated species	III. Marine migrants	IV and V. Freshwater species
Total volume and/or estimated volume of different salinity ranges	Increased volume translates to an increase in available habitat for all species, especially those that spend most of their time in the water column. Brackish water habitat is good for resident and estuary associated marine migrants while marine water is good for marine species. High water levels that inundate supratidal areas are positive for juvenile marine fish and small estuarine species.					
Floods	The larvae of resident species are washed into the sea at the onset of floods.	Juvenile marine and catadromous species use floodwaters entering the sea as a cue for locating and migrating into estuaries, whereas adults and sub-adults exit during floods or use them to overcome obstacles to move upstream. Major river flooding associated with high sediment loads can cause gill clogging and hypoxia for fish in the estuary. Large aggregations of kob and other fish with preferences for high turbidity often occur immediately adjacent to estuary mouths during floods. Estuarine connectivity driven by flood events.				High flow velocities may flush some individuals downstream into the estuary
Salinities	Resident and estuary associated marine species very tolerant of salinities in the range 1-35.				Tend to stay as close as possible to salinity 35. Stressed in salinity less than 20.	Highly variable and most prefer salinity < 10
Turbidity	Tolerant of a wide range of turbidity.	Turbidity preferences and tolerances vary among species. High turbidity tolerance (physiological adaptation) among some species affords them refuge and access to a specialist ecological niche.			Generally prefer low turbidity.	Tolerant of a wide range of turbidity.

<table>
<tr><th>Variables</th><th>Ia. Estuarine residents (breed only in estuaries)</th><th>Ib. Estuarine residents (breed in estuaries and the sea)</th><th>IIa. Estuary dependent marine species</th><th>IIb and c. Estuary associated species</th><th>III. Marine migrants</th><th>IV and V. Freshwater species</th></tr>
<tr><td>Dissolved oxygen</td><td colspan="4">Most resident and estuary associated marine species become stressed when oxygen drops below 4 mg/ℓ. However, surface respiration is an adaptation by most estuarine and freshwater species to overcome hypoxia. Skin respiration is also an adaptation in some species, e.g. mudskippers whereas sole gill-morphology allows survival in hypoxic conditions.</td><td>Little tolerance to low oxygen levels/hypoxia</td><td>Surface respiration is an adaptation by some estuarine and freshwater species to overcome hypoxia. Some indigenous species adapted to low oxygen, e.g. air-breathing organs, skin respiration and aestivation e.g. Galaxiidae</td></tr>
<tr><td>Subtidal, intertidal and supratidal habitat</td><td colspan="6">With the obvious exception of mudskippers and to a lesser extent other burrow-symbiotic gobies, “petrophyllic” blennies and clinids, most fish are confined to the subtidal at low tide but forage in the intertidal during high tide. Intertidal reaches are nonetheless extremely important foraging areas for most fish species. Shallow marginal areas tend to be warmer than deeper channel areas and are thus favourable for metabolic processes. Juveniles and small adults also use shallow water as a predation refuge.</td></tr>
<tr><td>Other abiotic components (temperature)</td><td colspan="6">Low temperatures can increase the risk of mass mortalities at very low salinities. Sex ratios can be skewed in fish where sex determination is temperature related. Increases in temperature tend to skew towards males, decreases towards females. Consequently, climate change and local scale anthropogenic influences on temperature could have a profound impact on fish populations. Growth rates and gonadal development tend to decrease either side of the optimal temperatures for individual species. Fish move according to their preferred temperature, constraints more in temporarily open/closed than permanently open estuaries.</td></tr>
<tr><td>Sediment characteristics (including sedimentation)</td><td colspan="6">Individual species preferences are highly variable and often related to preferred food sources. Burying ability and crypsis of some fish (e.g. sole Heteromycteris capensis) are governed by sediment characteristics. Some fish are directly and indirectly impacted e.g. Psammogobius knysnaensis are psammophyllic but have commensal/mutual relationships with burrowing invertebrates which are distributed according to their burrowing ability and sediment characteristics.</td></tr>
<tr><td>Phytoplankton biomass</td><td colspan="6">High phytoplankton production contributes to turbidity in estuaries and probably favours those species with higher turbidity preferences. Phytoplankton is also a food source for filter-feeding fish and invertebrates. Fish also benefit indirectly from proliferation of invertebrates that feed on phytoplankton. Omnivorous filter-feeding fish will out-compete</td></tr>
</table>

<table>
<tr><th>Variables</th><th>Ia. Estuarine residents (breed only in estuaries)</th><th>Ib. Estuarine residents (breed in estuaries and the sea)</th><th>IIa. Estuary dependent marine species</th><th>IIb and c. Estuary associated species</th><th>III. Marine migrants</th><th>IV and V. Freshwater species</th></tr>
<tr><td></td><td colspan="6">selective feeders during periods of high phytoplankton biomass.

Harmful algal blooms in estuaries, usually a result of eutrophication, have a number of direct (toxicity) and indirect (e.g. hypoxia) impacts on fish. Blue-green Microcystis blooms, common in SA estuaries, can cause skin and/or organ lesions in fish resulting in poor health, reduced reproductive success and mortalities. Golden algae Prymnesium parvum, an invasive species recorded in Zandvlei, causes fatal gill haemorrhaging and induces abortion and premature spawning in fish.</td></tr>
<tr><td>Benthic micro-algae biomass</td><td colspan="6">Detritivores, especially mullet, benefit from high microphytobenthos biomass. South African fish biomass in estuaries is dominated by mullet (> 60%) and therefore overall fish biomass is largely reflective of benthic algal biomass.</td></tr>
<tr><td>Zooplankton biomass</td><td colspan="6">Most juvenile fish in estuaries feed on zooplankton. Filter and particulate feeders benefit from increased zooplankton biomass. Many fish species are able to switch between filter and targeted feeding modes to take advantage of dominant zooplanktonic food sources. One caveat is that predatory marine zooplankters (e.g. chaetognaths) may have a devastating impact on recruiting fish larvae. Jellyfish may do the same.</td></tr>
<tr><td>Aquatic macrophyte cover</td><td colspan="6">Juveniles of most fish species find refuge in littoral macrophyte beds during the daytime but move into open water or to the surface during the night as oxygen levels drop in the littoral zone.</td></tr>
<tr><td>Benthic invertebrate biomass</td><td colspan="6">Many estuary associated fish species feed on benthic invertebrates and will thus benefit from increases in benthic invertebrate biomass. Burrow-associated fish (e.g. gobies) diversity and numbers will vary according to that of benthic invertebrates (e.g. sand prawn).</td></tr>
</table>

Variables	Ia. Estuarine residents (breed only in estuaries)	Ib. Estuarine residents (breed in estuaries and the sea)	IIa. Estuary dependent marine species	IIb and c. Estuary associated species	III. Marine migrants	IV and V. Freshwater species
Fish biomass	No major piscivorous species in these categories. Most of the fish biomass consists of planktivores and small zoobenthivores. Probably inter and intraspecific competition for space, habitat and food resources though.		Fish biomass dominated by estuary associated marine species that utilise different food chains, e.g. groovy mullet *Liza dumerili* is a detritivore, spotted grunter *Pomadasys commersonnii* a zoobenthivore and dusky kob *Argyrosomus japonicas* a piscivore. The piscivores benefit from the high biomass of estuarine resident and small marine migrants in the estuary.			Introduced freshwater fish may outcompete and eat estuary fish and prey on catadromous recruits moving upstream but also result in a substantial increase in biomass, e.g. the sharp tooth catfish *Clarias gariepinus* has invaded the Great Fish system via the Orange River water transfer scheme. Introduced species are usually more tolerant of poor water quality, thereby becoming the dominant fish in some systems.

Table 4.31 Summary of fish responses to different abiotic states

Abiotic state	Response
State 1: Marine dominated	*L. richardsonii* become dominant in the lower and middle reaches whereas REI species e.g. *Myxus capensis* and *Monodactylus falciformis* are concentrated on the upper reaches. Although in low numbers, more marine species will occur in the lower and middle reaches of the estuary (A, B, C). Increase in benthic algal biomass will benefit all mullet species. Visual benthic invertivores and piscivorous predators can benefit from low turbidity in the lower reaches but prey species may burrow down or move elsewhere specifically for this reason. Low oxygen levels in Zone D bottom waters will exclude benthic fish as well as their prey.
State 2: Full salinity gradient	Fish will be distributed according to their salinity preferences and overall recruitment into the estuary along the salinity gradient should be at a maximum. Increases in phytoplankton and zooplankton production translate into more food for juvenile and larval fish of most species. Again, elevated benthic algal biomass will benefit all mullet species. REI in Zone D will see an increase in *G. aestuaria, Myxus* and other REI species. An increase in benthic invertebrate burrowers will favour *P. commersonnii, L. lithognathus* and similar exploited species. A slight drop in macrophyte biomass will see the same in associated species such as pipefish *S. temminckii*.
State 3: Partial salinity gradient	Fish will be distributed according to their salinity preferences. Elevated phytoplankton and zooplankton biomass translate into more food for juvenile and larval fish of most species as does the elevated benthic algal biomass benefit all mullet species. Although the salinity gradient within the estuary is partial, accompanied by more intense olfactory cues it will now extend further into the sea. This will maintain or increase larval and juvenile recruitment into the estuary.
State 4: Limited salinity penetration	Estuary residents and fish with a preference for the REI zone will disperse throughout the estuary. Lower phyto and zooplankton production will favour omnivorous fish with a catholic diet as well as those smaller species such as *G. aestuaria* able to switch feeding modes from filter to selective feeding. Lower benthic algal biomass will see mullet especially *L. richardsonii* lose their numerical dominance of the fish assemblage. Increased turbidity will favour piscivorous predators such as *A. japonicus* but limit visual invertebrate feeders such as *L. lithognathus*. Catadromous glass eels will recruit into the catchment or adult silver eels migrate back via the estuary into the sea.
State 5: Freshwater dominated	Estuary residents e.g. *G. aestuaria* will be confined to the upper reaches to avoid being swept out to sea. The remaining fish with an REI preference will still be dispersed throughout the estuary as will some freshwater species. REI and facultative catadromous species e.g. *M. falciformis* and *M. capensis* may use elevated water levels to overcome obstacles and swim upstream into the river's freshwater reaches. Catadromous glass eels will recruit into the catchment or adult silver eels migrate back via the estuary into the sea. Elevated silt loads will replenish specialist habitat for young-of-the-year *A. japonicus,* Zambezi shark *Carcharhinus leucas* (if it occurs) and similar species. Fish will be concentrated in eddies and backwaters where food is accumulated and entrained. Burrowing invertebrates such as sandprawn *Callichirus kraussi* will burrow down to their preferred salinity thereby escaping fish preying upon them. Most marine vagrant species will leave the estuary.

4.8.1.3 Reference Condition

Table 4.32 summarised the key drivers and changes in fish assbemblage from Reference Condition to Present State.

Table 4.32 Summary of relative changes in fish assemblages from Reference Condition to Present State

Key drivers	Change
⇧⇩Floods	Only a 5% change in floods from reference. Slightly lower flow velocities during floods may reduce recruitment effect and shorter duration of high flow periods may reduce the recruitment frequency. The lack of sediment scouring floods results in marine sediment build up in the lower reaches of the estuary altering habitat composition and slight decline in Zostera beds will have had a negative impact on fish diversity and biomass. Fluvial sediment (sand) accumulation may be slightly higher in the middle to upper reaches. Overall increase in sand has seen *Callichirus kraussii* (prey) expansion upstream accompanied by psammophyllic and commensal burrow dwellers e.g. *P. knysnaensis*.
⇧Salinities	Salinity has increased upstream due to lower flows. The estuary was always a more marine dominated system but relative occurrence and the species composition of the fish assemblage (e.g. *Myxus capensis*) suggest that the REI zone was persistent throughout much of the estuary for extended periods. So, REI species now confined to the headwaters much of the time whereas estuary dependent marine species e.g. *L. lithognathus* abundant throughout the estuary. Highest densities of the opportunistic *Liza richardsonii* population were in the lower reaches salinity > 30 (Zone A) and in upper reaches salinity 0-10 (Zone D) relating to high but different food items of benthic diatoms and invertebrate / epiphytic algae in each zone respectively. Higher salinity translates into shallower burrows and increased prey availability for invertebrate feeders as well as the expansion of these prey items upstream. This also explains the highest densities of *L. lithognathus* being in the middle reaches (Zones B and C)
⇧Sediment ∆ characteristics	Marine sediments and associated invertebrates e.g. *C. kraussi* have expanded upstream translating into more foraging area and prey for visual benthic invertivores. An increase in the number of invertebrate burrows should also see an increase in the number of commensal fish e.g. *P. knysnaensis* that find refuge within them. An agriculture-related increase in fines from upstream may benefit sole burrowing and crypsis as well as provide more of crucial habitat for 0+ juvenile kob.
⇧⇩Turbidity	Increased turbidity will favour soniferous fish whereas clearer water will favour visual feeders.
⇧Benthic micro-algae biomass	All mullet species will have benefitted from an increase in benthic micro-algal biomass and should be more abundant throughout the estuary. However, this increase may have been dampened by the increase in bioturbators in the system.
⇩Zooplankton biomass	Most juvenile fish in estuaries feed on zooplankton. The adults and juveniles of filter and particulate feeders will be affected by a decreased zooplankton biomass.

Key drivers	Change
⇩Benthic invertebrate biomass	A decrease in invertebrate biomass should affect invertebrate feeders e.g. *P. commersonnii, R. holubi*. Again, a decrease in the number of invertebrate burrows should also see a decrease in the number of commensal fish e.g. *P. knysnaensis* that find refuge within them.
⇩⇧ Fish biomass	Fish biomass influences the number of piscivorous fish. Increased salinity should have seen a reduction of REI forage fish e.g. *G. aestuaria* but an increase in marine opportunists e.g. *L. richardsonii*. However, there has also been severe overexploitation nationwide of the larger piscivorous species e.g. dusky kob.

4.8.2 Fish health

The fish health scores for the Present State are presented in **Table 4.33**.

Table 4.33 Present fish health scores, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

Variable	Summary of change	Score	Confidence
a. Species richness	Increased trend of post larval drift species occurrence in the estuary extending ranges westwards coupled with introduced freshwater species has resulted in an overall increase in species diversity. 78 species from 40 families have been recorded. Persistence of estuarine fish represents a positive whereas aliens represent a negative change.	90	H
b. Abundance	With the exception of *G.aestuaria*, a decrease in abundance (~15%) and diversity of small bodied species and juvenile fish due to loss of recruitment cues. This decrease dampened by drop in predation due to a drastic (nationwide) decline (60%-95 %) in abundance of large exploited species.	80	H
c. Community composition	REI fish component now confined to the upper reaches for most of the time. Increase in abundance of small-bodied filter, particulate, detrital and benthic diatom feeders but a drastic decline in the influence of large piscivorous predators – upper trophic levels depleted by overfishing throughout the coast. MPA status has helped alleviate the latter especially *L. amia*. Range expansion and persistence of estuarine-dependent species also positive w.r.t. community composition.	75	H
Fish health score min (a to c)		**75**	**H**
% of impact non-flow related impacts		50	
Adjusted score		80	M

4.9 BIRDS

4.9.1 Overview

4.9.1.1 Main grouping and baseline description

For the purposes of this study, the birds found on the estuary have been grouped into eight groups based on a combination of diet and taxonomic groupings (**Table 4.34**).

Table 4.34 Major bird groups found in the Goukou Estuary, and their defining features

Bird groups	Defining features, typical/dominant species
Piscivorous cormorants	These swimming piscivores catch their prey by following it under water and therefore prefer deeper water habitat. These include Reed Cormorant, Cape Cormorant, White-breasted Cormorant and African Darter.
Piscivorous wading birds	This group comprises the egrets, herons, ibises and spoonbill. Loosely termed piscivores, their diet varies in plasticity, with fish usually dominating, but often also includes other vertebrates, such as frogs, and invertebrates. The ibises were included in this group, though their diet mainly comprises invertebrates and is fairly plastic. They tend to be tolerant of a wide range of salinities. Wading piscivores prefer shallow water up to a certain species dependant wading depth.
Herbivorous waterfowl	This group is dominated by species that tend to occur in lower salinity or freshwater habitats and are associated with the presence of aquatic plants such as *Potamageton* and *Phragmites*. The group includes some of the ducks (e.g. Southern Pochard), and all the rallids (e.g. Redknobbed Coot, African Purple Swamphen). Some herbivorous waterfowl such as Egyptian Goose probably feed in terrestrial areas away from the estuary and floodplain as well as in the estuary.
Omnivorous waterfowl	This group comprises ducks which eat a mixture of plant material and invertebrate food such as small crustaceans - Yellow-billed Duck, Cape Teal, Red-billed Teal and Cape Shoveller. Although varying in tolerance, these species are fairly tolerant of more saline conditions.
Benthivorous waders	This group includes all the waders in the order Charadriiformes (e.g. Greenshank, Curlew Sandpiper). They are the smallest species on the estuary, and feed on benthic macroinvertebrates in exposed and shallow intertidal areas. Invertebrate-feeding waders forage mainly on exposed sandbanks, mudflats and in the inter-tidal zone.
Piscivorous gulls and terns	This group comprises the rest of the Charadriiformes, and includes all the gull and tern species using the estuary. These species are primarily piscivorous, but also take invertebrates. Most are euryhaline, but certain tern species on the estuary tend to be associated with low salinity environments. Gulls and terns can be very abundant and use the estuary primarily for roosting
Piscivorous kingfishers	Kingfishers breed and perch on the river banks and prefer areas of open water with overhanging vegetation.
Birds of prey	This group are not confined to a diet of fish, but also take other vertebrates and invertebrates. Species in this group include African Fish Eagle and African Marsh Harrier.

A total of 52 non-passerine waterbird species have been recorded on the Goukou Estuary. Across all CWAC[1] counts between 2000-2013, there were a total of 45 species recorded in summer and 46 recorded in winter. An average number of waterbird species recorded per count between 2000 and 2013 was 26 in summer and 22 in winter. 20 species were recorded in January 1981 and 21 species were recorded in December 2013 (this study). One species recorded in January 1981 (Ruddy Turnstone) has not been recorded since.

During 2000-2014, the Goukou Estuary supported an average of 254 birds in summer and 181 birds in winter. The avifauna was dominated by waders (42%) and gulls and terns (32%). The most numerous benthivorous wading birds during summer were the migratory Grey Plover (9%), Common Greenshank (7%) and Common Whimbrel (7%) as well as the resident Blacksmith Lapwing (6%). The Curlew Sandpiper was counted in large numbers in 1981 (150 birds), since then it has only occurred in sizeable numbers only in one year (46 birds in 2005). The Kelp Gull was the most numerous species within the piscivorous gulls and terns group and alone comprised 25% of all birds. Tern numbers were higher during summer than winter, when the migratory Common Tern was more common. Historically the Caspian Tern was also recorded in Goukou Estuary but has not been recorded in counts since 2000.

In winter, the avifauna were much more evenly spread across different groups of birds and mainly comprised of resident species. The most common species were the Kelp Gull (17%), Yellow-billed Duck (13%), African Sacred Ibis (10%) and Reed Cormorant (8%). The numbers of both cormorants and waterfowl were higher in winter than summer, which was mainly due to higher numbers of White-breasted Cormorants and Yellow-billed Ducks.

Community composition was fairly similar in the 1981 count, the 2000-2013 CWAC summer counts and the December 2013 count. The most notable difference was the higher total number of birds, and the higher number of herbivorous waterfowl (mainly Red-knobbed Coot) in the 1981 survey.

The avifauna was dominated by piscivores (mainly gulls and cormorants) in both seasons, although the contribution of benthivores (mainly waders) almost equalled that of piscivores in summer. In winter the proportion of omnivores became more predominant. The piscivorous birds include the gulls, which also eat invertebrates, the cormorants, terns, kingfishers, ospreys and fish eagles which concentrate on fish (although fish eagles do take other vertebrate prey), and the herons and egrets, which include a variety of vertebrates (e.g. frogs) in their diet. Piscivore numbers are low in summer, consisting mainly of birds whose numbers tend to be stable year round (e.g. kingfishers, herons), but increase in winter due to increases in the numbers of cormorants and grebes. As is typical of marine or freshwater habitats, many of these are species that feed elsewhere during the breeding season, or coastal species that may be seeking more sheltered feeding areas during winter.

The omnivorous species comprise most of the waterfowl, which consume small invertebrates as well as plant material. They are dominated by Yellow-billed Duck. The herbivore group consists of waterfowl that tend to feed predominantly on submerged macrophytes and often shelter near reedbeds, which can be found fringing the upper parts of the estuary. The low numbers of these and other waterfowl may be indicative of the low levels of submerged and emergent macrophytes and

[1] CWAC data were obtained from the Animal Demography Unit, University of Cape Town

absence of backwaters in this system, with decreases in numbers possibly a result of increased salinity of the system. It should be noted that small flocks of exotic waterfowl (domestic duck and geese) also regularly occur on the system.

Gulls and terns are concentrated in the mouth area, which they tend to use as a roosting area. While a few waders that usually associate with sandy habitats occur at the mouth, most of the waders are found on the intertidal mudflat and saltmarsh areas in the lower estuary between the mouth and the powerline. As one progresses up the estuary to encounter narrower intertidal areas, and grassy verges, the type of waders also tends to change. Piscivorous wading birds are found throughout the estuary but are more common in the middle reaches, where fish also tend to be most abundant. The waterfowl tend to be found in the upper reaches of the estuary where there are more reedbeds and the estuary is dominated by the open channel.

4.9.1.2 Description of factors influencing microalgae

Avifaunal communities in estuaries are likely to be affected primarily by the supply (or ‘catchability’) of suitably-sized food (plants, invertebrates or fish) and availability of suitable feeding, roosting and breeding habitat, but will also be influenced by inter- and intraspecific competitive interactions, as well as external factors such as breeding success on distant breeding grounds or human disturbance. These relationships may vary seasonally, from estuary to estuary, or between biogeographical zones. Certain groups or species are liable to be more responsive to changes in system variables than others, depending on their ability to adapt to a range of circumstances (e.g. Turpie and Hockey, 1997). Very few quantitative studies have been made of the influence of abiotic and biotic factors on bird community structure and abundance in South African estuaries. Because numerous factors affect avifaunal community structure and abundance, it is difficult to demonstrate these effects empirically (Evans, 1997, Hockey and Turpie, 1999). Thus predictions regarding the reference state and future scenarios have to be made on the basis of qualitative (“gut-feel”) understanding of the relationships between elements of estuarine bird communities and their main drivers (**Table 4.35**).

Table 4.35 Effect of abiotic characteristics and processes, as well as other biotic components on bird groupings

Factor	Cormorants and wading piscivores	Kingfishers and fish-eagle	Waterfowl	Waders, gulls and terns
Salinities			Certain species of waterfowl prefer lower salinities.	
Turbidity	Negatively affects visibility for foraging.			
Intertidal area				Waders rely mostly on intertidal areas for feeding.

Factor	Cormorants and wading piscivores	Kingfishers and fish-eagle	Waterfowl	Waders, gulls and terns
Sediment characteristics (including sedimentation)				Different types of waders tend to be found on sediments of different characteristics; pattern of sediments in mouth area affect suitability for gull/tern roosts.
Primary productivity	Indirectly though influence on food supply.			
Submerged macrophytes abundance			Has positive influence on herbivorous waterfowl numbers.	
Abundance of reeds and sedges			Has positive influence on some herbivorous waterfowl species.	
Abundance of zooplankton			Assumed positive for some omnivorous species.	
Benthic invertebrate abundance				Primary food source for invertebrate-feeding waders.
Fish biomass	Piscivores will increase with increasing numbers of small to medium-sized fish.			

Different trophic groups of birds were assumed to be influenced primarily by the availability (or catchability) of food, in turn influenced by its abundance and size class distribution. In addition to the relationship between food groups, the availability of food is in turn expected to be influenced by salinity, nutrients and relative availability of different habitat types (e.g. mudflats, sandflats, vegetated habitats). The latter variables are influenced by freshwater inputs to the estuary.

Where the composition and productivity of a food group is determined by abiotic factors such as salinity or sediment particle size, these variables may indirectly determine the nature of the avifaunal community. For example, a broad assumption applied to invertebrate feeding waders could be that wader densities are negatively correlated with sediment sand fraction, because the latter is negatively correlated with invertebrate density/availability.

In some cases, predictions about the avifaunal community can be made directly from the estimates of the other specialists. In cases where insufficient information is given it is necessary to second-guess the relevant responses of the other biotic groups in order to estimate the avifaunal response.

A summary of responses to various abiotic states is presented in **Table 4.36**.

Table 4.36 Summary of bird responses to different abiotic states

Abiotic state	Response
State 1: Marine dominated	Due to higher salinities, waterfowl will tend to be confined to the uppermost reaches of the system; greater fish biomass in middle reaches will be beneficial for piscivorous species; greater tidal influence in lower reaches will be beneficial for waders.
State 2: Full salinity gradient	Waterfowl will tend to occur in the upper half of the estuary; favourable conditions for phytoplankton, invertebrates and fish production will attract waders and piscivores to the lower and middle reaches.
State 3: Partial salinity gradient	As above, but the particularly favourable conditions for fish could attract more piscivores to the system.
State 4: Limited salinity penetration	Species will be distributed according to their salinity preferences; the system is likely to be less favourable for waders and piscivores than States 3 and 2.
State 5: Freshwater dominated	Waterfowl will be found throughout the system, however, numbers of waders and piscivorous birds expected to be lower as a result of reduced productivity as well as intertidal and shallow habitat availability.

4.9.1.3 Reference Condition

Estimation of the Reference Condition takes into account the expected response to flow-related and non-flow related drivers into account, in conjunction with any evidence from existing data. Key flow-related changes and their expected effect are summarised in **Table 4.37**.

Table 4.37 Summary of relative changes in birds from Reference Condition to Present State

Key drivers	Change
⇧Salinities	Reduced suitable habitat for waterfowl.
⇩Turbidity	Favours piscivores, but likely to be minor effect.
⇩Intertidal area, Stabilisation of mouth sediments	Significantly reduced availability and suitability of intertidal areas >> reduced wader numbers, reduced habitat for gulls and terns.
⇩Salt marsh	Reduced area of Spartina marshes in lower estuary and mouth region will have led to reduction in productivity and numbers of larger waders and other waterbirds.
⇩Emergent veg/reed marsh	Decreased habitat and food source for skulking rallids and waterfowl. Relates to the increased salinity.
⇩Benthic invertebrate abundance	Would have negative impact on waders (captured in habitat change).
⇩Fish biomass	Decrease in biomass of smaller fish species and juvenile fish may have had slight negative impact on piscivorous groups.

Available bird count data suggest an overall decline in bird numbers from the 1980s mainly due to a decline in the numbers of waterfowl and waders. Note that the 1981 count is not taken to be the Reference Condition, as many changes would have taken place up to that point.

Given that the abundance of fish has been estimated to have declined to 75% of reference, it would be reasonable to assume that the piscivorous groups could have been negatively impacted to some extent, assuming that food may have been a limiting factor (Note that many of the species in these groups have broader diets than just fish). Coupled with habitat loss, stabilisation of the mouth area and increased disturbance on the estuary, this could have led to reasonable declines. However, this is likely to have been compensated to some extent for some wading bird species by regional population increases (e.g. Sacred Ibis, African Spoonbill).

Over the longer term, numbers of waders are likely to have been negatively affected by the loss of intertidal areas, reduced benthic biomass, as well as by increased human disturbance and reductions in global populations of migratory wader species. There is no evidence of changes since 2009, but there is some evidence that wader numbers may have declined since 1981.

Apart from Egyptian Goose, waterfowl numbers are likely to have decreased as a result of the increased salinity of the estuary, reduction in availability of reed habitat and submerged macrophytes and reduced productivity of the system. While 67 Red-knobbed Coot were recorded in 1981, few have been recorded since. Egyptian Goose numbers have increased as a result of regional population increases due to agricultural expansion, although their numbers do not appear to have increased to the same extent as some other systems, probably due to the nature of land use in this area.

Numbers of piscivorous kingfishers and African Fish Eagle are likely to have been relatively constant over time. While the African Fish Eagle is only sporadically observed, the estuary has almost certainly formed part of the territory for a pair over the long term.

4.9.2 Bird health

The invertebrate health scores for the Present State are presented in **Table 4.38**.

Table 4.38 Bird health score, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

Variable	Summary of change	Score	Confidence
a. Species richness	Possible slight reduction in average instantaneous species richness.	95	M
b. Abundance	Numbers of all groups expected to have declined, with overall decrease in numbers. Waterfowl numbers decrease due to increase salinity and reduced veg but augmented by EG; Wader numbers reduced by habitat loss, invert biomass and population changes; Numbers of piscivores groups likely to have declined due to declines in fish, though some wading birds probably increased in recent decades.	73	M
c. Community composition	Reduced numbers of some of the more numerous groups – waders, gulls and terns, influx of EG, so moderate change in community composition.	84	M
Bird health score min (a to c)		**73**	**M**
% of impact non-flow related impacts		50	
Adjusted score		87	M

5 PRESENT ECOLOGICAL STATUS

The individual present health scores for the various abiotic and biotic components are used to determine the PES of the Goukou Estuary, in accordance with the EHI as presented in **Table 5.1**.

The Estuarine Health Score for the Goukou Estuary is 69, thus a **Present Ecological Status** of **Category C.**

Table 5.1 Present Ecological Status of the Goukou Estuary

Variable	Weight	Score
Hydrology	25	54
Hydrodynamics and mouth condition	25	95
Water quality	25	75
Physical habitat alteration	25	65
Habitat health score		**72**
Microalgae	20	57
Macrophytes	20	68
Invertebrates	20	60
Fish	20	75
Birds	20	73
Biotic health score		**67**
ESTUARY HEALTH SCORE Mean (Habitat health, Biological health)		**69**
PRESENT ECOLOGICAL STATUS (PES)		**C**
OVERALL CONFIDENCE		**Medium**

5.1 RELATIVE CONTRIBUTION OF FLOW AND NON-FLOW RELATED FACTORS ON HEALTH

In scoring the various abiotic and biotic components, specialists were also asked to estimate the extent to which the shift from Reference Condition to Present State was attributed to flow related or non-flow related effects. Flow related effects specifically relate to changes caused by a modification in river (volume) inflow (i.e. either base flows, seasonal distribution of flows or flood characteristics). Non-flow related effects include, for example, pollution from land-based activities such as agriculture, urban runoff and wastewater discharges, fishing, human disturbance of birds, habitat destruction associated with development and over-harvesting of estuarine vegetation.

Specialist concluded that non-flow related factors contributed significantly to ecological modification in the Goukou Estuary from Reference to the Present (see earlier Present Health Score tables) as summarised in **Table 5.2.**

Hypothetically removing non-flow related factors specialists estimated that the PES of the Goukou Estuary could improve to a Category B, demonstrating that the modification in river inflow patterns only partly contributed to the present ecological health status in the Goukou Estuary (i.e. Category C), mainly associated with significant reduction in low flows (i.e. base flows).

Table 5.2 Estimated effect of non-flow related factors on the present health of the Goukou Estuary

Component	% of modification in health (non-flow related factors)	Key non-flow related factors
Hydrology	N/A	Flow related issues
Hydrodynamics and mouth condition	0	Shifts in condition primarily as a result of changes in river inflow.
Water quality	80	Nutrient input mainly from agricultural activities and sporadically malfunctioning wastewater treatment work (WWTW) infrastructure.
Physical habitat alteration	86	Low-lying developments and inappropriate bank protection.
Microalgae	60	Nutrient input mainly from agricultural activities and sporadically malfunctioning WWTW infrastructure.
Macrophytes	60	Degradation of estuarine habitat due to development, agriculture and bait collection activities. Alien vegetation in riparian zone. Nutrient input mainly from agricultural activities and sporadically malfunctioning WWTW infrastructure.
Invertebrates	10	Limited bait collection pressures.
Fish	50	Fishing pressures. Introduction of alien species.
Birds	50	Non-flow related impacts include broader population changes (increases in Egyptian Goose and some wading birds, and general declines in certain waders), loss of habitat and human disturbance on the estuary.

5.2 OVERALL CONFIDENCE OF STUDY

The overall confidence of this study is **Medium (60 – 80% certainty),** derived from the medium confidence reflected in most of the abiotic and biotic components. In terms of the abiotic components, it was not possible to define and characterise the five abiotic states for this system with high/medium confidence, mainly because long-term river inflow records were not available at the head of the estuary. Data from the Duiwenhoks station (H8H1) had to be used as proxy. Water quality data on river inflow were also not available for river inflow near the head of the estuary and conditions had to be extrapolated from further upstream (H9H5) as well as using downstream data from the Duiwenhoks system (H8H1). However, the Department of Agriculture, Forestry and Fisheries (DAFF) in conjunction with the Council for Scientific and Industrial Research (CSIR) collected salinity and other water quality parameters (i.e. temperature, pH, dissolved oxygen and turbidity) as part of a long-term monitoring programme in this estuary which enhanced confidence in the assessment of those parameters. Overall confidence in the abiotic components still came to medium, because specialists were able to draw on experience from their collective research on other, related systems. Medium confidence in the macrophyte component is largely attributed to recent extensive, research conducted by the Nelson Mandela Metropolitan University on estuarine systems in the region. Medium confidence in the microalgae and invertebrate components is attributed to the availability of some historical data sets on this system, but mostly because specialists were able to draw on experience from their collective research on other, related systems. Extensive data on the fish component collected by DAFF as part of their long-term monitoring programmes in estuaries significantly contributed to the medium (even high) confidence in this component. Historical data on the bird component were also available from the Coordinated Waterbird Counts (CWAC) programme. The character of the Goukou Estuary also allowed specialists to draw on experience from their collective research on other, related systems, warranting a medium confidence in the biotic components.

6 THE RECOMMENDED ECOLOGICAL CATEGORY

6.1 ECOLOGICAL IMPORTANCE

The Goukou Estuary is part of the Stilbaai Marine Protected Area (MPA) formally promulgated on 17 October 2008 (**Figure 6.1**). The Goukou Estuary was rated 32nd in terms of its ecological importance in Turpie and Clark's (2007) updated estuarine importance rating for all South African estuaries.

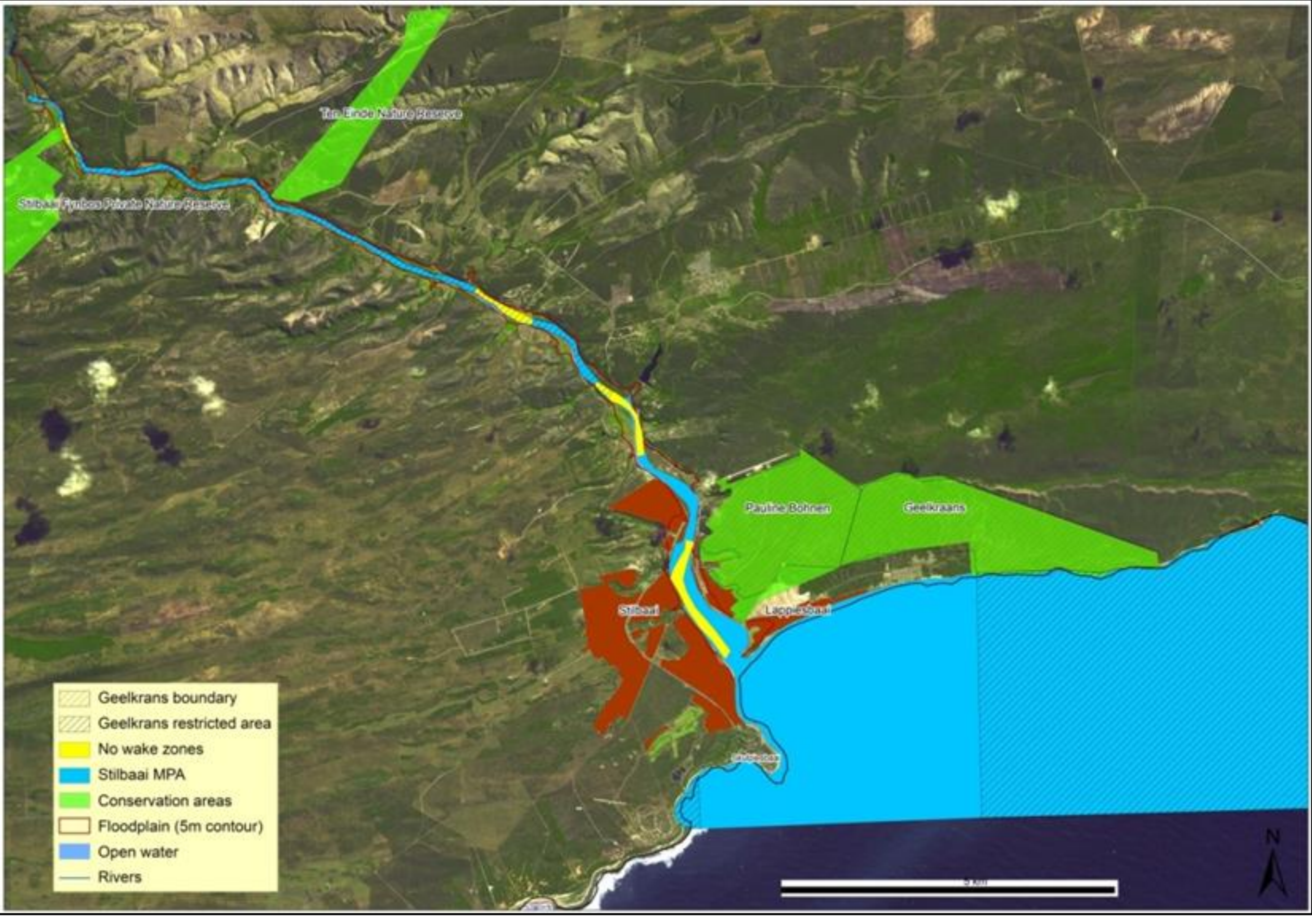


Figure 6.1 Zonation of Stilbaai Marine Protected Area)

The 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. These importance scores ideally refer to the system in its Present State. The scores have been determined for all South African estuaries (Turpie and Clark, 2007), apart from functional importance, which is scored by the specialists in the workshop (**Table 6.1**). The EIS for the Goukou Estuary and the importance rating is presented in **Tables 6.2** and **6.3**, respectively.

Table 6.1 Estuarine Importance Scores (EIS) for the Goukou Estuary

Criterion	Weight	Score
Estuary Size	15	90
Zonal Rarity Type	10	20
Habitat Diversity	25	90
Biodiversity Importance	25	97
Functional Importance	25	100
Weighted Estuary Importance Score		**83**

A score of 100 for functional importance was mainly attributed to the importance of this system as a nursery for exploited marine-living fish (e.g. collapsed stock: dusky cob, white steenbras), as well as being a very important movement corridor for river invertebrates and fish breeding in sea, e.g. eels (CITES listed species), crabs, gobies, freshwater prawn.

Referring to the estuarine importance rating system (DWAF, 2008), the importance score of the Goukou Estuary – a score of 83 - translates into an importance rating of **'Highly Important'** (**Table 6.3**).

Table 6.2 Estuarine Importance rating system (DWAF, 2008)

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

6.2 RECOMMENDED ECOLOGICAL CATEGORY

Applying the guidelines for the determination of the Recommended Ecological Category (**Table 6.4**), the Goukou Estuary should at least be managed in a **Category A or at least a Best Attainable State (BAS)**. The motivation being that the estuary is highly important and part of a MPA.

Table 6.3 Guidelines to assign REC based on protection status and importance, as well as PES of estuary (DWAF, 2008)

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

Protection status and importance	REC	Policy basis
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

Considering the various flow and non-flow related factors that currently contributes to a PES of Category C (see **Section 5**), specialists agreed that several of the flow related and non-flow related impacts on the system are reversible, or at least partially reversible. However, it is unlikely to fully restore the ecological status of this estuary to a Category A, given the social and economic demand for water in the catchment, as well as extensive urban development along its banks. The REC for the Goukou Estuary, therefore, was set as a **Category B.**

7 CONSEQUENCES OF ALTERNATIVE SCENARIOS

7.1 DESCRIPTION OF SCENARIOS

The future scenarios that were assessed for the Goukou Estuary are summarised in **Table 7.1**.

Table 7.1 Summary of flow scenarios

Scenario	Description	MAR (million m^3)	Percentage remaining
Reference	Natural flow regime before development	115.95	100
Present	Present day (2004) development	91.73	79
Scenario 1	Restore about 50% of baseflow (Present WRYM with no afforestation and decreased abstractions)	101.69	88
Scenario 2	Reduce Present MAR by about 10% (Present WRYM with two dummy dams with abstractions)	82.57	71
Scenario 3	Reduce Present MAR by about 15% (Scenario 2 with increased abstraction)	73.41	63
Scenario 4	Reduce Present MAR by about 30% (Scenario 3 with increased abstraction)	55.64	48

The occurrences of the flow distributions (mean monthly flows in m^3/s) under the future Scenarios of the Goukou Estuary, derived from an 85-year simulated data set are provided in **Tables 7.2** to **7.5** and in **Figures 7.1** to **7.4**. The full sets 85-year series of simulated monthly runoff data for the future Scenarios are provided in Table 7.6 to 7.9.

Table 7.2 Summary of the monthly flow (in m^3/s) distribution under Scenario 1 (refer to Table 3.2 for colour coding of abiotic states)

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	23.4	30.8	27.2	16.6	16.7	24.2	30.3	17.9	8.1	10.1	34.9	29.1
99	19.5	23.6	16.6	12.3	13.2	16.3	29.0	14.9	7.5	9.8	26.8	15.7
90	11.2	9.3	4.8	3.5	6.4	7.6	8.6	7.4	5.3	5.1	6.6	7.0
80	5.8	7.3	3.4	2.5	3.3	5.7	6.0	5.0	3.5	3.4	5.4	5.2
70	4.4	4.8	2.1	1.3	2.2	3.9	3.8	3.6	2.9	2.6	3.8	4.0
60	3.5	3.4	1.4	0.8	1.0	3.3	3.0	3.0	2.2	2.3	3.5	3.2
50	2.8	2.4	1.0	0.6	0.7	2.4	2.3	2.7	1.9	2.0	2.6	2.8
40	2.1	1.8	0.6	0.4	0.5	1.6	1.8	2.0	1.5	1.8	2.3	2.4
30	1.8	1.2	0.5	0.3	0.4	1.1	1.5	1.1	1.2	1.4	1.6	2.0
20	1.4	0.9	0.4	0.3	0.3	0.4	1.3	0.7	0.8	1.0	1.4	1.5
10	1.1	0.7	0.4	0.3	0.3	0.3	0.7	0.4	0.5	0.8	1.0	1.2
1	0.6	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.6	0.7
0.1	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.6	0.5

Table 7.3 Summary of the monthly flow (in m^3/s) distribution under Scenario 2 (refer to Table 3.2 for colour coding of abiotic states)

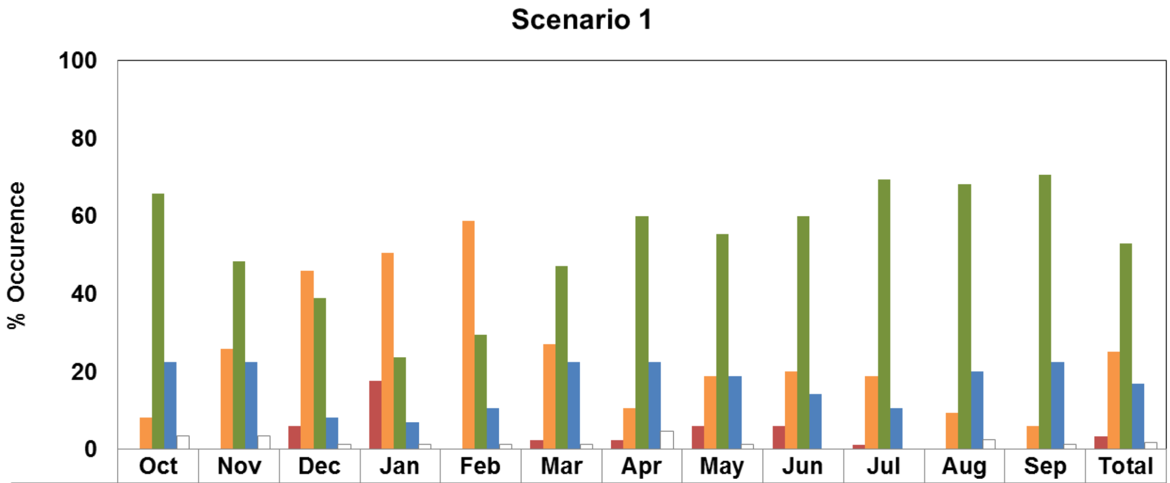
%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	23.1	29.5	27.0	15.7	15.0	22.3	30.0	16.4	7.8	9.9	34.3	28.8
99	17.7	22.2	15.6	11.4	11.7	15.0	28.8	13.7	7.3	9.6	26.6	15.0
90	10.6	8.1	3.8	2.5	4.9	5.9	8.1	7.1	5.0	4.8	6.2	6.7
80	5.6	6.1	2.5	1.5	2.3	4.1	5.4	4.7	3.2	3.1	4.9	4.8
70	3.7	3.7	1.2	0.6	0.9	2.9	3.4	3.1	2.5	2.1	3.5	3.6
60	2.6	2.4	0.7	0.2	0.2	2.0	2.6	2.6	1.9	1.9	2.9	2.7
50	1.8	1.5	0.4	0.1	0.1	1.5	1.6	2.1	1.6	1.6	2.2	2.2
40	1.2	0.8	0.2	0.1	0.1	0.5	1.2	1.4	1.2	1.4	1.9	1.8
30	0.9	0.5	0.2	0.0	0.0	0.1	0.8	0.9	0.8	1.0	1.3	1.5
20	0.6	0.3	0.1	0.0	0.0	0.0	0.5	0.3	0.5	0.7	1.0	0.9
10	0.4	0.2	0.1	0.0	0.0	0.0	0.2	0.1	0.2	0.6	0.6	0.5
1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2
0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1

Table 7.4 Summary of the monthly flow (in m^3/s) distribution under Scenario 3 (refer to Table 3.2 for colour coding of abiotic states)

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	22.7	29.2	26.7	15.4	13.9	20.8	29.7	16.1	7.5	9.6	32.8	28.5
99	16.4	21.9	15.3	11.1	11.0	14.5	28.5	13.4	7.0	9.4	26.1	14.7
90	10.1	7.8	3.3	2.2	4.5	5.5	7.8	6.8	4.7	4.5	5.9	6.3
80	5.3	5.6	2.0	1.0	1.8	3.8	4.6	4.1	2.9	2.8	4.6	4.6
70	3.4	3.4	0.9	0.3	0.4	2.3	2.9	2.9	2.1	1.8	3.1	3.3
60	2.3	2.1	0.4	0.1	0.1	1.2	2.3	2.3	1.6	1.6	2.5	2.4
50	1.5	1.2	0.3	0.1	0.1	0.8	1.0	1.4	1.2	1.3	1.9	1.9
40	0.9	0.5	0.2	0.1	0.0	0.2	0.6	0.8	0.8	1.1	1.5	1.5
30	0.7	0.3	0.1	0.0	0.0	0.1	0.3	0.4	0.5	0.7	0.9	1.2
20	0.4	0.3	0.1	0.0	0.0	0.0	0.1	0.0	0.2	0.4	0.6	0.6
10	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.3
1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1

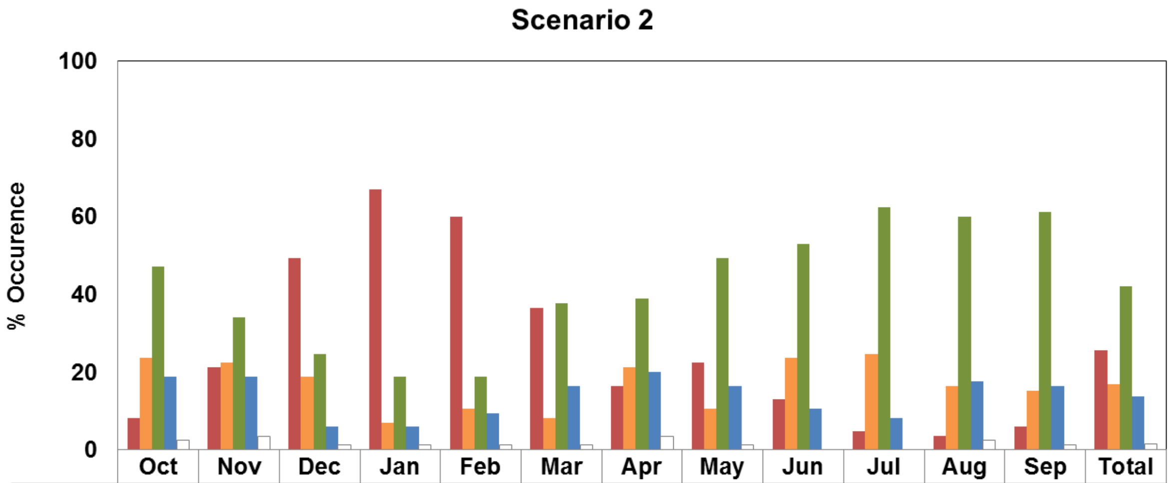
Table 7.5 Summary of the monthly flow (in m^3/s) distribution under Scenario 4 (refer to Table 3.2 for colour coding of abiotic states)

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	21.9	27.9	26.0	14.7	11.8	19.3	28.8	15.4	6.8	8.9	31.0	25.5
99	14.8	21.1	14.6	9.9	10.0	13.3	26.3	12.7	6.3	8.6	24.3	13.6
90	9.0	6.9	2.1	1.0	3.2	4.8	6.7	5.7	3.9	3.6	5.2	5.6
80	4.0	4.3	0.9	0.3	0.6	2.3	3.0	2.9	2.1	2.0	3.5	3.6
70	2.5	2.6	0.4	0.1	0.2	1.0	2.0	2.0	1.4	1.1	2.2	2.3
60	1.2	1.1	0.3	0.1	0.1	0.2	1.4	1.5	0.8	0.8	1.4	1.5
50	0.8	0.5	0.2	0.1	0.1	0.2	0.3	0.6	0.4	0.5	0.9	0.8
40	0.7	0.3	0.2	0.1	0.0	0.1	0.2	0.2	0.3	0.4	0.6	0.6
30	0.5	0.3	0.1	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.4	0.3
20	0.3	0.2	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.2	0.3	0.3
10	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2
1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1



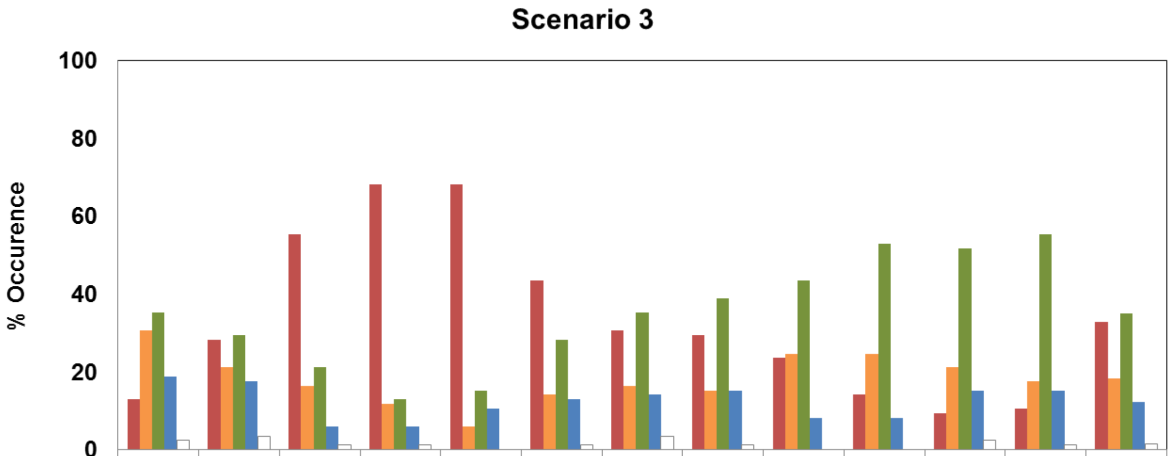
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	6	18	0	2	2	6	6	1	0	0	3
State 2	8	26	46	51	59	27	11	19	20	19	9	6	25
State 3	66	48	39	24	29	47	60	55	60	69	68	71	53
State 4	22	22	8	7	11	22	22	19	14	11	20	22	17
State 5	4	4	1	1	1	1	5	1	0	0	2	1	2

Figure 7.1 Occurrence of the various abiotic states under the Scenario 1 (refer to Table 3.2 for colour coding of abiotic states)



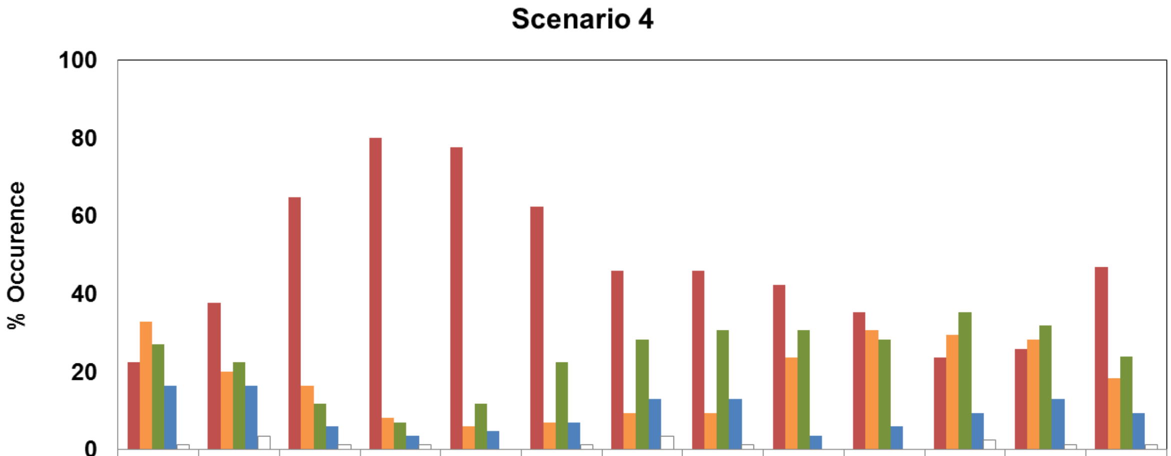
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	8	21	49	67	60	36	16	22	13	5	4	6	26
State 2	24	22	19	7	11	8	21	11	24	25	16	15	17
State 3	47	34	25	19	19	38	39	49	53	62	60	61	42
State 4	19	19	6	6	9	16	20	16	11	8	18	16	14
State 5	2	4	1	1	1	1	4	1	0	0	2	1	2

Figure 7.2 Occurrence of the various abiotic states under the Scenario 2 (refer to Table 3.2 for colour coding of abiotic states)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	13	28	55	68	68	44	31	29	24	14	9	11	33
State 2	31	21	16	12	6	14	16	15	25	25	21	18	18
State 3	35	29	21	13	15	28	35	39	44	53	52	55	35
State 4	19	18	6	6	11	13	14	15	8	8	15	15	12
State 5	2	4	1	1	0	1	4	1	0	0	2	1	1

Figure 7.3 Occurrence of the various abiotic states under the Scenario 3 (refer to Table 3.2 for colour coding of abiotic states)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	22	38	65	80	78	62	46	46	42	35	24	26	47
State 2	33	20	16	8	6	7	9	9	24	31	29	28	18
State 3	27	22	12	7	12	22	28	31	31	28	35	32	24
State 4	16	16	6	4	5	7	13	13	4	6	9	13	9
State 5	1	4	1	1	0	1	4	1	0	0	2	1	1

Figure 7.4 Occurrence of the various abiotic states under the Scenario 4 (refer to Table 3.2 for colour coding of abiotic states)

Table 7.6 Simulated monthly flows (in m^3/s) for Scenario 1 (refer to Table 3.2 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	1.6	0.9	4.8	0.8	8.1	3.8	7.7	2.9	5.6	3.4	3.6	3.0
1921	1.2	0.5	1.9	7.2	1.9	6.2	2.9	1.1	1.0	2.3	1.6	1.2
1922	1.8	4.2	0.5	0.3	0.3	12.4	6.0	6.2	4.3	2.2	1.4	0.9
1923	3.2	4.4	0.5	0.3	0.4	0.3	0.4	0.3	1.3	0.9	5.7	2.6
1924	0.8	2.1	0.6	0.3	0.3	3.6	1.6	0.3	2.2	1.3	1.0	3.1
1925	3.5	2.0	0.4	0.3	0.3	0.6	1.6	0.5	0.7	2.5	2.4	2.2
1926	7.9	4.8	0.5	0.3	0.5	1.2	1.3	2.1	1.2	0.4	2.5	1.3
1927	0.5	2.1	0.5	0.3	0.3	7.8	2.5	0.4	0.8	0.5	1.8	3.4
1928	1.4	31.6	14.2	0.9	0.7	1.6	1.2	2.4	1.8	6.4	5.3	3.1
1929	1.8	0.6	1.0	0.4	17.1	7.7	2.1	3.8	2.2	1.0	1.9	2.0
1930	4.1	1.2	0.3	0.3	0.3	7.3	10.1	2.8	0.8	4.7	2.9	2.6
1931	8.1	2.4	9.8	2.8	4.8	2.0	0.4	0.3	1.3	1.4	0.9	30.6
1932	11.0	1.6	0.4	0.3	0.4	1.4	0.7	2.9	1.7	0.9	6.5	2.8
1933	0.7	7.7	1.4	3.5	3.5	6.0	1.9	0.3	0.3	3.8	4.1	2.8
1934	23.8	13.6	1.3	0.3	0.4	1.3	1.7	7.1	6.0	2.8	1.4	4.1
1935	2.8	4.8	1.5	0.4	0.5	0.4	0.3	3.2	1.0	2.0	1.1	4.0
1936	3.2	18.0	7.6	1.2	0.3	6.3	2.0	0.3	0.4	1.4	1.2	2.4
1937	0.8	1.8	4.2	1.8	0.3	3.3	3.3	1.1	0.9	1.4	1.1	1.8
1938	3.9	7.5	2.7	0.6	3.8	9.5	3.8	0.9	0.3	2.6	12.4	5.1
1939	2.0	1.4	0.4	0.7	12.4	5.2	3.5	1.7	1.0	0.8	0.7	2.0
1940	1.0	5.6	0.9	1.0	0.4	0.3	7.9	2.8	3.1	2.0	2.2	2.7
1941	5.2	2.6	0.8	2.5	0.5	1.6	1.5	2.3	1.5	0.9	0.8	1.5
1942	2.1	0.7	2.6	9.5	3.2	1.2	1.3	0.6	0.3	0.3	1.2	7.4
1943	3.1	8.3	2.7	0.4	0.3	3.3	1.8	4.7	2.7	2.5	3.0	6.4
1944	5.1	1.0	0.3	0.3	0.3	0.3	0.4	7.0	5.2	2.5	3.6	3.2
1945	6.7	2.0	0.4	0.3	0.4	11.4	3.8	0.3	0.3	1.1	1.4	1.3
1946	1.3	0.8	0.3	0.3	0.7	12.0	5.0	2.8	1.8	4.3	2.3	3.0
1947	3.1	2.9	0.4	2.6	0.5	4.9	5.6	2.0	0.7	1.0	0.8	1.9
1948	13.3	4.4	0.5	0.9	0.4	0.3	1.5	3.0	1.6	0.8	0.6	1.1
1949	0.6	12.1	2.5	0.3	0.3	0.3	1.8	1.8	0.8	1.9	2.2	1.7
1950	5.4	8.7	1.7	11.4	3.6	3.2	1.3	1.6	2.5	6.7	3.5	7.0
1951	2.7	0.7	0.3	0.8	0.8	0.3	1.2	0.5	0.5	0.8	2.5	9.9
1952	4.3	7.3	2.3	0.5	1.3	0.3	2.3	1.0	1.4	7.2	3.7	5.3
1953	5.9	5.0	0.6	0.3	0.3	1.3	6.1	11.4	4.3	2.7	11.7	5.3
1954	1.3	2.2	0.5	2.5	10.5	2.3	0.7	0.4	1.0	1.9	2.6	3.2
1955	2.4	1.7	0.4	0.3	0.3	3.6	1.8	7.9	3.2	2.0	2.5	2.5
1956	5.2	1.4	4.8	0.6	3.1	2.3	1.4	3.5	8.1	4.4	5.1	8.0
1957	4.8	1.0	0.3	0.3	0.3	4.7	2.9	18.2	7.1	1.8	6.4	3.5
1958	2.8	0.9	0.4	3.6	6.8	6.1	10.1	7.0	2.4	9.8	7.7	4.1
1959	8.5	2.5	0.5	0.6	0.5	3.4	2.1	2.9	3.1	2.4	1.4	2.3
1960	1.4	4.0	4.0	3.4	1.2	2.1	1.6	3.0	1.7	2.4	3.4	3.0
1961	4.3	1.8	0.4	0.5	2.5	4.3	3.7	1.3	1.3	1.0	25.1	8.7
1962	8.3	8.0	1.2	1.6	0.4	7.4	3.3	2.7	1.2	2.6	1.4	0.7
1963	2.6	1.8	4.3	2.9	1.5	4.0	1.6	0.5	6.2	2.4	4.1	7.0
1964	4.4	3.3	0.6	0.3	1.6	3.4	2.5	4.6	2.0	1.6	1.9	1.2
1965	12.4	9.6	3.5	2.0	0.3	0.9	1.4	5.4	2.3	0.9	8.5	6.7
1966	1.9	0.6	0.3	0.3	1.0	5.3	30.5	14.3	5.1	4.8	3.9	5.1
1967	2.1	3.1	0.5	0.3	0.3	0.9	2.3	3.6	6.6	2.7	5.8	3.3
1968	1.9	5.4	0.6	0.3	0.4	0.4	1.5	0.5	4.3	2.1	2.3	1.9
1969	1.0	0.4	0.3	0.3	2.4	0.4	0.3	0.3	0.8	0.8	4.4	1.9
1970	2.7	0.6	1.2	0.3	5.9	5.6	8.1	6.3	3.4	10.1	11.3	4.5
1971	2.0	5.8	0.9	0.4	3.2	3.0	3.5	3.3	2.0	2.0	5.5	5.7
1972	1.5	1.9	0.4	0.3	0.3	0.3	1.6	1.1	2.4	2.3	2.8	2.1
1973	1.2	1.5	1.8	4.5	7.2	5.8	1.7	7.7	3.1	1.0	5.8	3.9
1974	1.9	1.7	0.4	0.6	0.3	0.3	0.7	2.2	2.9	3.2	6.6	7.6
1975	2.7	3.5	1.2	0.4	3.6	4.8	3.2	3.4	7.4	5.2	2.8	2.6
1976	11.4	7.7	2.1	0.4	8.4	3.3	3.0	12.4	5.5	2.2	2.4	2.9
1977	2.8	4.8	1.7	0.4	0.3	0.4	3.1	1.1	2.2	2.4	3.6	2.4
1978	3.1	1.3	2.5	0.8	4.0	0.8	0.3	3.6	1.6	7.4	6.4	5.2
1979	4.6	1.2	1.8	2.0	0.6	0.3	1.1	0.3	2.2	1.0	1.5	2.4
1980	3.4	11.7	3.4	17.1	12.0	10.1	19.5	10.1	3.5	3.3	11.2	5.5
1981	1.5	0.9	4.0	0.6	0.9	2.7	28.7	8.9	3.1	3.9	3.6	8.6
1982	4.6	1.0	0.4	0.3	0.7	0.4	1.1	3.8	5.1	5.4	3.1	6.5
1983	3.7	4.9	1.0	0.4	0.5	3.5	1.7	0.5	0.5	2.0	1.5	0.7
1984	2.7	0.7	0.4	8.5	7.1	1.2	4.4	2.0	2.2	7.7	3.7	1.2
1985	12.3	8.3	4.4	0.6	0.6	0.8	1.0	0.7	0.3	0.5	35.8	12.8
1986	5.8	2.7	0.5	0.3	0.4	0.3	10.1	3.1	1.9	1.4	3.7	4.8
1987	1.7	0.6	1.0	0.3	0.3	1.7	6.5	2.2	2.3	1.8	2.7	2.3
1988	2.0	0.8	2.2	1.8	0.5	2.6	8.7	3.0	1.2	1.1	1.8	1.4
1989	13.5	8.9	0.9	0.3	0.9	0.7	12.0	4.9	5.3	2.8	1.3	1.4
1990	1.7	0.7	1.2	2.2	3.2	0.6	0.4	0.8	0.6	0.8	0.8	0.5
1991	18.7	5.1	1.2	0.6	1.5	1.8	1.4	1.0	3.5	4.0	2.4	2.4
1992	12.8	9.5	1.4	0.4	0.4	0.4	16.3	6.9	2.1	1.8	2.1	4.1
1993	1.7	0.7	5.9	1.3	2.3	2.8	2.8	1.4	1.4	1.7	6.3	3.9
1994	3.9	0.8	9.0	2.4	2.9	4.6	5.2	5.3	2.1	1.2	1.4	2.1
1995	1.4	13.0	14.3	3.3	0.4	2.2	1.0	0.4	0.3	1.8	1.2	1.3
1996	7.9	22.1	5.2	0.3	0.5	3.3	2.4	4.1	2.8	4.9	4.7	2.5
1997	1.0	0.9	0.4	0.6	0.8	7.0	6.5	3.5	1.5	1.8	1.4	1.3
1998	0.7	3.4	3.8	2.5	4.9	3.9	2.6	1.3	0.7	1.3	0.9	1.8
1999	3.5	0.7	0.3	5.0	1.6	14.6	4.6	3.3	1.3	0.6	0.6	0.9
2000	1.7	4.0	2.1	0.4	0.3	1.2	6.0	1.9	0.4	0.4	4.2	2.9
2001	1.3	3.1	0.5	0.9	1.0	0.3	1.5	2.3	1.6	1.9	3.9	4.0
2002	1.2	0.7	0.9	0.9	0.3	25.1	8.6	8.1	3.6	1.6	2.8	1.6
2003	4.3	0.9	0.4	0.7	2.2	1.1	6.0	2.3	1.4	1.9	1.1	1.3
2004	16.2	4.3	28.3	10.7	0.8	2.4	7.1	4.4	3.8	2.0	1.6	1.3

Table 7.7 Simulated monthly flows (in m³/s) for Scenario 2 (refer to Table 3.2 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.9	0.4	3.8	0.3	6.9	2.9	7.5	2.6	5.4	3.1	3.3	2.7
1921	0.4	0.1	0.9	6.0	1.1	6.0	2.1	0.8	0.7	2.1	1.3	0.4
1922	0.9	3.1	0.1	0.0	0.0	0.0	3.8	5.7	4.1	1.9	1.1	0.3
1923	2.0	3.3	0.2	0.0	0.0	0.0	0.0	0.0	0.4	0.6	4.9	1.5
1924	0.2	1.0	0.1	0.0	0.0	2.0	0.8	0.0	1.8	1.0	0.7	2.7
1925	2.4	1.0	0.1	0.0	0.0	0.0	0.8	0.3	0.5	2.1	1.9	1.8
1926	7.5	3.7	0.3	0.0	0.0	0.1	0.6	1.7	0.8	0.2	2.1	0.5
1927	0.1	1.0	0.0	0.0	0.0	5.5	1.6	0.2	0.5	0.3	1.4	3.0
1928	0.5	30.3	13.2	0.4	0.1	0.7	0.8	2.1	1.5	6.1	5.1	2.2
1929	1.0	0.2	0.2	0.1	15.4	6.6	1.3	3.6	1.9	0.7	1.6	1.2
1930	3.8	0.4	0.0	0.0	0.0	5.2	9.8	2.5	0.6	4.4	2.6	2.3
1931	7.8	1.5	9.5	2.0	3.7	1.2	0.1	0.1	0.9	1.0	0.6	30.4
1932	9.9	0.7	0.2	0.0	0.1	0.2	0.2	2.4	1.3	0.6	5.8	1.9
1933	0.3	6.1	0.6	2.6	2.5	5.7	1.2	0.1	0.0	3.1	3.7	1.8
1934	23.7	12.5	0.6	0.1	0.0	0.2	1.4	6.5	5.7	2.5	1.1	3.8
1935	1.8	3.7	0.8	0.1	0.0	0.0	0.0	1.5	0.6	1.6	0.8	3.5
1936	2.1	16.8	6.6	0.5	0.0	4.9	1.2	0.0	0.2	1.0	0.4	1.9
1937	0.1	0.8	3.0	0.9	0.0	2.2	3.0	0.8	0.7	1.2	0.8	1.5
1938	2.9	7.3	1.8	0.1	2.6	9.2	3.0	0.3	0.1	2.1	11.1	4.8
1939	1.1	0.6	0.1	0.1	10.9	4.2	3.2	1.0	0.8	0.6	0.2	1.6
1940	0.2	5.0	0.4	0.2	0.0	0.0	6.0	2.6	2.8	1.8	1.9	2.4
1941	4.9	1.7	0.2	1.5	0.1	0.7	1.2	2.0	1.2	0.6	0.6	1.1
1942	1.2	0.1	1.6	8.3	2.3	0.5	0.6	0.0	0.0	0.0	0.9	6.6
1943	2.2	8.0	1.9	0.1	0.0	2.0	0.9	4.3	2.4	2.2	2.8	6.2
1944	4.0	0.4	0.1	0.0	0.0	0.0	0.0	4.9	4.7	2.1	3.1	2.8
1945	6.5	1.1	0.2	0.0	0.0	9.6	3.0	0.2	0.2	0.9	1.0	0.5
1946	0.5	0.1	0.0	0.0	0.0	9.9	4.7	2.5	1.5	4.1	1.4	2.8
1947	2.1	1.9	0.1	1.5	0.1	3.6	5.3	1.1	0.5	0.7	0.2	1.5
1948	12.1	3.5	0.2	0.2	0.0	0.0	0.5	2.6	0.8	0.6	0.4	0.4
1949	0.1	10.1	1.7	0.1	0.0	0.0	0.6	1.0	0.1	1.5	1.8	1.3
1950	4.8	7.4	0.9	10.5	2.7	2.3	0.6	1.3	2.3	6.4	3.2	6.7
1951	1.8	0.3	0.1	0.0	0.1	0.0	0.4	0.2	0.3	0.6	2.0	8.8
1952	3.3	6.1	1.5	0.1	0.4	0.0	1.2	0.3	1.1	6.8	3.4	5.1
1953	5.6	3.9	0.3	0.0	0.0	0.2	5.4	10.1	4.1	2.5	11.6	4.3
1954	0.8	1.2	0.2	1.4	10.1	1.6	0.2	0.3	0.7	1.5	2.2	2.9
1955	1.5	0.8	0.1	0.0	0.0	2.1	1.3	7.4	2.9	1.7	2.3	1.6
1956	5.0	0.6	3.8	0.1	2.0	1.5	0.7	3.2	7.9	4.1	4.9	7.7
1957	3.8	0.5	0.1	0.0	0.0	3.0	2.4	16.7	6.8	1.1	6.1	2.6
1958	1.9	0.3	0.2	2.2	5.6	5.8	9.9	6.7	2.1	9.6	7.5	3.1
1959	8.3	1.7	0.2	0.2	0.2	1.8	1.7	2.6	2.8	2.1	1.1	2.0
1960	0.6	3.0	3.0	2.5	0.4	1.3	1.3	2.7	1.4	2.2	3.2	2.7
1961	4.0	0.9	0.1	0.1	1.2	3.8	3.4	1.0	1.0	0.7	25.0	7.7
1962	8.0	7.8	0.5	0.9	0.1	5.9	3.1	2.5	0.9	2.3	1.1	0.2
1963	1.5	0.9	3.3	2.0	0.7	3.0	0.9	0.3	5.9	2.1	3.9	6.7
1964	3.4	2.4	0.3	0.0	0.4	2.2	2.2	4.4	1.7	1.3	1.6	0.4
1965	11.3	9.3	2.6	1.2	0.0	0.1	1.0	5.0	2.0	0.6	8.3	6.4
1966	1.0	0.2	0.0	0.0	0.0	3.8	30.1	13.2	4.8	4.6	3.6	4.9
1967	1.2	2.2	0.2	0.0	0.0	0.0	1.2	3.0	6.0	1.8	5.5	3.1
1968	1.0	4.2	0.1	0.0	0.0	0.0	0.2	0.3	3.6	1.6	2.0	1.0
1969	0.2	0.1	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.5	3.8	0.8
1970	1.6	0.1	0.4	0.0	4.0	4.1	7.8	6.0	3.2	9.9	10.2	3.6
1971	1.2	4.6	0.3	0.1	1.9	2.1	3.2	3.0	1.7	1.7	5.3	5.5
1972	0.7	1.0	0.1	0.0	0.0	0.0	0.3	0.8	2.0	1.9	2.3	1.7
1973	0.4	0.6	1.0	3.5	6.0	5.5	0.9	7.5	2.8	0.4	5.4	3.7
1974	1.0	0.8	0.1	0.0	0.0	0.0	0.0	1.4	2.4	2.7	6.3	7.4
1975	1.8	2.5	0.4	0.1	2.3	3.7	3.0	3.2	7.2	5.0	2.5	2.4
1976	11.2	6.5	1.3	0.1	6.8	2.4	2.7	12.3	5.3	2.0	2.2	2.6
1977	1.8	3.7	0.9	0.1	0.0	0.0	1.6	0.8	1.9	2.0	3.1	2.1
1978	2.1	0.4	1.6	0.2	3.0	0.3	0.1	2.2	1.2	7.2	6.1	4.9
1979	3.5	0.5	1.0	1.1	0.1	0.1	0.2	0.1	1.8	0.6	1.2	2.0
1980	2.4	10.5	2.5	16.2	10.7	9.9	19.4	9.9	3.2	3.0	11.0	4.6
1981	0.8	0.5	2.8	0.1	0.1	1.7	28.6	8.0	2.8	3.7	3.3	8.4
1982	3.5	0.4	0.1	0.1	0.1	0.1	0.1	3.1	4.5	4.9	2.2	6.2
1983	2.7	3.8	0.3	0.1	0.1	2.0	0.9	0.3	0.3	1.7	0.7	0.2
1984	1.5	0.1	0.1	6.7	5.9	0.4	4.2	1.2	2.0	7.5	2.8	0.6
1985	11.0	7.0	3.4	0.2	0.1	0.1	0.6	0.0	0.0	0.3	35.1	12.0
1986	5.5	1.8	0.3	0.1	0.0	0.0	7.6	2.6	1.6	1.1	3.5	4.6
1987	0.9	0.2	0.2	0.0	0.0	0.5	5.7	1.9	2.1	1.6	2.4	1.4
1988	1.2	0.3	1.2	1.0	0.1	1.5	8.4	2.1	0.9	0.8	1.5	0.6
1989	12.4	7.6	0.4	0.0	0.0	0.0	10.6	4.6	5.1	1.9	1.0	0.7
1990	0.8	0.1	0.4	1.1	2.1	0.2	0.1	0.0	0.3	0.6	0.1	0.1
1991	16.6	4.2	0.5	0.0	0.5	0.9	0.7	0.7	3.2	3.8	2.2	1.5
1992	11.7	8.2	1.0	0.1	0.1	0.1	13.8	6.6	1.8	1.5	1.8	3.9
1993	0.8	0.2	4.5	0.6	1.4	1.8	2.5	1.1	1.1	1.4	6.0	2.9
1994	2.8	0.3	7.5	1.5	1.9	3.5	4.9	5.0	1.8	1.0	1.1	1.8
1995	0.5	11.9	13.2	2.4	0.1	1.1	0.3	0.0	0.0	1.3	0.4	0.9
1996	7.2	20.7	4.4	0.2	0.1	1.8	1.9	3.8	2.5	4.6	4.4	1.5
1997	0.4	0.3	0.1	0.1	0.1	5.8	6.2	3.2	1.2	1.5	1.2	0.5
1998	0.2	2.1	2.7	1.6	3.7	2.9	2.3	1.0	0.4	1.0	0.7	1.5
1999	3.2	0.1	0.0	3.3	0.7	13.4	3.7	3.1	1.0	0.4	0.4	0.2
2000	0.7	2.6	1.2	0.1	0.0	0.1	5.3	1.6	0.2	0.2	3.7	1.9
2001	0.5	2.0	0.1	0.1	0.2	0.0	0.6	1.8	1.2	1.5	3.5	3.7
2002	0.5	0.2	0.1	0.1	0.0	23.1	8.3	7.9	3.3	1.3	2.5	0.8
2003	4.0	0.3	0.1	0.1	1.0	0.4	5.5	2.0	1.2	1.6	0.8	1.0
2004	14.9	3.4	28.2	9.6	0.3	1.4	6.8	4.1	3.5	1.1	1.3	0.5

Table 7.8 Simulated monthly flows (in m^3/s) for Scenario 3 (refer to Table 3.2 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.7	0.4	3.1	0.3	6.2	2.6	7.2	2.3	5.1	2.8	3.1	2.4
1921	0.4	0.1	0.1	5.6	0.8	5.7	1.8	0.5	0.5	1.8	1.1	0.2
1922	0.6	2.8	0.1	0.0	0.0	0.0	2.3	5.4	3.8	1.6	0.8	0.3
1923	1.5	2.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.2	1.2
1924	0.2	0.5	0.1	0.0	0.0	0.8	0.5	0.0	1.3	0.7	0.4	2.4
1925	2.1	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.6	1.5
1926	7.2	3.4	0.3	0.0	0.0	0.0	0.0	0.6	0.5	0.1	1.7	0.2
1927	0.1	0.3	0.0	0.0	0.0	4.3	1.3	0.0	0.2	0.0	1.1	2.7
1928	0.2	30.0	12.9	0.4	0.1	0.1	0.4	1.8	1.2	5.9	4.8	1.9
1929	0.7	0.2	0.1	0.1	14.2	6.4	1.0	3.3	1.6	0.4	1.4	0.9
1930	3.5	0.2	0.0	0.0	0.0	3.9	9.6	2.3	0.4	4.1	2.3	2.0
1931	7.5	1.2	9.2	1.7	3.4	0.9	0.1	0.0	0.2	0.7	0.3	30.1
1932	9.6	0.5	0.2	0.0	0.1	0.1	0.1	0.8	1.0	0.3	5.5	1.6
1933	0.3	5.5	0.3	2.3	2.2	5.4	0.9	0.1	0.0	2.3	3.4	1.5
1934	23.4	12.2	0.6	0.1	0.0	0.1	0.1	6.2	5.4	2.2	0.9	3.5
1935	1.5	3.4	0.5	0.1	0.0	0.0	0.0	0.1	0.3	1.3	0.5	3.2
1936	1.9	16.5	6.3	0.3	0.0	4.2	0.9	0.0	0.0	0.4	0.1	1.6
1937	0.1	0.2	2.7	0.7	0.0	1.6	2.7	0.5	0.4	0.9	0.5	1.2
1938	2.6	7.0	1.6	0.1	2.1	8.9	2.7	0.3	0.1	1.3	10.8	4.5
1939	0.8	0.3	0.1	0.1	10.0	3.9	2.9	0.7	0.5	0.4	0.2	0.9
1940	0.2	4.5	0.4	0.0	0.0	0.0	4.7	2.3	2.5	1.5	1.6	2.2
1941	4.6	1.4	0.2	1.0	0.1	0.1	0.8	1.7	1.0	0.3	0.3	0.8
1942	0.9	0.1	1.0	8.0	2.0	0.2	0.3	0.0	0.0	0.0	0.0	5.9
1943	1.9	7.7	1.6	0.1	0.0	1.2	0.6	4.0	2.1	1.9	2.5	5.9
1944	3.7	0.4	0.1	0.0	0.0	0.0	0.0	3.1	4.4	1.8	2.8	2.5
1945	6.2	0.8	0.2	0.0	0.0	8.4	2.8	0.2	0.1	0.2	0.6	0.2
1946	0.2	0.1	0.0	0.0	0.0	8.4	4.4	2.2	1.2	3.8	1.1	2.5
1947	1.8	1.6	0.1	0.9	0.1	3.0	5.0	0.8	0.2	0.4	0.2	1.0
1948	11.7	3.2	0.2	0.1	0.0	0.0	0.0	1.4	0.6	0.3	0.2	0.1
1949	0.1	9.3	1.4	0.1	0.0	0.0	0.0	0.1	0.0	1.1	1.4	1.0
1950	4.5	7.1	0.7	10.2	2.4	2.0	0.3	1.0	2.0	6.1	3.0	6.4
1951	1.5	0.3	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.2	0.4	8.5
1952	3.0	5.8	1.2	0.1	0.1	0.0	0.3	0.0	0.8	6.5	3.2	4.8
1953	5.3	3.6	0.3	0.0	0.0	0.1	4.0	9.8	3.8	2.2	11.3	4.0
1954	0.8	0.7	0.2	0.7	9.8	1.3	0.2	0.1	0.1	1.1	1.9	2.6
1955	1.2	0.5	0.1	0.0	0.0	1.0	1.0	7.1	2.6	1.4	2.0	1.3
1956	4.7	0.3	3.5	0.1	1.4	1.2	0.4	2.9	7.6	3.8	4.6	7.4
1957	3.5	0.5	0.1	0.0	0.0	1.6	2.1	16.4	6.5	0.9	5.7	2.3
1958	1.6	0.3	0.2	1.3	5.3	5.6	9.6	6.4	1.8	9.3	7.2	2.9
1959	8.0	1.4	0.2	0.2	0.2	0.7	1.4	2.3	2.6	1.8	0.8	1.8
1960	0.3	2.7	2.7	2.2	0.2	1.0	1.0	2.4	1.1	1.9	2.9	2.4
1961	3.8	0.6	0.1	0.1	0.2	3.5	3.1	0.7	0.7	0.4	24.7	7.4
1962	7.7	7.5	0.5	0.4	0.1	5.3	2.8	2.2	0.6	2.1	0.8	0.2
1963	0.9	0.6	3.0	1.7	0.4	2.7	0.6	0.0	5.6	1.8	3.6	6.5
1964	3.1	2.1	0.3	0.0	0.0	1.4	1.9	4.1	1.4	1.0	1.3	0.3
1965	10.8	9.0	2.3	0.9	0.0	0.0	0.3	4.7	1.7	0.4	8.0	6.2
1966	0.7	0.2	0.0	0.0	0.0	2.3	29.8	12.9	4.5	4.3	3.3	4.6
1967	0.9	1.9	0.2	0.0	0.0	0.0	0.1	2.4	5.7	1.5	5.2	2.8
1968	0.7	3.9	0.1	0.0	0.0	0.0	0.1	0.0	1.9	1.3	1.7	0.7
1969	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.5
1970	1.3	0.1	0.1	0.0	3.1	3.8	7.5	5.7	2.9	9.6	9.9	3.3
1971	1.0	4.3	0.3	0.1	1.0	1.8	3.0	2.7	1.5	1.4	5.0	5.2
1972	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.9	1.6	2.0	1.4
1973	0.2	0.3	0.6	3.1	5.7	5.2	0.6	7.2	2.5	0.3	4.9	3.4
1974	0.8	0.5	0.1	0.0	0.0	0.0	0.0	0.0	1.7	2.4	6.0	7.1
1975	1.5	2.2	0.2	0.1	1.6	3.4	2.7	2.9	6.9	4.7	2.2	2.1
1976	10.9	6.2	1.0	0.1	6.2	2.1	2.4	12.0	5.0	1.7	1.9	2.3
1977	1.5	3.4	0.6	0.1	0.0	0.0	0.4	0.5	1.6	1.8	2.8	1.8
1978	1.8	0.2	1.3	0.1	2.5	0.3	0.1	1.3	0.9	6.9	5.8	4.6
1979	3.2	0.5	0.4	0.8	0.1	0.1	0.1	0.0	0.5	0.4	0.9	1.7
1980	2.1	10.3	2.2	15.9	10.4	9.6	19.1	9.6	2.9	2.8	10.7	4.3
1981	0.8	0.5	1.9	0.1	0.1	0.8	28.3	7.7	2.5	3.4	3.1	8.1
1982	3.2	0.4	0.1	0.1	0.1	0.1	0.1	1.4	3.9	4.6	2.0	6.0
1983	2.4	3.5	0.3	0.1	0.1	0.9	0.6	0.1	0.2	1.2	0.5	0.2
1984	0.8	0.1	0.1	5.8	5.6	0.2	3.8	0.9	1.7	7.2	2.5	0.6
1985	10.5	6.7	3.1	0.2	0.1	0.1	0.1	0.0	0.0	0.1	33.6	11.7
1986	5.3	1.5	0.3	0.1	0.0	0.0	6.2	2.3	1.3	0.8	3.2	4.3
1987	0.7	0.2	0.1	0.0	0.0	0.0	4.3	1.6	1.8	1.3	2.1	1.1
1988	0.9	0.3	0.6	0.7	0.1	1.0	8.1	1.8	0.6	0.5	1.2	0.3
1989	12.1	7.4	0.4	0.0	0.0	0.0	9.1	4.3	4.8	1.6	0.7	0.5
1990	0.4	0.1	0.1	0.5	1.8	0.2	0.1	0.0	0.1	0.1	0.1	0.1
1991	15.1	3.9	0.2	0.0	0.1	0.5	0.4	0.4	2.9	3.5	1.9	1.3
1992	11.4	7.9	1.0	0.1	0.1	0.1	12.4	6.3	1.5	1.2	1.5	3.6
1993	0.6	0.2	3.9	0.3	1.1	1.6	2.2	0.9	0.8	1.2	5.7	2.6
1994	2.5	0.3	7.0	1.3	1.7	3.2	4.6	4.7	1.5	0.7	0.8	1.5
1995	0.3	11.5	12.9	2.1	0.1	0.5	0.1	0.0	0.0	0.4	0.1	0.6
1996	6.9	20.4	4.1	0.2	0.1	1.0	1.7	3.5	2.3	4.3	4.2	1.3
1997	0.4	0.3	0.1	0.1	0.1	4.1	5.9	2.9	0.9	1.2	0.9	0.3
1998	0.2	1.3	2.4	1.3	3.4	2.6	2.0	0.7	0.2	0.7	0.4	1.2
1999	2.9	0.1	0.0	2.5	0.4	13.1	3.4	2.8	0.7	0.2	0.2	0.1
2000	0.1	2.3	0.9	0.1	0.0	0.0	4.2	1.3	0.2	0.2	2.9	1.6
2001	0.3	1.6	0.1	0.0	0.1	0.0	0.0	0.8	0.9	1.2	3.2	3.4
2002	0.5	0.2	0.1	0.0	0.0	21.5	8.0	7.6	3.0	1.0	2.2	0.5
2003	3.7	0.3	0.1	0.1	0.1	0.1	4.8	1.7	0.9	1.3	0.5	0.7
2004	14.6	3.1	27.9	9.3	0.3	0.8	6.6	3.8	3.2	0.9	1.0	0.3

Table 7.9 Simulated monthly flows (in m^3/s) for Scenario 4 (refer to Table 3.2 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.7	0.4	1.1	0.3	4.8	1.9	6.5	1.6	4.4	2.1	2.4	1.7
1921	0.4	0.1	0.1	2.8	0.3	4.8	1.1	0.2	0.2	0.3	0.3	0.2
1922	0.1	1.1	0.1	0.0	0.0	0.0	1.1	4.7	3.1	0.9	0.4	0.3
1923	0.3	1.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.5	0.5
1924	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.2	0.1	0.2
1925	0.9	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.4
1926	5.8	2.7	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2
1927	0.1	0.0	0.0	0.0	0.0	2.7	0.6	0.0	0.0	0.0	0.1	0.4
1928	0.2	28.7	12.2	0.4	0.1	0.1	0.1	0.2	0.3	4.0	4.1	1.2
1929	0.6	0.2	0.1	0.1	12.0	5.7	0.4	2.5	0.9	0.3	0.3	0.3
1930	2.5	0.2	0.0	0.0	0.0	2.3	8.9	1.6	0.4	2.7	1.6	1.3
1931	6.8	1.1	8.0	1.0	2.7	0.2	0.1	0.0	0.1	0.2	0.3	26.8
1932	8.9	0.5	0.2	0.0	0.1	0.1	0.1	0.3	0.4	0.3	2.8	0.9
1933	0.3	4.1	0.3	0.9	1.5	4.7	0.4	0.1	0.0	0.3	2.4	0.8
1934	22.7	11.5	0.6	0.1	0.0	0.1	0.1	3.4	4.7	1.5	0.7	2.3
1935	0.8	2.7	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.8
1936	1.1	15.8	5.6	0.3	0.0	2.2	0.3	0.0	0.0	0.1	0.1	0.2
1937	0.1	0.1	0.1	0.1	0.0	0.2	1.4	0.2	0.2	0.2	0.2	0.2
1938	0.9	6.2	0.9	0.1	0.6	8.2	2.0	0.3	0.1	0.4	8.9	3.8
1939	0.7	0.3	0.1	0.1	7.4	3.2	2.2	0.6	0.5	0.4	0.2	0.2
1940	0.2	1.6	0.4	0.0	0.0	0.0	2.8	1.6	1.8	0.8	0.9	1.5
1941	3.9	0.7	0.2	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3
1942	0.3	0.1	0.3	5.2	1.3	0.2	0.1	0.0	0.0	0.0	0.0	3.1
1943	1.2	7.0	0.9	0.1	0.0	0.1	0.2	2.0	1.4	1.2	1.8	5.2
1944	3.0	0.4	0.1	0.0	0.0	0.0	0.0	2.4	3.7	1.1	2.1	1.8
1945	5.5	0.6	0.2	0.0	0.0	6.7	2.1	0.2	0.1	0.2	0.2	0.2
1946	0.2	0.1	0.0	0.0	0.0	6.8	3.7	1.5	0.5	3.1	0.8	1.5
1947	1.0	0.9	0.1	0.1	0.1	1.0	4.3	0.2	0.2	0.2	0.2	0.3
1948	9.1	2.5	0.2	0.1	0.0	0.0	0.0	0.9	0.6	0.2	0.2	0.1
1949	0.1	6.7	1.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3
1950	2.3	6.4	0.6	8.9	1.7	1.3	0.2	0.2	0.9	5.4	2.3	5.7
1951	1.1	0.3	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.2	0.3	6.1
1952	2.3	5.1	0.6	0.1	0.1	0.0	0.1	0.0	0.1	3.4	2.5	4.1
1953	4.6	2.9	0.3	0.0	0.0	0.1	1.9	9.1	3.1	1.5	10.6	3.3
1954	0.8	0.5	0.2	0.1	6.9	0.6	0.2	0.1	0.1	0.4	0.6	0.7
1955	0.5	0.3	0.1	0.0	0.0	0.3	0.3	5.3	1.9	0.9	1.1	0.8
1956	3.8	0.3	2.1	0.1	0.2	0.3	0.3	1.6	6.9	3.1	3.9	6.7
1957	2.8	0.5	0.1	0.0	0.0	0.4	1.3	15.7	5.8	0.9	4.3	1.8
1958	0.8	0.3	0.2	0.2	3.4	4.9	8.9	5.7	1.2	8.6	6.5	2.2
1959	7.3	1.1	0.2	0.2	0.2	0.2	0.2	0.7	1.9	1.1	0.5	0.7
1960	0.3	1.2	2.0	1.5	0.2	0.2	0.2	1.4	0.6	1.0	2.1	1.7
1961	3.1	0.3	0.1	0.1	0.1	0.7	2.4	0.3	0.3	0.2	22.9	6.7
1962	7.0	6.8	0.5	0.1	0.1	2.8	2.1	1.5	0.2	1.1	0.4	0.2
1963	0.1	0.1	1.1	1.0	0.2	1.6	0.2	0.0	3.9	1.1	2.9	5.8
1964	2.4	1.4	0.3	0.0	0.0	0.1	0.4	2.8	0.7	0.5	0.6	0.3
1965	9.3	8.3	1.6	0.2	0.0	0.0	0.1	2.1	1.0	0.2	6.7	5.5
1966	0.7	0.2	0.0	0.0	0.0	0.6	29.1	12.2	3.8	3.6	2.6	3.9
1967	0.7	0.8	0.2	0.0	0.0	0.0	0.1	0.2	4.9	0.8	4.5	2.1
1968	0.5	2.8	0.1	0.0	0.0	0.0	0.1	0.0	0.3	0.5	1.0	0.3
1969	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.3
1970	0.2	0.1	0.1	0.0	0.6	3.1	6.8	5.0	2.2	8.9	9.2	2.6
1971	1.0	2.9	0.3	0.1	0.1	0.2	1.8	2.0	0.8	0.7	4.3	4.5
1972	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.7
1973	0.2	0.1	0.1	1.0	5.0	4.5	0.3	6.1	1.8	0.3	3.5	2.7
1974	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.1	1.4	5.3	6.4
1975	1.2	1.2	0.2	0.1	0.1	2.0	2.0	2.2	6.2	4.0	1.5	1.4
1976	10.2	5.5	0.6	0.1	4.5	1.4	1.7	11.3	4.3	1.0	1.2	1.6
1977	0.8	2.7	0.2	0.1	0.0	0.0	0.1	0.1	1.4	1.0	0.8	0.7
1978	0.7	0.2	0.1	0.1	0.7	0.3	0.1	0.0	0.1	5.4	5.1	3.9
1979	2.5	0.5	0.4	0.2	0.1	0.1	0.1	0.0	0.1	0.1	0.2	0.3
1980	0.3	9.2	1.5	15.2	9.7	8.9	18.4	8.9	2.2	2.1	10.0	3.6
1981	0.8	0.5	0.3	0.1	0.1	0.2	25.7	7.0	1.8	2.7	2.4	7.4
1982	2.5	0.4	0.1	0.1	0.1	0.1	0.1	1.4	2.1	3.9	1.3	5.2
1983	1.7	2.8	0.3	0.1	0.1	0.1	0.2	0.1	0.2	0.5	0.5	0.2
1984	0.2	0.1	0.1	3.6	4.9	0.2	2.4	0.4	0.8	6.4	1.8	0.6
1985	9.1	6.0	2.4	0.2	0.1	0.1	0.1	0.0	0.0	0.1	31.7	11.0
1986	4.6	0.8	0.3	0.1	0.0	0.0	5.0	1.6	0.6	0.4	2.2	3.5
1987	0.7	0.2	0.1	0.0	0.0	0.0	2.2	0.9	1.1	0.6	1.4	0.5
1988	0.5	0.3	0.3	0.1	0.1	0.2	5.4	1.1	0.3	0.3	0.3	0.3
1989	10.1	6.7	0.4	0.0	0.0	0.0	7.1	3.6	4.1	1.1	0.7	0.5
1990	0.3	0.1	0.1	0.1	0.3	0.2	0.1	0.0	0.1	0.1	0.1	0.1
1991	13.3	3.2	0.2	0.0	0.1	0.2	0.2	0.1	0.4	2.0	1.2	0.9
1992	10.4	7.2	1.0	0.1	0.1	0.1	11.1	5.6	0.8	0.6	0.8	2.9
1993	0.6	0.2	1.8	0.3	0.1	0.4	1.5	0.2	0.3	0.4	4.8	1.9
1994	1.8	0.3	5.6	0.6	1.0	2.5	3.9	4.0	0.8	0.5	0.5	0.4
1995	0.3	9.5	12.2	1.4	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1
1996	3.8	19.7	3.4	0.2	0.1	0.2	0.3	2.2	1.6	3.6	3.5	0.7
1997	0.4	0.3	0.1	0.1	0.1	2.8	5.2	2.2	0.7	0.5	0.4	0.3
1998	0.2	0.2	0.2	0.6	2.7	1.9	1.3	0.1	0.1	0.1	0.1	0.2
1999	1.4	0.1	0.0	0.4	0.2	12.0	2.7	2.1	0.3	0.2	0.2	0.1
2000	0.1	0.2	0.2	0.1	0.0	0.0	1.9	0.6	0.2	0.2	0.9	0.9
2001	0.3	0.3	0.1	0.0	0.1	0.0	0.0	0.2	0.3	0.4	0.9	2.7
2002	0.5	0.2	0.1	0.0	0.0	20.0	7.3	6.9	2.3	0.7	1.1	0.5
2003	2.3	0.3	0.1	0.1	0.1	0.1	2.0	1.0	0.3	0.6	0.4	0.3
2004	13.1	2.4	27.2	8.6	0.3	0.2	5.1	3.1	2.5	0.6	0.4	0.3

7.2 HYDROLOGY

Tables 7.10 and **7.11** provide summaries of the changes in low flows and flood regime that have occurred under the different scenarios. The freshwater reduction to the micro-habitats will remain similar to Present State under the Future Scenarios.

Table 7.10 Summary of the change in low flow conditions to the Goukou Estuary under a range of flow scenarios

Percentile	Monthly flow (m^3/s)					
	Natural	Present	1	2	3	4
30%	1.6	0.8	1.1	0.5	0.2	0.1
20%	1.2	0.3	0.7	0.2	0.1	0.1
10%	0.7	0.1	0.4	0.0	0.0	0.0
% Similarity in low flows		**30.2**	**59.7**	**16.8**	**9.3**	**6.9**

Table 7.11 Summary of the ten highest simulated monthly volumes to the Goukou Estuary under Reference Condition, Present State and a range of flow scenarios

Date	Monthly volume (million m^3/month)					
	Natural	Present	1	2	3	4
Aug 1986	98.98	96.00	96.00	94.12	89.98	84.97
Nov 1928	83.43	78.95	78.95	78.60	77.85	74.36
Apr 1967	81.82	79.00	79.00	77.96	77.21	75.40
Sep 1932	81.82	79.36	79.36	78.69	77.89	69.51
Dec 2005	78.36	75.92	75.92	75.62	74.84	72.97
Apr 1982	77.05	74.49	74.49	74.08	73.33	66.70
Aug 1967	70.02	67.15	67.15	66.89	66.11	61.39
Mar 2003	68.73	64.30	64.30	61.96	57.63	53.52
Oct 1934	66.43	63.73	63.73	63.36	62.58	60.71
Nov 1996	57.26	54.11	54.11	53.65	52.90	51.09
Apr 1981	52.83	50.59	50.59	50.18	49.43	47.62
Oct 1991	50.98	47.40	47.40	44.47	40.41	35.66
May 1958	49.10	46.26	46.26	44.69	43.91	42.04
Nov 1936	46.89	44.01	44.01	43.56	42.81	40.99
Jan 1981	46.09	43.85	43.85	43.31	42.53	40.66
Apr 1993	43.50	39.79	39.79	35.88	32.05	28.85
Oct 2004	43.48	40.45	40.45	39.95	39.18	34.97
Feb 1930	42.54	39.64	39.64	37.56	34.72	29.25
Dec 1929	39.41	36.21	36.21	35.44	34.66	32.79
Mar 2000	39.33	36.44	36.44	35.97	35.19	32.26

Date	Monthly volume (million m^3/month)					
	Natural	Present	1	2	3	4
% Similarity in floods		**94.64**	**94.64**	**92.62**	**89.90**	**84.00**

The hydrology health scores for the present and future scenarios are provided in **Table 7.12.**

Table 7.12 Hydrology health scores for present and future scenarios

Variable	Weight	Scenario					
		PRESENT	1	2	3	4	CONF
a. % Similarity in low flows	55	30	42	17	9	7	L
b. % Similarity in flood volumes	35	95	95	93	90	84	M
c. % Similarity in freshwater input from fountains and seeps	10	40	40	40	40	40	L
Hydrology weighted mean (a,b)		**54**	**60**	**46**	**40**	**37**	**L/M**

7.3 PHYSICAL HABITATS

The relevant changes in sediment dynamics and geomorphology drivers is that a further progressive reduction in large floods occurs under Scenarios 2, 3 and 4 (about 2, 5 and 11% respectively *compared to present*), while both the present and Scenario 1 reduce large floods by 5% *from Reference Condition*. A summary of the expected changes in the physical habitat of the Goukou Estuary under each of the future scenarios are provided in **Table 7.13**.

Table 7.13 Summary of physical habitat changes under different scenarios

Parameter	Scenario
a. Supratidal area and sediments	The only potential new changes are related to changes in flood regime. Changes to low flows have virtually no impact on sediment dynamics and morphology within the estuary. Thus Scenario 1 is not different from the Present State. Scenarios 2, 3 and 4 have additional 2, 5 and 11% (negative) change effect respectively on flood regime which will translate into direct associated effects on sediment dynamics and morphology in the estuary. Under Scenarios 2, 3 and 4 there will be progressively less large floods which flush out sediments from the estuary and deposit new sediments on the floodplain. Slightly longer retention of riverine sediment deposits, enabling more consolidation and more enduring plant growth, all contribution to slightly less dynamic estuarine geomorphology.
b. Intertidal areas and sediments	Same as for supratidal. Also progressively slightly more ingress of marine sediments under Scenarios 2, 3 and 4.
c. Subtidal area and sediments	Same as for intertidal.

Parameter	Scenario
d. Estuary *bathymetry* (relates to water volume)	Under Scenarios 2, 3 and 4 there would be progressively slightly less flushing of sediments due to further floods reduction, thus slightly reduced water volume. Scenarios 2, 3 and 4 would also progressively allow slightly larger marine waters and sediment ingress, thus slightly reduced water volume. Overall all these effects considered small, only altering marginally the score from present (proportion of small percentage change on top of only a 15% change).

The physical habitat health scores for the present and future scenarios are provided in **Table 7.14**.

Table 7.14 Physical habitat health scores for present and future scenarios

Variable		Scenario					
		Present	**1**	**2**	**3**	**4**	**Confidence**
a	Supratidal area and sediments	65	65	63	60	54	L(1); VL(2-4)
b	Intertidal areas and sediments	65	65	63	60	54	L(1); VL(2-4)
c	Subtidal area and sediments	72	72	70	68	61	L(1); VL(2-4)
d	Estuary bathymetry/water volume	85	85	84	83	80	L(1); VL(2-4)
Physical habitat score min (a to d)		**65**	**65**	**63**	**60**	**54**	**L(1); VL(2-4)**

7.4 HYDRODYNAMICS AND MOUTH CONDITION

A summary of the expected changes in the hydrodynamic and mouth conditions in the Goukou Estuary under each of the future scenarios are provided in **Table 7.15**.

Table 7.15 Summary of the changes in the hydrodynamics under the various scenarios

<table>
<tr><th>Parameter</th><th>Future scenarios</th></tr>
<tr><td>Mouth condition</td><td>No change as it is n permanently open estuary.</td></tr>
<tr><td>Inundation</td><td>Sc1: Similar to present
Sc2: Additional 2% reduction in inundation.
Sc3: Additional 5% reduction in inundation.
Sc4: Additional 11% reduction in inundation.</td></tr>
<tr><td>Tidal range</td><td>Shift in tidal amplitude under the future scenarios are driven by change in State 1 and 4.
<table><tr><th>REFERENCE</th><th>PRESENT</th><th>1</th><th>2</th><th>3</th><th>4</th></tr><tr><td>1.75</td><td>1.71</td><td>1.74</td><td>1.70</td><td>1.67</td><td>1.61</td></tr></table></td></tr>
<tr><td>Dominant circulation process</td><td>Under the Reference Conditions the tide was the dominant circulation process for about 79% of the time this has increase to about 83% of the time under the Present State.

Under Scenarios 1 to 4 will remain the dominant mixing process and occur for 81%,</td></tr>
</table>

<table>
<tr><th>Parameter</th><th>Future scenarios</th></tr>
<tr><td></td><td>85%, 86% and 89%, respectively.</td></tr>
<tr><td>Water column structure</td><td>From Reference to Present there has been some loss of stratification in in the lower reaches (Zone A and B) and a slight increase in the upper reaches (Zone D) as a result of decreasing flow.

Sc1: The system becomes more homogenous, with a decrease in stratification the lower reaches (Zone A and B) and a slight increase in the upper reaches (Zone D) of the system.
Sc2: The system becomes more homogenous, with an additional loss in stratification in the lower reaches (Zone A and B) and an increase in the upper reaches (Zone D).
Sc3: The system becomes more homogenous, with an additional loss in stratification in the lower reaches (Zone A and B) and an increase in the upper reaches (Zone D).
Sc4: The system becomes very homogenous, with a significant loss in stratification in the lower reaches and the upper reaches (Zone D) become more stratified as average flow decreases.

<table>
<tr><th rowspan="2">ZONE</th><th colspan="6">ΔS</th></tr>
<tr><th>Reference</th><th>Present</th><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>A</td><td>10</td><td>8</td><td>9</td><td>8</td><td>7</td><td>5</td></tr>
<tr><td>B</td><td>15</td><td>11</td><td>13</td><td>10</td><td>9</td><td>6</td></tr>
<tr><td>C</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>D</td><td>2</td><td>3</td><td>3</td><td>4</td><td>4</td><td>5</td></tr>
</table></td></tr>
<tr><td>Retention</td><td>The high retention states (1 and 2) have increased from 17% under the Reference Condition to about 35% under the Present State.

Under Scenarios 1 to 4 high retention states (1 and 2) have increased from 17% under Reference to 28%, 43%, 51% and 65%, respectively.</td></tr>
<tr><td>Connectivity with the riparian area</td><td>The Goukou Estuary has a high degree of connectivity with the riparian areas in the form of permanently damp seeps and adjacent fountain habitat. These serve, for example, as eels habitat (Paling gat) and bathing areas for Cape Clawless Otters. Due to the damming and over-abstraction of the surrounding fountains and seeps, the direct riparian connectivity is estimated to be reduced by at least 50%.</td></tr>
</table>

The hydrodynamics and mouth condition health scores for the present and future scenarios are provided in **Table 7.16**.

Table 7.16 Hydrodynamics and mouth condition health scores for present and future scenarios

Variable		Weight	Scenario					Confidence
			Present	1	2	3	4	
a	% similarity in abiotic states and mouth condition	34	100	100	100	100	100	M
b	% similarity in the water column structure	33	90	92	86	82	73	M
c	% similarity in water retention time	No data						
d	% similarity in tidal amplitude and symmetry)	33	99	100	99	98	96	M
Hydrodynamics and mouth weighted mean (a to d)			**95**	**99**	**98**	**98**	**96**	**M**

7.5 WATER QUALITY

Table 7.17 provides a summary the occurrence of various abiotic states under reference, present and each of the future scenarios for the Goukou Estuary.

Table 7.17 Summary of the occurrence of the abiotic states under the Reference Condition, Present State and Scenarios 1 to 4

Abiotic state	Natural	Present	Scenario			
			1	2	3	4
State 1: Marine dominated, no REI	2	18	3	26	33	47
State 2: Full salinity gradient	14	17	25	17	18	18
State 3: Partial salinity gradient	62	48	53	42	35	24
State 4: Limited salinity penetration	19	15	17	14	12	9
State 5: Freshwater dominated	2	2	2	2	1	1

Table 7.18 provides a summary of the expected average changes in various water quality parameters in different zones under present and future scenarios, while **Table 7.19** summarised the cause of such changes.

Table 7.18 Estimated changes in water quality in different zones under different scenarios

Zone	Volume weighting	Estimated salinity concentration based on distribution of abiotic states					
		Reference	Present	Scn 1	Scn 2	Scn 3	Scn 4
A (lower)	0.25	28	30	29	30	31	32
B	0.30	19	21	20	22	23	25
C	0.30	10	14	11	15	17	20
D (upper)	0.10	5	9	6	10	12	15
Freshwater micro-habitat	0.05	15	30	30	30	30	30
Zone	**Volume weighting**	**Estimated DIN concentration (µg/ℓ) based on distribution of abiotic states**					
		Reference	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
A (lower)	0.25	51	63	64	63	58	57
B	0.35	51	104	104	105	101	101
C	0.30	51	202	202	204	199	199
D (upper)	0.10	51	184	199	178	166	152

Zone	Volume weighting	Estimated DIP concentration (µg/ℓ) based on distribution of abiotic states					
		Reference	Present	Scn 1	Scn 2	Scn 3	Scn 4
A (lower)	0.25	10	12	12	12	11	11
B	0.35	10	20	20	21	20	20
C	0.30	10	20	20	21	20	20
D (upper)	0.10	10	20	20	21	20	20
Zone	**Volume weighting**	**Estimated turbidity (ntu) based on distribution of abiotic states**					
		Reference	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
A (lower)	0.25	10	11	11	11	10	10
B	0.35	10	11	11	11	10	10
C	0.30	10	12	12	12	11	11
D (upper)	0.10	10	17	18	16	15	14
Zone	**Volume weighting**	**Estimated dissolved oxygen (mg/ℓ) based on distribution of abiotic states**					
		Reference	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
A (lower)	0.25	8	8	8	8	8	8
B	0.35	8	6	6	6	6	6
C	0.30	8	6	6	6	6	6
D (upper)	0.10	7[1]	5[2]	5[3]	5[4]	5[5]	5[6]

[1] Bottom water 2 mg/ℓ for ~16 % of the time [2] Bottom water 2 mg/ℓ for ~35 % of the time
[3] Bottom water 2 mg/ℓ for ~28 % of the time [4] Bottom water 2 mg/ℓ for ~43 % of the time
[5] Bottom water 2 mg/ℓ for ~51 % of the time [6] Bottom water 2 mg/ℓ for ~65 % of the time

Table 7.19 Summary of water quality changes under different scenarios

Parameter	Summary of changes
Changes salinity gradient	<u>Estuary water column:</u> Scenario 1: While salinity ⇧ due to increase in low flow conditions from Reference, there is a well-established REI zone for most of the year under this scenario. Scenario 2 to 4: ⇧ due to increase in low flow conditions, with REI not present for most of summer. <u>Freshwater Habitats:</u> Similar to present , salinity ⇧ due to reduction in flow from riparian fountains and seeps above and in EFZ
Inorganic nutrients (DIN and DIP) in estuary	⇧ due to agricultural activities in catchment (and WWTW), as well as effects of urban runoff along banks (Zones B and C). Similarity to reference "improve" from present in Scenarios 2-4 as less enriched river water becomes less.
Turbidity in estuary	⇧ due to agricultural activities in catchment. Similarity to reference "increase" from present in scenarios where less enriched water reaching the estuary.
Dissolved oxygen in estuary	⇩ due to agricultural activities in catchment (and WWTW), as well as effects of urban runoff along banks (Zones B and C). Similarity with reference "decreases" from present in Scenarios 2-4, as occurrence of low flow states increases
Toxic substances in estuary	⇧ due to agricultural activities in catchment, also diffuse runoff from urban areas adjacent to estuary

The EHI scores for water quality are presented in **Table 7.20**.

Table 7.20 Water quality health scores for present and future scenarios

Variable		Weight	Scenario					
			Present	**1**	**2**	**3**	**4**	**Confidence**
1	**Similarity in salinity: weighted mean (a,b)**	40	87	95	82	80	74	
a	Estuary water column	95	88	96	83	80	74	M
b	Freshwater micro-habitat	5	67	67	67	67	67	L
2	**General water quality min (a to d)**	60	67	67	67	69	69	
a	DIN/DIP concentrations		67	67	67	69	69	L/M
b	Turbidity		93	93	93	96	97	M
c	Dissolved oxygen		90	91	90	90	89	M
d	Toxic substances		80	80	80	80	80	L
Water quality score weighted mean (1,2)			**75**	**78**	**73**	**73**	**71**	**L/M**

7.6 MICROALGAE

A summary of the expected changes under various scenarios for the microalgae component in the Goukou Estuary is provided in **Table 7.21**.

Table 7.21 Summary of change in microalgae under different scenarios

Scenario	Summary of changes
1	50% of the flow is restored to the estuary (MAR = 88%), flood volumes are similar to present (5% lost). Changes to low flows have virtually no impact on sediment dynamics and morphology within the estuary. **Phytoplankton**: The 12% decrease in river flow from reference is predicted to shift the system to have a higher proportion of low flows (40% reduction from reference) and a decrease in flood volume (5% decrease). Elevated turbidity (7% increase), particularly at high flows, limit phytoplankton growth, whereas increased residence time (11% higher than reference) and elevated nutrients (33% higher than reference) are likely to result a 22% increase in phytoplankton biomass from reference (half of the change from present). With regards to community composition the reduced river flow and elevated nutrients favour a decrease in the diatoms:flagellates ratio, and an increase in dinoflagellates, blue-greens and chlorophytes (32% change) **Benthic microalgae**: The largest factors affecting benthic microalgae are related to catchment flow reductions (incl. flood volume), sediment input (lower coarse sediment) and elevated nutrients. Assuming a 34% increase in biomass related to reduction in river flow (12%), floods (5%) and nutrients (33%*0.5; benthic microalgae dependent on water column and mineralised nutrients). The small decrease in flood volume is likely to have increased sedimentation in the upper reaches, farm dams are likely to have removed some coarse sediment, and the intrusion of marine sediment into the estuary is likely to have increased. The change in community composition related to sediment type (5%) and elevated nutrients (33%*0.5; benthic microalgae dependent on water column and mineralised nutrients) is likely to be 22%.
2	Additional 10% of flow is lost from present MAR (71%), flood volumes decrease further 2% from present (7% lost). Changes to low flows have virtually no impact on sediment dynamics and morphology within the estuary. **Phytoplankton**: Based on a regression of abundance scores (reference, present and scenario 1) the 29% decrease in river flow from reference is predicted to change the abundance by 54% (score = 46); the result of a higher proportion of low flows (83% reduction from reference) and a decrease in flood volume (7% decrease), elevated turbidity (7% increase), increased residence time (26% higher than reference), and elevated nutrients (32% higher than reference). With regards to community composition the reduced river flow (29%) and elevated nutrients (32%) favour a decrease in the diatoms:flagellates ratio, and an increase in dinoflagellates, blue-greens and chlorophytes (61%*0.70 = 57). **Benthic microalgae**: The largest factors affecting benthic microalgae are related to catchment flow reductions (incl. flood volume), sediment input (lower coarse sediment) and elevated nutrients. Assuming a 52% increase in biomass related to reduction in river flow (29%), floods (7%) and nutrients (32%*0.5; benthic microalgae dependent on water column and mineralised nutrients). The small decrease in flood volume is likely to have increased sedimentation in the upper reaches, farm dams are likely to have removed some coarse sediment, and the intrusion of marine sediment into the estuary is likely to have increased. The change in community composition related to sediment type (7%) and elevated nutrients (32%*0.5; benthic microalgae dependent on water column and mineralised nutrients) is likely to be 23%.

Scenario	Summary of changes
3	Additional 15% of flow is lost from present MAR (Scenario 3 MAR = 63%) and flood volumes decrease 10% from reference. **Phytoplankton**: Based on a regression of abundance scores (reference, present and scenario 1) the 37% decrease in river flow from reference is predicted to change the abundance by 66% (score = 34); the result of a higher proportion of low flows (91% reduction from reference) and a decrease in flood volume (10% decrease), elevated turbidity (4% increase), increased residence time (34% higher than reference), and elevated nutrients (30% higher than reference). With regards to community composition the reduced river flow (37%) and elevated nutrients (30%) favour a decrease in the diatoms:flagellates ratio, and an increase in dinoflagellates, blue-greens and chlorophytes (67%*0.70 = 47% change). **Benthic microalgae**: The largest factors affecting benthic microalgae are related to catchment flow reductions (incl. flood volume), sediment input (lower coarse sediment) and elevated nutrients. Assuming a 62% increase in biomass related to reduction in river flow (37%), floods (10%) and nutrients (30%*0.5; benthic microalgae dependent on water column and mineralised nutrients). The small decrease in flood volume is likely to have increased sedimentation in the upper reaches, farm dams are likely to have removed some coarse sediment, and the intrusion of marine sediment into the estuary is likely to have increased. The change in community composition related to sediment type (10%) and elevated nutrients (30%*0.5; benthic microalgae dependent on water column and mineralised nutrients) is likely to be 25%.
4	Additional 30% of flow is lost from present MAR (Scenario 4 MAR = 48%) and flood volumes decrease 16% from reference. **Phytoplankton**: Based on a regression of abundance scores (reference, present and scenario 1) the 52% decrease in river flow from reference is predicted to change the abundance by 85% (score = 15); the result of a higher proportion of low flows (93% reduction from reference) and a decrease in flood volume (16% decrease), elevated turbidity (3% increase), increased residence time (48% higher than reference), and elevated nutrients (29% higher than reference). With regards to community composition the reduced river flow (52%) and elevated nutrients (29%) favour a decrease in the diatoms:flagellates ratio, and an increase in dinoflagellates, blue-greens and chlorophytes (81%*0.70 = 57% change). **Benthic microalgae**: The largest factors affecting benthic microalgae are related to catchment flow reductions (incl. flood volume), sediment input (lower coarse sediment) and elevated nutrients. Assuming an 83% increase in biomass related to reduction in river flow (52%), floods (16%) and nutrients (29%*0.5; benthic microalgae dependent on water column and mineralised nutrients). The decrease in flood volume is likely to have increased sedimentation in the upper reaches, farm dams are likely to have removed some coarse sediment, and the intrusion of marine sediment into the estuary is likely to have increased. The change in community composition related to sediment type (21%) and elevated nutrients (29%*0.5; benthic microalgae dependent on water column and mineralised nutrients) is likely to be 36%.

The EHI scores for microalgale under the various scenarios are presented in **Table 7.22**.

Table 7.22 Microalgae health scores for present and future scenarios

Variable	Scenario					
	Present	**1**	**2**	**3**	**4**	**Confidence**
Phytoplankton						
b. Species richness	95	95	95	95	95	L
b Abundance	57	78	46	34	15	M
c. Community composition	63	68	57	53	43	M
Benthic microalgae						
a. Species richness	95	95	95	95	95	L
b Abundance	58	66	48	38	17	M
c. Community composition	79	80	77	75	64	M
Microalgae score min (a to c)	**57**	**66**	**46**	**34**	**15**	**M**

7.7 MACROPHYTES

A summary of the expected changes under various scenarios for the macrophyte component in the Goukou Estuary is provided in **Table 7.23**.

Table 7.23 Summary of change in macrophytes under different scenarios

Scenario	Summary of changes
1	The restoration of 50% of baseflow will improve conditions as salinity will decrease. Salinity in Zone C where the pondweed grows will decrease from 14 (present) to 11 bringing it closer to the optimum of 10; more in the salinity range of tolerance for this submerged macrophyte. The decrease in salinity in the upper reaches of the estuary from 9-6 will increase reed growth. Although there is an improvement in macrophyte abundance and community composition, the overall loss of habitat due to agriculture and development remains.
2	Present MAR will decrease by 10% resulting in an increase in salinity in Zone C and D with some negative responses from the plants. The state of the macrophytes will be poorer compared to the present.
3	The 15% reduction in MAR, decrease in baseflow and increase in salinity will decrease growth of all macrophytes. In particular there will be a dieback of reeds, sedges and pondweed in Zone C where salinity is now 17 compared to 10 for Reference Conditions. The increase in salinity in Zone D from 5 (reference) to 12 is within the range of tolerance of the dominant plants located in this zone. However the increase in salinity, will decrease macrophyte productivity as the plants cope with the salinity stress. The decrease in floods will prevent inundation of the supratidal marshes causing salt accumulation and die-back.
4	The 30% reduction in MAR, decrease in baseflow and increase in salinity will decrease growth of all macrophytes. There will be a further dieback of reeds, sedges and pondweed in Zone C where salinity is now 20 compared to 10 for Reference Conditions. The increase in salinity in Zone D from 5 (reference) to 15 is within the range of tolerance of the reeds in this zone but is not ideal for pondweed. However, the increase in salinity, will decrease macrophyte productivity as the plants cope with the salinity stress. The decrease in floods will cause an 11% reduction in inundation of the supratidal marshes causing salt accumulation and die-back.

The EHI scores for marcophytes under the various scenarios are presented in **Table 7.24**.

Table 7.24 Macrophyte health scores for present and future scenarios

Variable	Scenario					
	Present	**1**	**2**	**3**	**4**	**Confidence**
a. Species richness	80	85	75	70	65	M
b. Abundance	72	74	67	611	55	M
c. Community composition	68	72	65	57	51	M
Macrophyte score min (a to c)	**68**	**72**	**65**	**57**	**51**	**M**

7.8 INVERTEBRATES

A summary of the expected changes under various scenarios for the invertebrate component in the Goukou Estuary is provided in **Table 7.25**, while the health scores for the present and future scenarios are provided in **Table 7.26**.

Table 7.25 Summary of change in macrophytes under different scenarios

Scenario	Summary of changes
1	Under this scenario, the increase in baseflow leads to the presence of the REI for most of the year compared to present. Salinity along the estuary has otherwise barely changed, although there is a marginal increase in stratification. The greater persistence of the REI will lead to less temporal variability among invertebrate communities and an overall increase in biomass compared to present. Microhabitats will remain similar to present, thus the communities associated with them not change.
2	No REI is present during the summer months particularly, with salinity increasing slightly along the length of the estuary compared to Present State. No oligohaline community will be present and the increased plankton biomass associated with the REI will not develop. Low oxygen concentrations in deeper areas of the estuary will also increase. Variability among invertebrate groups decreases marginally and biomass remains similar to present. Microhabitats remain similar.
3 and 4	Scenarios 3 and 4 follow the trajectory described under Scenario 2, the net result leading to a decrease in invertebrate overall. Submerged macrophyte will increase and this will lead to a change in community composition among the benthic community particularly. Microhabitats remain similar to Present State, although their role as nodes of recruitment into adjacent parts of the estuary increases. Under Scenario 4, some zooplankters (e.g. *Acartia natalensis*) will probably disappear from the main estuary (diapause eggs will not hatch), although the species will follow a normal life cycle in seep areas. Fringing reeds and sedges also decease in biomass, but will remain associated with seeps where invertebrates utilizing these habitats will become more isolated from the main estuary, particularly during summer (underlining the importance of the seeps to the estuary). Floods under Scenario 4 also reduce further (by 11%) and the benthic community in the lower estuary will probably increase in biomass as flushing of sediment is reduced and sandy substrata extends further up-estuary.

Table 7.26 Invertebrates health scores for present and future scenarios

Variable	Scenario					
	Present	1	2	3	4	Confidence
Zooplankton						
a. Species richness	100	100	100	100	95	M
b. Abundance	65	70	62	57	50	M
c. Community composition	65	70	62	57	50	M
Hyperbenthos						
a. Species richness	100	100	100	100	90	M
b. Abundance	65	70	62	57	50	M
c. Community composition	60	65	55	50	45	M
Benthos						
a. Species richness	100	100	100	100	90	M
b. Abundance	60	65	55	50	40	M
c. Community composition	60	65	55	50	40	M
Invertebrate score min (a to c)	**60**	**65**	**55**	**50**	40	M

7.9 FISH

A summary of the expected changes under various scenarios for the fish component in the Goukou Estuary is provided in **Table 7.27**, while the health scores for the present and future scenarios are provided in **Table 7.28**.

Table 7.27 Summary of change in fish under different scenarios

Scenario	Summary of changes
Reference	The system will still be marine dominated to a certain degree especially for the lower 4 km of the estuary due to tidal/inflow dynamics. REI species will increase in range and biomass in the system. Change in prevalent salinity regimes ↓ will cause invertebrate organisms to burrow deeper becoming less available to estuary-associated marine species. Increase phyto and zooplankton production should benefit juveniles of all species.
Present	Fish assemblages more marine dominated compared to Reference Condition Ia and Ib occur in lower to middle reaches. Estuary dependent marine species distributed throughout the system. Estuary associated and marine migrants associated with lower and middle reaches according to prevalent salinity regime. Fresh water species confined to upper reaches. Occasional low oxygen levels at depth in the upper reaches (Zone D) will exclude benthic species or restrict them to the marginal areas.
1	Population dynamics to change to a less marine dominated assembly and increase in REI species e.g. *G.aestuaria*, *Myxus capensis*. Marine migrants associated with lower reaches of the estuary. Estuary resident and breeding species (Ia, Ib) distributed throughout the system except mouth area (Zone A). Longer high flow periods, increased connectivity and recruitment with marine environment and other estuaries in region for estuary dependent and associated marine species. Freshwater species do penetrate down to middle reaches during high flow periods.

Scenario	Summary of changes
2 and 3	Loss of REI for extended periods during summer months. REI species located only at the head of the system and population threshold decreased. Estuary resident / breeding Ia species widely distributed through the system but in lower densities and biomass. Obligate estuary-dependent and estuary-associated marine species occur throughout the whole system during low flow summer periods. Recruitment does decline due to lesser volume and temporal high flow periods. Marine vagrants increase in occurrence towards middle/upper reaches of the system.
4	Loss of the REI for a large part of the year and REI species (if they still occur) confined mostly to the head of the system. An exception would be *G.aestuaria* (Ia) which would be distributed throughout the system but in much lower densities and biomass. Estuary-dependent and associated marine species occur throughout the whole system during low flow summer periods but recruitment much less due to decrease in flow volume (52% MAR) and duration of high-flow periods. Marine vagrantsestablished in lower, middle reaches and become completely dominant section of population assembly.

Table 7.28 Fish health scores for present and future scenarios

Variable	Scenario					
	Present	1	2	3	4	Confidence
a. Species richness	90	95	80	75	60	H
b. Abundance	80	90	80	75	60	H
c. Community composition	75	90	70	70	50	H
Fish score min (a to c)	**75**	**90**	**70**	**70**	**50**	**H**

7.10 BIRDS

A summary of the expected changes under various scenarios for the bird component in the Goukou Estuary is provided in **Table 7.29**, while the health scores for the present and future scenarios are provided in Table **7.20**.

Table 7.29 Summary of change in birds under different scenarios

Scenario	Summary of changes
1	Estuary moves towards natural. Freshwater penetrates lower into the system. Abundance and productivity of all groups is higher. Expect increases in numbers of waterfowl and piscivorours bird groups.
2 and 3	Reduction in freshwater inflow means salinity penetrates further up the estuary. Reduced productivity, fish recruitment declines due to reduction in floods. Reductions in abundance of waterfowl and piscivorous groups relative to present.
4	Further reduction in flows. Trends described in above scenario are exacerbated.

Table 7.30 Bird health scores for present and future scenarios

Variable	Scenario					
	Present	1	2	3	4	Confidence
a. Species richness	95	95	95	90	90	M
b. Abundance	73	79	69	66	54	M
c. Community composition	84	88	82	79	70	M
Bird scores min (a to c)	**73**	**79**	**69**	**66**	**54**	**M**

7.11 ECOLOGICAL CATEGORIES ASSOCIATED WITH SCENARIOS

The individual health scores for the various abiotic and biotic components are used to determine the ecological status or ecological category for the Goukou Estuary under each of the future scenarios (**Table 7.31**), again using the EHI.

Table 7.31 EHI score and corresponding Ecological Categories under present and future scenarios

Variable	Weight	Scenario					
		Present	1	2	3	4	Conf*
Hydrology	25	54	60	46	40	37	L/M
Hydrodynamics and mouth condition	25	95	99	98	98	96	M
Water quality	25	76	78	73	73	71	M/H
Physical habitat alteration	25	75	65	63	60	54	L
Habitat health score	**50**	**72**	**76**	**70**	**68**	**65**	
Microalgae	20	57	66	46	34	15	M
Macrophytes	20	68	72	65	57	51	M
Invertebrates	20	60	65	55	50	40	M
Fish	20	75	90	70	70	50	H
Birds	20	73	79	69	66	54	M
Biotic health score	**50**	**67**	**74**	**61**	**55**	**42**	
ESTUARY HEALTH SCORE		**69**	**75**	**66**	**62**	**53**	**M**
ECOLOGICAL CATEGORY		**C**	**B/C**	**C**	**C/D**	**D**	**M**

* Conf = Confidence

8 RECOMMENDATIONS

8.1 RECOMMENDED ECOLOGICAL FLOW SCENARIO

The EWR methods for estuaries (DWAF, 2008) set the following as a guideline for the Ecological Flow Requirement Scenario: *"The recommended Ecological Flow Requirement scenario is defined as the flow scenario (or a slight modification thereof) that represents the highest change in river inflow that will maintain the estuary in the Recommended Ecological Category".*

In the case of the Goukou Estuary a **Category B** was proposed as the REC. Applying this guideline, none of the potential flow scenarios evaluated as part of this study were able to reverse modification in the ecological state to a Category B. This is mainly as a result of significant non-flow related impacts also contributing to the present ecological status in the estuary. However, Scenario 1 could restore the estuary to a Category B/C (just below a Category B). Scenario 1 assumes a 50% base flow return to the estuary, e.g. through removal of alien invasive plants, as well as reducing run-off river abstraction during the low flow season. Restoring some base flow addresses the key flow-related factor contributing to the changes in ecological health in this estuary, namely the re-establishment of the REI zone (see Section 5). Considering the significant contribution of non-flow related factors, the present health in the Goukou Estuary (**Table 5.2**), as well as the reversibility of some of these impacts, **Scenario 1** was identified as the **recommended flow scenario** from an ecological perspective (**Table 8.1**).

Table 8.1 Recommended ecological flow scenario for the Goukou Estuary (Category B)

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	23.4	30.8	27.2	16.6	16.7	24.2	30.3	17.9	8.1	10.1	34.9	29.1
99	19.5	23.6	16.6	12.3	13.2	16.3	29.0	14.9	7.5	9.8	26.8	15.7
90	11.2	9.3	4.8	3.5	6.4	7.6	8.6	7.4	5.3	5.1	6.6	7.0
80	5.8	7.3	3.4	2.5	3.3	5.7	6.0	5.0	3.5	3.4	5.4	5.2
70	4.4	4.8	2.1	1.3	2.2	3.9	3.8	3.6	2.9	2.6	3.8	4.0
60	3.5	3.4	1.4	0.8	1.0	3.3	3.0	3.0	2.2	2.3	3.5	3.2
50	2.8	2.4	1.0	0.6	0.7	2.4	2.3	2.7	1.9	2.0	2.6	2.8
40	2.1	1.8	0.6	0.4	0.5	1.6	1.8	2.0	1.5	1.8	2.3	2.4
30	1.8	1.2	0.5	0.3	0.4	1.1	1.5	1.1	1.2	1.4	1.6	2.0
20	1.4	0.9	0.4	0.3	0.3	0.4	1.3	0.7	0.8	1.0	1.4	1.5
10	1.1	0.7	0.4	0.3	0.3	0.3	0.7	0.4	0.5	0.8	1.0	1.2
1	0.6	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.6	0.7
0.1	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.6	0.5

However, in order to improve from a Category B/C (Scenario 1 only), additional intervention in terms of non-flow related impacts will be essential to improve the ecological health of the estuary to a Category B. As a minimum, the **following non-flow related interventions must be undertaken** in order achieve the REC (Category B):

- Restore 50% of the flood plain and riparian habitat along length of estuary;
- Identify all fountains, spring and seeps and ensure adequate freshwater supply to riparian zone and estuary to facilitate connectivity between estuary and terrestrial environment (critical factor for the protection of eels);
- Control/reduce fishing effort through improved compliance monitoring of fishing activities and banning of night fishing;
- Prepare and implement guidelines on appropriate bank stabilisation along the estuary;
- Control boating activities on the estuary towards mitigating bank erosion (e.g. through proper zonation and establishment and enforcement of boating carrying capacity limits);
- Institute proper stormwater management in future development planning (e.g. management of runoff from hardened surfaces and associated pollution);
- Upgrade and maintain sewage infrastructure (e.g. restore broken pipes and install back-up pumps for pump station in close proximity of the estuary);
- Ensure that the water quality and volumes discharged through the Riversdal WWTW meet permit requirements as issued under the National Water Act;
- Prepare and implement guidelines on appropriate (nature-friendly) structures to secure access to the estuary.

These interventions should be undertaken in collaboration with various responsible departments in DWS, as well as other national and provincial departments and institutions responsible for estuarine resource management such as DAFF, Department of Environmental Affairs (DEA: Oceans and Coasts), South African National Biodiversity Institute (SANBI), CapeNature, as well as relevant municipal authorities. It is recommended that the estuarine management planning process and the associated institutional structures (as required under the Integrated Coastal Management Act 2008) be used as mechanisms through which to facilitate the implementation these interventions.

8.2 ECOLOGICAL SPECIFICATIONS

The EcoSpecs and associated TPCs representative of a **Category B for the Goukou Estuary** are presented in **Table 8.2**.

Table 8.2 EcoSpecs and Thresholds of Potential Concern (TPCs) for the Goukou Estuary (Category B)

Component	EcoSpecs	Thresholds of Potential Concern
Hydrology	Maintain flow regime as per recommended ecological flow Ensure the persistence of freshwater seepage sites in the lower and middle reaches of the estuary.	River inflow: ▪ < 0.3 m^3/s for more than 1 month a year ▪ < 1.0 m^3/s for more than 3 month a year ▪ Maintain water levels in fountains (determine trough baseline study)

Component	EcoSpecs	Thresholds of Potential Concern
Hydrodynamics	▪ Maintain connectivity with marine environment ▪ Maintain connectivity with terrestrial environment through the presence of fountains and seeps	▪ Average tidal amplitude < 20% of present observed data from the water level recorder in the estuary near the mouth during low flows (summer) ▪ Loss of wet riparian zones
Sediment	▪ Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) for biota ▪ No significant changes in sediment grain size and organic matter distribution patterns for biota ▪ No significant change in average sediment composition and characteristics ▪ No significant change in average bathymetry	▪ Average sediment composition in any survey (% fractions) along estuary change from that of the Present State (2014 baseline, to be measured) by 30% ▪ Average organic fraction in sediment along length of estuary > 5% ▪ Average bathymetry along main channel in the middle and lower reaches (10 km upstream) change by 30% in any survey from that of the Present State (2015 baseline, to be measured) (system expected to significantly fluctuate in terms of bathymetry between flood) ▪ Average bathymetry along main channel in the upper reaches (above 10 km from the mouth – above Zone C) change by 10% in any survey from that of the Present State (2015 baseline, to be measured)
Water quality	Salinity distribution not to cause exceedance of TPCs for biota (see below)	▪ Salinity > 0 at head of estuary ▪ Average salinity in Zone D > 5 ▪ Average salinity in Zone C > 20 ▪ Average salinity 9.5 km upstream from mouth > 20 more than three months of the year ▪ Salinity in interstitial water at seep sites > 20 ▪ Salinity > 40 in saltmarsh sediments (linked to decrease in moisture and drying of floodplain habitat).
	System variables (pH, dissolved oxygen and turbidity) not to cause exceedance of TPCs for biota (see below)	River inflow: ▪ 6.0 < pH > 8.0 (black water system) ▪ DO < 5 mg/ℓ ▪ Suspended solids > 5 mg/ℓ (low flow) Estuary: ▪ Average turbidity > 10 NTU (low flow) ▪ Average 6.0 < pH > 8.5 (increasing with increase in salinity) ▪ Average DO < 5 mg/ℓ
	Inorganic nutrient concentrations (NO_3-N, NH_3-N and PO_4-P) not to cause in exceedance of TPCs for macrophytes and microalgae (see below)	River inflow: ▪ NO_x-N > 150 µg/ℓ over two consecutive months ▪ NH_3-N> 20 µg/ℓ over two consecutive months ▪ PO_4-P > 20 µg/ℓ over two consecutive

Component	EcoSpecs	Thresholds of Potential Concern
		months Estuary (except during upwelling or floods): ▪ Average NO_x-N > 150 µg/ℓ single concentration > 200 µg/ℓ ▪ Average NH_3-N > 20 µg/ℓ during survey, single concentration > 100 µg/ℓ ▪ Average PO_4-P > 20 µg/ℓ during survey, single concentration > 50 µg/ℓ
	Presence of toxic substances (e.g. trace metals and pesticides/herbicides) not to cause exceedance of TPCs for biota (see below)	River inflow: ▪ Trace metals (to be confirmed) ▪ Pesticides/herbicides (to be confirmed) Estuary ▪ Concentrations in water column exceed target values as per South African Water Quality Guidelines for coastal marine waters (DWAF, 1995) ▪ Concentrations in sediment exceed target values as per WIO Region guidelines (UNEP/Nairobi Convention Secretariat and CSIR, 2009)
Microalgae	▪ Maintain a low median phytoplankton biomass ▪ Maintain a high median intertidal benthic microalgal biomass ▪ Prevent formation of localised phytoplankton blooms	▪ Median phytoplankton chlorophyll *a* (minimum 5 sites) exceeds 3.5 µg/ℓ ▪ Median intertidal benthic chlorophyll *a* (minimum 5 sites) exceeds 42 mg/m^2 ▪ Site specific chlorophyll *a* concentration exceeds 20 µg/ℓ and cell density exceeds 10 000 cells/ℓ
Macrophytes	▪ Maintain the distribution of macrophyte habitats, particularly the submerged macrophytes, salt marsh, reeds and sedges ▪ Maintain pockets of reeds in lower and middle reaches (linked to freshwater seepage sites) ▪ Maintain the reed and sedge stands in the upper reaches of the estuary. ▪ Rehabilitate 20% of the floodplain habitat by removing agriculture and invasive plants ▪ Maintain the integrity of the riparian zone	▪ Greater than 20 % change in the area covered by salt marsh, reeds and sedges (2014 survey). Loss of submerged macrophytes (e.g. *Stukenia pectinata, Zostera capensis*) over a three year period ▪ Decrease in cover of reeds at the freshwater seepage sites in the lower and middle reaches of the estuary (linked to salinity in interstitial water > 20 for three months) ▪ Increase in bare areas in the salt marsh (linked to a decrease in moisture and increase in salinity in sediment – i.e. drying of floodplain habitat) ▪ Loss and die-back of reeds fringing the estuary in the upper reaches (linked to salinity being > 20 for three months) ▪ Invasive plants (e.g. *Acacia cyclops*, prickly pear) cover > 5% of total floodplain area • Unvegetated, cleared areas along the banks caused by human disturbance

Component	EcoSpecs	Thresholds of Potential Concern
Invertebrates	▪ Maintain rich populations of the mudprawn *Upogebia africana* on mudbanks in the middle estuary (Zones A and B) ▪ Maintain rich invertebrate communities associated with the REI zone in the upper estuary (zooplankton and benthos)	▪ Mudprawn density should not deviate from average baseline levels (as determined in the eight visits undertaken quarterly in the first two years) by more than 25% in each season ▪ The dominant species in the zone (zooplankton and benthos) should not deviate from average baseline levels (as determined in the eight visits undertaken quarterly in the first two years) by more than 40% in each season
Fish	Fish assemblage should comprise the 5 estuarine association categories in similar proportions (diversity and abundance) to that under the reference (see 2015 EWR report). Numerically assemblage should comprise: ▪ Ia estuarine residents (50-80% of total abundance) ▪ Ib marine and estuarine breeders (10-20%) ▪ IIa obligate estuarine-dependent (10-20%) ▪ IIb estuarine associated species (5-15%), ▪ IIc marine opportunists (20-80%) ▪ III marine vagrants (not more than 5%) ▪ IV indigenous fish (1-5%) ▪ V catadromous species (1-5%) Category Ia species should contain viable populations of at least four species (including *G.aestuaria, Hyporamphus capensis, Omobranchus woodii*). Category IIa obligate dependents should be well represented by large exploited species especially *A. japonicus, L. lithognathus, P. commersonii, Lichia amia* REI species dominated by both *Myxus capensis* and *G. aestuaria*.	▪ Ia estuarine residents < 50% ▪ Ib marine and estuarine breeders < 10% ▪ IIa obligate estuarine-dependent < 10% ▪ IIb estuarine associated species < 5% ▪ IIc marine opportunists < 20% ▪ III marine vagrants > 5% ▪ IV indigenous fish < 1% ▪ V catadromous species < 1% (also linked to presence of freshwater seepage areas) ▪ Ia represented only by *G. aestuaria* ▪ IIa exploited species in very low numbers or absent ▪ REI species represented only by *G. aestuaria*, *Myxus capensis* absent

Component	EcoSpecs	Thresholds of Potential Concern
Birds	The estuary should contain a diverse avifaunal community that includes representatives of all the original taxonomic groups (see 2015 EWR report). Tern roosts should be seen at the estuary on a regular basis. Apart from gulls, terns and regionally increasing species such as Egyptian Goose, the estuary should generally support more than 200 birds.	▪ Numbers of birds other than gulls, terns and regionally increasing species fall below 120 for three consecutive counts ▪ Numbers of waterbird species drop below 15 for three consecutive counts

8.3 BASELINE SURVEYS AND LONGTERM MONITORING PROGRAMME

Additional baseline studies that are important to the improvement of the confidence of the EWR study is provided in **Table 8.3.** These components are all important to improves the confidence overall, but especially the sediment dynamics and invertebrate components are of a high priority. The recommended long-term monitoring programme, the purpose of which is to test for compliance with EcoSpecs and TPCs and to continuously improve understanding of ecosystem function, is presented in **Table 8.4**. While all components in the long-term monitoring programme remain important, certain primary (abiotic) data, as highlighted in **Table 8.4**, is of highest priority.

The implementation of the baseline and long-monitoring programme should be undertaken in collaboration of various responsible departments in DWS, as well as other national and provincial departments and institutions responsible for estuarine resource management such as DAFF, DEA: Oceans and Coasts, SANBI, CapeNature, as well as relevant municipal authorities. It is recommended that the estuarine management planning process and the associated institutional structures (as required under the Integrated Coastal Management Act 2008) be used as a mechanisms to coordinate and execute this long-term monitoring programme.

Table 8.3 Additional baseline surveys to improve confidence of EWR study on the Goukou Estuary (priority components are highlighted)

Component	Action	Temporal scale (frequency and when)	Spatial scale (Stations)
Hydrodynamics	Measure freshwater inflow into the estuary	Continuous	Near head of estuary (station H9H5 to far upstream, new station is required)
	Aerial photographs of estuary (spring low tide)	Baseline	Entire estuary
Sediment dynamics	Monitoring berm height using appropriate technologies	Quarterly	Mouth

Component	Action	Temporal scale (frequency and when)	Spatial scale (Stations)
	Bathymetric surveys: Series of cross section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detail in mouth including berm (every 100 m). Vertical accuracy at least 5 cm	Once-off	Entire estuary
	Collect sediment grab samples (at cross section profiles) for analysis of particle size distribution (and ideally origin, i.e. microscopic observations)	Once-off	Entire estuary
Water quality	River inflow: Conductivity, temperature, suspended solids, pH, inorganic nutrients (N, P and Si) and organic content (TP and Kjeldahl N) in river inflow	Monthly, continuous	Near head of estuary (station H9H5 to far upstream, new station is required)
	River inflow: Psticides/herbicide and metal accumulation	Once-off	Near head of estuary (H9H5 to far upstream, new station is required)
	Collect surface and bottom water samples for inorganic nutrients (and organic nutrient) and suspended solid analysis, together the in situ salinity, temperature, pH, dissolved oxygen and turbidity profiles	Quarterly, preferably over two years	Entire estuary (10-15 stations)
	Measure pesticides/herbicides and metal accumulation in sediments (for metals investigate establishment of distribution models – see Newman and Watling, 2007)	Once-off	Entire estuary, including depositional areas (i.e. muddy areas)
Microalgae	▪ Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae ▪ Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. spectrophotometer, HPLC, fluoroprobe ▪ Intertidal and subtidal benthic chlorophyll-a measurements (4 replicates each) using a recognised technique, e.g. sediment corer or fluoroprobe	Quarterly, preferably over two years	Along length of estuary minimum five stations

Component	Action	Temporal scale (frequency and when)	Spatial scale (Stations)
Invertebrates	▪ Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh) along the estuary at five sites ▪ Collect grab samples (5 replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each samples to be sieved through 500 um) ▪ Collect sled samples (day) at same zooplankton sites for hyper benthos (190 um) ▪ Intertidal invertebrate hole counts using 0.25 m^2 grid (5 replicates per site) ▪ Establish the species concerned using a prawn pump (Zones A and B) ▪ Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton) ▪ Three replicate hole counts of Upogebia africana at three intertidal sites in Zone B	Quarterly, preferably over two years	Minimum of five sites along length of estuary. For intertidal counts – minimum of five sites.

Table 8.4 Recommended long-term monitoring programme for the Goukou Estuary (priority components are highlighted)

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (No. stations)
Hydrodynamics	Measure freshwater inflow into the estuary	Continuous	Near head of estuary (H9H5 to far upstream, new station is required)
	Aerial photographs of estuary (spring low tide)	Every three years	Entire estuary
Sediment dynamics	Monitoring berm height using appropriate technologies	Quarterly	Mouth
	Bathymetric surveys: Series of cross section profiles and a longitudinal profile collected at fixed 500m intervals, but in more detail in mouth including berm (every 100 m). Vertical accuracy at least 5 cm	Every three years (and after large resetting event)	Entire estuary
	Collect sediment grab samples (at cross section profiles) for analysis of particle size distribution (and ideally origin, i.e. microscopic observations)	Every three years	Entire estuary
Water quality	River inflow: Conductivity, temperature, suspended solids, pH, inorganic nutrients (N, P and Si) and organic content (TP and Kjeldahl N) in river inflow	Monthly, continuous	Near head of estuary (H9H5 to far upstream, new station is required)
	River inflow: Pesticides/herbicide and metal contamination	Seasonally, or when contamination is expected	Near head of estuary (H9H5 to far upstream, new station is required)
	Collect in situ continuous salinity data with mini Conductivity-Temperature-Depth (CTD) probe at a depth of about 1 m	Continuous	3 sites - 5 km, 10 km from the mouth head and near head of estuary
	Record longitudinal in situ salinity and temperature pH, DO, turbidity profiles	Seasonally, every year	Entire estuary (17 stations)
	Collect surface and bottom water samples for inorganic nutrients (and organic nutrient) and suspended solid analysis, together the in situ salinity, temperature, pH, dissolved oxygen and turbidity profiles	Every three years (high flow and low flow) or when significant change in water quality expected	Entire estuary (10-17 stations)
	Measure pesticides/herbicides and metal accumulation in sediments (for metals investigate establishment of distribution models – see Watling and Newman, 2007)	Every 3 – 6 years	Entire estuary, including depositional areas (i.e. muddy areas)

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (No. stations)
Microalgae	▪ Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae. ▪ Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. spectrophotometer, HPLC, fluoroprobe. ▪ Intertidal and subtidal benthic chlorophyll-a measurements (4 replicates each) using a recognised technique, e.g. sediment corer or fluoroprobe.	Low flow surveys every three years	Along length of estuary minimum five stations
Macrophytes	▪ Ground-truthed maps to update the map produced for 2013 and to check the areas covered by the different macrophyte habitats ▪ Record boundaries of macrophyte habitats and total number of macrophyte species in the field. ▪ Assess extent of invasive species within the 5 m contour line ▪ Check for loss of reed and sedge area in the middle / upper reaches. Check for increase in bare areas in salt marsh habitat from mapping. ▪ Measure macrophyte and sediment characteristics along transects in the main salt marsh areas. Percentage plant cover measured in duplicate 1 m^2 quadrats along transects and an elevation gradient from the water to the terrestrial habitat ▪ Duplicate sediment samples collected in three zones along each transect to represent the lower intertidal, upper intertidal and supratidal salt marsh. Analysed in the laboratory for sediment moisture, organic content, electrical conductivity, pH and redox potential. In the field measure depth to water table and ground water salinity	Summer survey every three years	Entire estuary for mapping (transects located in the middle and lower reaches)
Invertebrates	▪ Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh) along the estuary at five sites ▪ Collect grab samples (5 replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each samples to be sieved through 500 um) ▪ Collect sled samples (day) at same zooplankton sites for hyper benthos (190 um) ▪ Intertidal invertebrate hole counts using 0.25 m^2	Every two years in mid-summer	Minimum of five sites along length of estuary. For intertidal counts – minimum of five sites.

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (No. stations)
	grid (5 replicates per site) ▪ Establish the species concerned using a prawn pump (Zones A and B) ▪ Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton) ▪ Three replicate hole counts of Upogebia africana at three intertidal sites in Zone B		
Fish	Record species and abundance of fish, based on seine net and gill net sampling	Summer and winter survey every three years	Entire estuary (17 stations)
Birds	Undertake counts of all non-passerine waterbirds, identified to species level.	Annual winter and summer surveys	Entire estuary (seven sections – see Figure F.6)

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APPENDIX A: ABIOTIC SPECIALIST REPORT

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A.1 AVAILABLE DATA

Abiotic data requirements for Intermediate level assessment (DWAF, 2008), as well as availability of data for this study, are presented below:

Data required	Availability	Reference
Simulated river runoff: Simulated over a 50-80 year period, provided as average monthly flows Flood hydrographs: Usually not required for Intermediate level, but reduction in floods should be estimated based on expert opinion	Simulated runoff data supplied by hydrologist for this study No flood hydrographs provided, flood data derived from simulated runoff	This study (see main report)
Sediment grabs, Sediment cores Bathymetric/topographical surveys and Sediment load at head of estuary: Available data (usually these measurements are not required as part of Intermediate level determination)	Collected as part of this study Bathymetric surveys (historical data)	This study (see Annexure A1 for data) CSIR unpublished data
Continuous flow gauging: Minimum of five years depending on mouth closure	Not available, scaled the flows form the Duiwenhoks gauge (1967)	DWS flow gauge:H8H1
Water level recordings and mouth observations: Minimum of five years depending on rate of mouth closure	Available since 1996	DWS water level recorder: Station H9T012
Water levels along estuary: Manually/digital recorded over one spring tidal cycle and one neap tidal cycle or continuous recordings over two weeks	Limited data available	CSIR (unpublished data)
Wave conditions	Use available data	
Aerial photographs	Available from CSIR archives	CSIR (unpublished data)
Water quality in river inflow (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary	Station in Goukou river too far upstream used Duiwenhoks EC, pH Inorganic Nutrients (1977-2013)	DWA water quality monitoring programme (station H8H1) De Villiers and Thiart (2007)

Data required	Availability	Reference
Longitudinal salinity and temperature profiles (in situ) collected over high and low flow period (or closed state for temporarily open estuaries)	Mar and Aug 1985 Mar, May and Sep 2003 Jan, Mar and May 2004 Dec 2013	Carter and Brownlie (1990) DAFF (unpublished data) This study (see Annexure A1 for data)
Water quality in estuary (i.e. system variables, and nutrients) taken along the length of the estuary (at least surface and bottom samples) during high and low flow period (or closed state for temporarily open/ estuaries)	pH, DO and inorganic nutrients (Mar and Aug 1985) pH, DO and turbidity (Mar and May 2004) pH, DO, turbidity, SS and inorganic nutrients Dec 2013	Carter and Brownlie (1990) DAFF (unpublished data) This study (see Annexure A1 for data)
Toxic substances in estuary (e.g. trace metals and hydrocarbons) in sediments along length of the estuary at least once during low flow	No data	
Water quality in sea (e.g. system variables, nutrients and toxic substances)	From literature	DWAF (1995)

A.2 PHYSICAL PROCESSES (SEDIMENT AND HYDRODYNAMICS)

A.2.1 Available data

Significantly more data is available on sediment dynamics and estuarine morphology of the Goukou Estuary than for most other SA estuaries, although the existing information still remains relatively meagre. The main sources of information related to sediment dynamics and morphology (some more anecdotal or circumstantial) are Day (1981), Harrison *et al.* (2000), Carter and Brownlie (1990), Sowman, *et al.* (1988), Theron *et al*. (2002), Theron (2004) and Beck *et al.* (2004). Most recently, a number of significant impacts on physical drivers and morphologic and sediment dynamics characteristics were observed during a site investigation conducted on 3 December 2013.

Sediment samples were collected in the mouth (between the high and low water mark) of the Goukou Estuary on 19 January 1996. This sediment sample had a median grain size of 0.27 mm which is described as medium sands based on the Udden-Wentworth classification (Tanner, 1969). Sediment samples were also collected in the Goukou Estuary on 19 July 2001. **FigureFigure A1.1** shows the grading results and plot of the sediments found at the bottom of the Goukou Estuary, along the distance of the main channel measured from the mouth to about 5.5 km upstream. (The mouth is at Chainage –65 m.) The median grain sizes of these samples ranged from about 0.2 mm to 0.4 mm, which is classified as fine to medium sands.

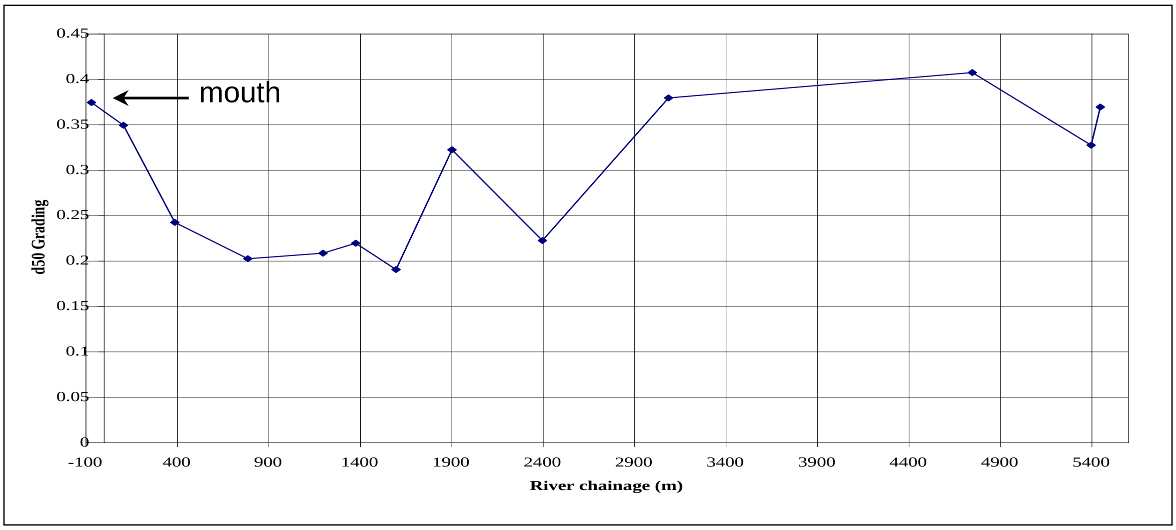

Figure A1.1 Median grain size (d50) plot for the Goukou Estuary: 19 July 2001

Sixteen sediment grab samples were also collected from approximately mid-channel along the Goukou Estuary during a field data collection campaign on 3 December 2013, at approximately the locations indicated in **Figure A2.1**. These samples all ranged from fine to medium sands (typical median grains sizes between about 0.13 mm to 0.5 mm; Udden-Wentworth sediment grain size scale; Wentworth, 1922), with light brown to medium brown colour and low organic content as well as low cohesiveness (containing virtually no clay material and very little silt). The details of the sediment grain size analyses for the December 2013 samples are presented in Annexure A2. Comparisons of this information with that of previous sediment surveys could not identify any distinct shifts or trend in the marine/riverine sediment balance.

A.2.2 Sediment supply

Catchment

The Goukou River is 67.4 km long with a mean annual run-off (MAR) of about 106 x 10^6 m^3. Five major tributaries are draining into the Goukou River, namely the Soetmelks, Naroo, Brak, Vet and Kruis Rivers. There is one major dam, the Korente-Vet Dam on the Vet River, north-west of Riversdal with a storage capacity of 9.5 x 10^6 m^3. There are a large number of farm dams scattered throughout the catchment of the Goukou River.

According to Msadala *et al.* (2010), the Goukou River catchment has a very low to moderately low erosion index (red ellipse in **Figure A1.2**). The sediment yield for this catchment has been estimated at 150 tonnes per km^2 which is considered to be low. Most of the sediment entering the river system from terrestrial sources is probably derived from the hilly areas in the upper catchment (Carter and Brownlie, 1990). Thus, the Goukou River delivers a relatively low sediment load into the estuary, most of which is fine sediments that are largely washed out to sea.

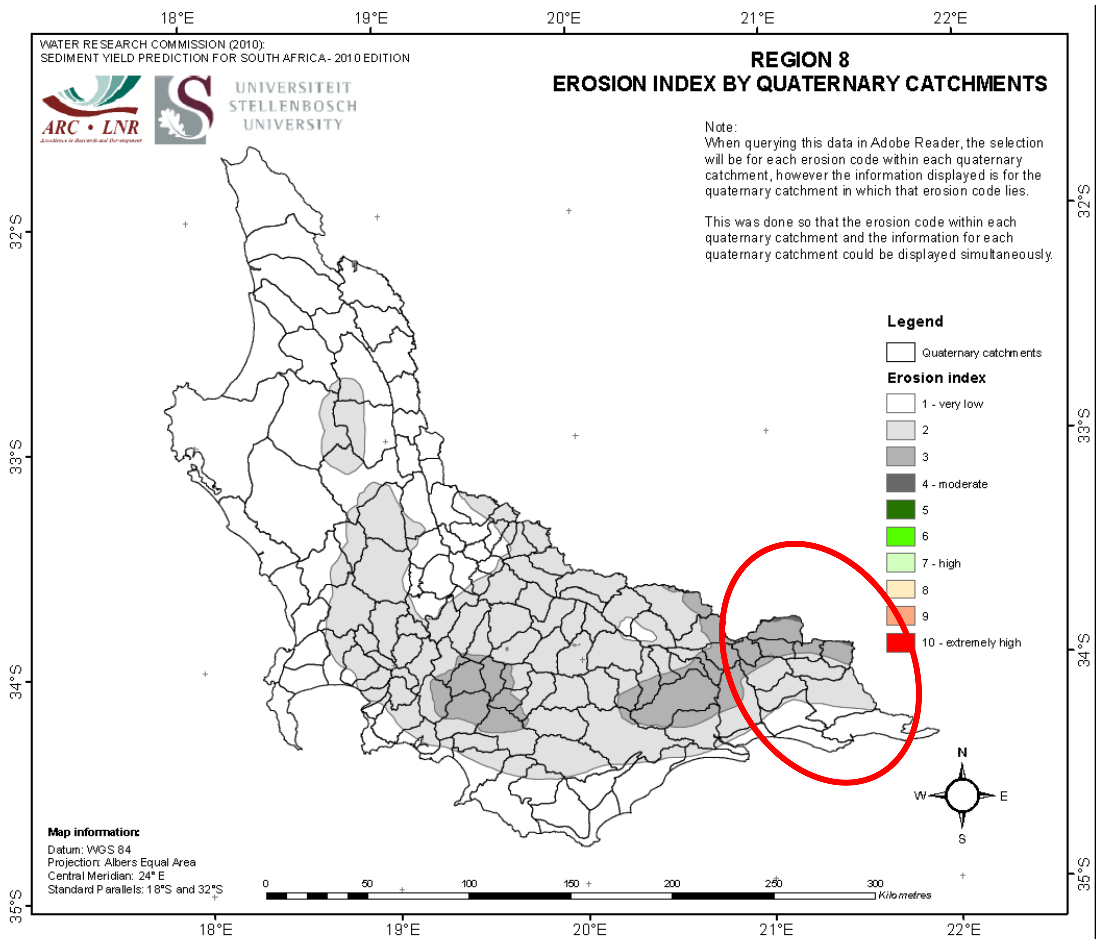

Figure A1.2 Erosion index for the Goukou catchment

The most recent available land-use data from the Goukou catchment has been provided by Harrisson *et al.* (2001). Agriculture accounts for about 35% of the land-cover of the Goukou catchment. About 2% of the catchment is degraded shrubland while approximately 63% is natural. Urban development accounts for about 1% of the land-cover. The significant agricultural activities in the catchment lead to increased land erosion and thus sediment yield to the estuary.

Marine supply

A more than ample supply of marine sediment is present at the Goukou Estuary mouth, for potential transport into the estuary. Thus, the amount of marine sediment intrusion into the estuary is mainly dependent on the (nett) transport capacity of the ebb and flood tidal flows near the mouth, and not on the amount of sediment available outside of the mouth. Previous research (Theron *et al.*, 2002; Beck *et al.*, 2004) showed that the sediment balance in the estuary relies on a subtle balance between dominant flood and ebb tide flows. It is therefore not correct to simply conclude that sedimentation occurs upstream due to the stronger flood tide since the cross-sections and durations of the flow differ during the two tidal phases.

A.2.3 Water levels and tidal action

The hydraulic and hydrodynamic regime of the Goukou Estuary is governed mainly by tidal action (and ocean tide) and river inflow. Tidal seawater levels predicted for Mossel Bay are shown schematically in **Figure A1.3**. Approximate maximum and minimum water levels recorded (by DWAF) in the Goukou Estuary, about 1.5 km upstream of the mouth, are also shown in **Figure A1.3.**

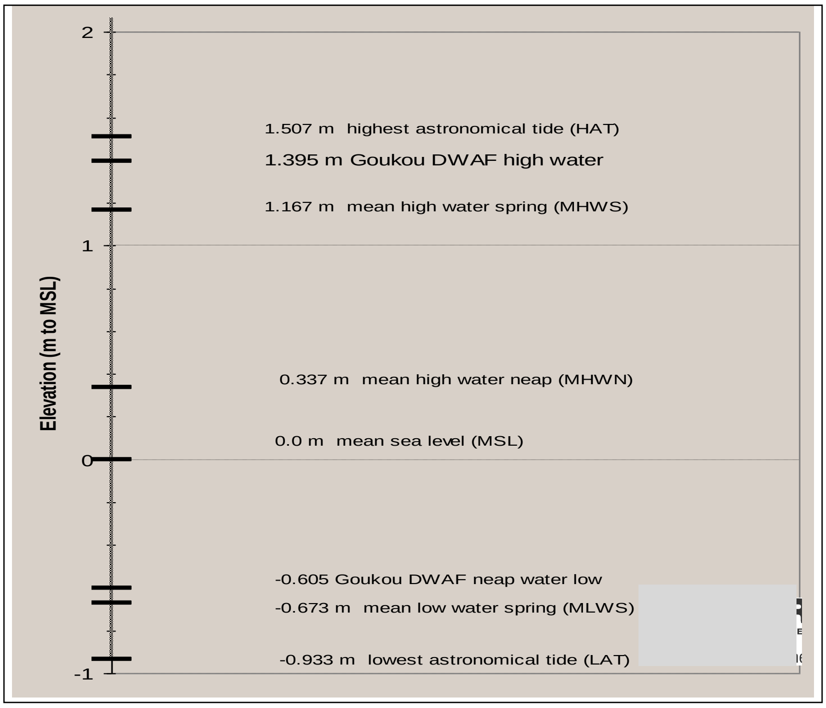

Figure A1.3 Stillwater levels at Goukou Estuary and Mossel bay

Water levels have been recorded in this system since 1995, but in earlier measurements the low tides are somewhat truncated as a result of the instument position. Since September 2011 the instument was move to a position where the full tidal cycle can be observed (**Figures A1.4 a-b**).The system is flood tide dominated with the flood tide being of significantly shorter duration than the ebb tide. The tide ranges from about 1.75 m at spring tide to about 0.5 m at neaps as measured at H9T012 (-0.605 m correction). Water levels vary between 1.25 to -0.5 m mean sea level (MSL). The highest water levels recorded in the estuary of about 1.4 m above mean sea level, are between mean high water spring in the ocean and highest astronomical tide (which statistically occurs once every 19 years). This indicates that the mouth does not significantly restrict tidal inflows.

The lowest water levels recorded in the estuary of about 0.6 m below mean sea level occur during neap tides and are approximately only 7 cm above mean low water spring in the ocean. The minimum water levels in the estuary are directly affected by the sill level of the estuary mouth. If the minimum water levels in the estuary were to progressively increase or decrease in the long term, this would indicate that the average sill level of the estuary mouth is undergoing a net increase or decrease.

The unrestricted mouth area results in very low water levels in the estuary especially at neap tides and also means that existing sandbanks will be more exposed at low tides and boating will be difficult. It also means that the mouth area will be at a maximum depth during high tides and especially at spring highs the water depth can easily be in the order of 3 m.

The lower reaches of the estuary (below the bridge) are well flushed by seawater during each tidal cycle, while the reach between the bridge and about 6 km upstream tends to form a high retention zone as a result of its increased depth. From 6 to 9 km the system is shallow (< 1.0 m deep) which acts as a significant constriction to tidal flows. From about 9 km to 16 km the sytem is once agian deep (2 – 3 m). In summer, the upper reaches of the estuary can be realtively stagnant in the absence of river inflow, while they can be well-flushed by river water during periods of high flow.

The mouth (and lower reaches) of the system can become somewhat constricted (by ~0.20 cm) during prolonged periods of low river flow. This reduces the tidal action and associated tidal flushing. This obstruction to tidal flows is normally removed as soon as river inflow increases and sediments are carried from the lowermost reaches of the mouth.

However, from various accounts by observers, it would appear that there may be some/significant sedimentation of the middle and upper reaches of the estuary. These sediments would be of fluvial origin. There are unfortunately no measurements or data available to prove these claims, or to conclusively disprove these perceptions.

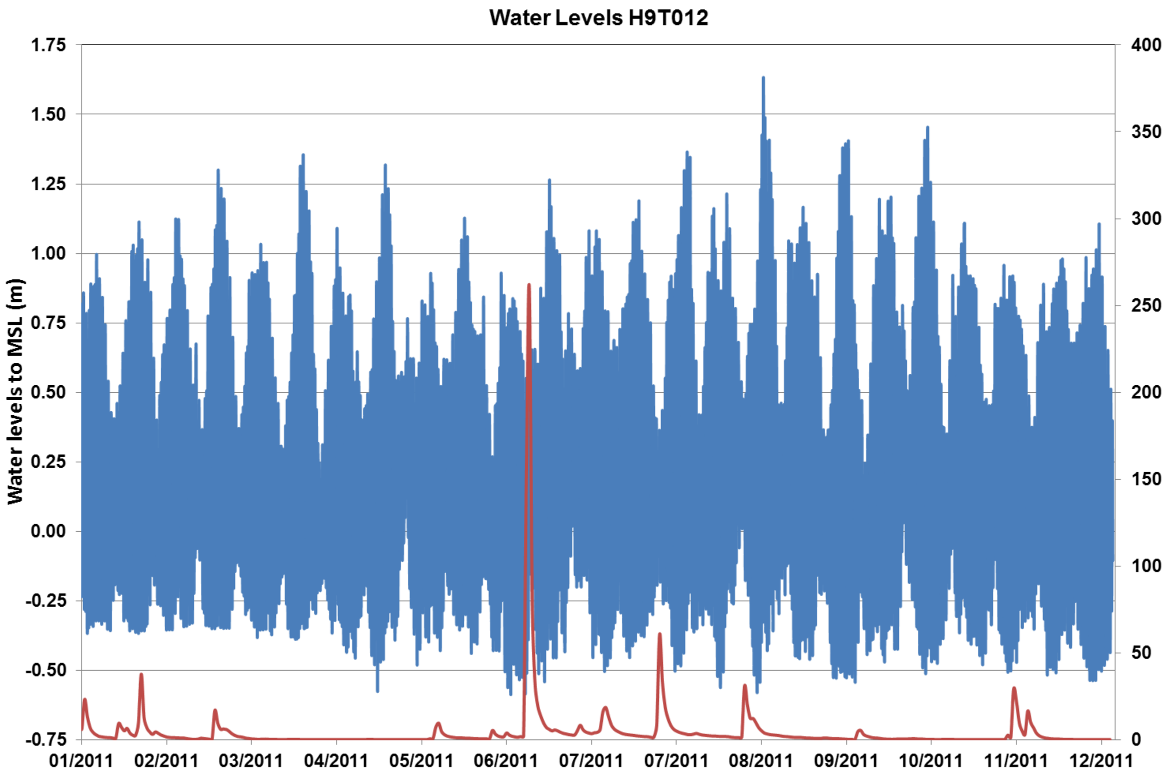

Figure A1.4a Goukou Estuary water levels (H9T012) depicted against estimated flows for 2011

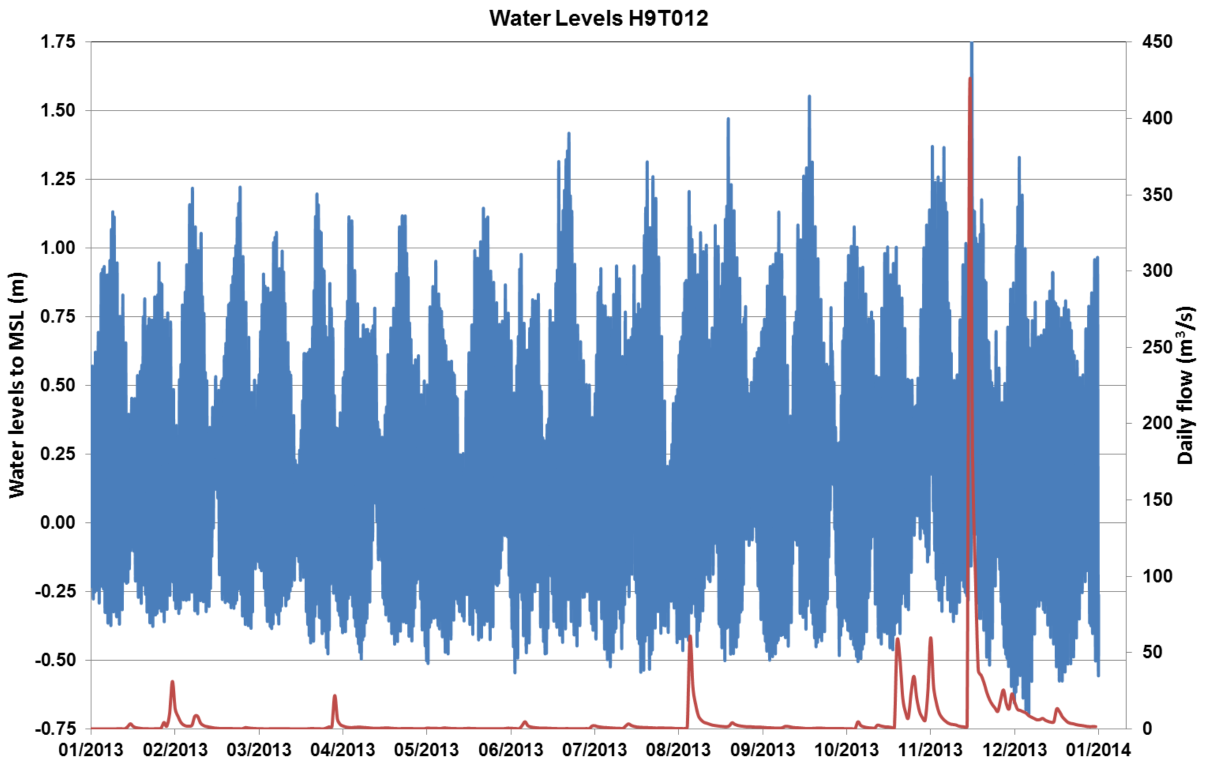

Figure A1.4b Goukou Estuary water levels (H9T012) depicted against estimated flows for 2012 and 2013

Figure A1.4b clearly shows the influence of a flood (average daily flow estimated between 400 and 450 m^3/s) on the system in November 2013, when water levels in the estuary are elevated nearly 0.5 m higher during the flood event.

Figure A1.5 depicts a comparison of tidal water levels recorded from neap to spring tide in March 2003. Tides measured in the Still Bay harbour are close to predicted tides for Mossel Bay. High tide levels in the estuary (about 1.5 km upstream) also followed the ocean tides relatively closely, but were slightly damped towards the spring period indicating some restriction or drag to tidal flows. On the other hand, low tide levels in the estuary are clearly cut off from about midway to the full spring period. This is a typical estuary mouth effect.

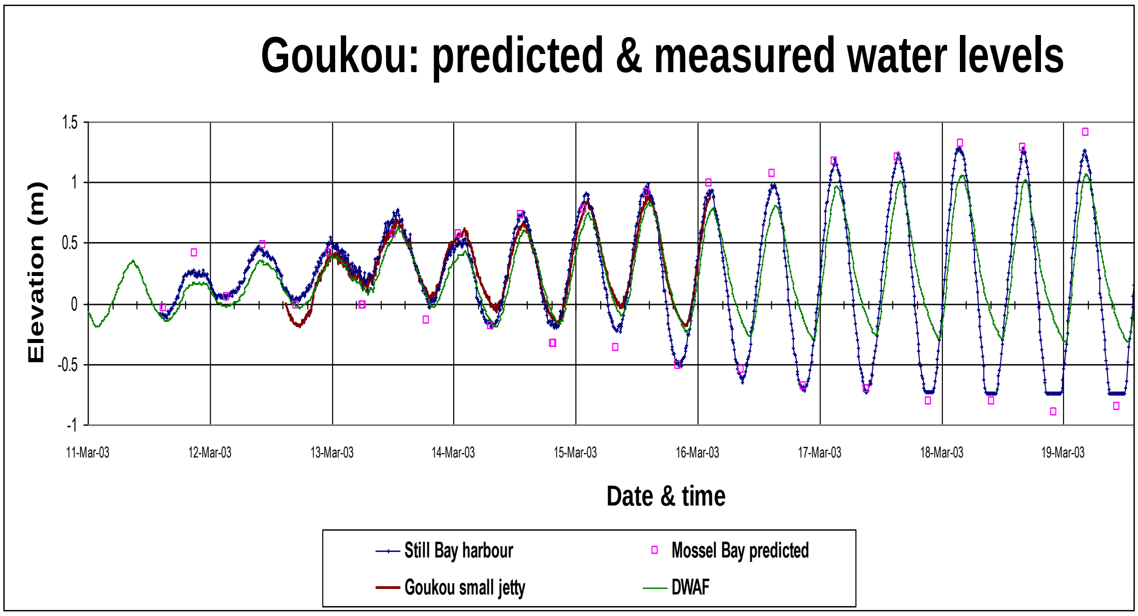

Figure A1.5 Predicted and measured water levels in the Goukou Estuary, March 2003

The effect of a river flood (24 -25 March 2003) on the relatively small permanently open Goukou Estuary was investigated by Theron (2004). Water levels were recorded in the estuary during a flood which had an estimated return period of about 1 in 10 years (**Figure A1.6**). The effect of the flood on the water levels was clearly discernible. Of importance is the fact that the maximum water level during this particular flood did not even attain the levels reached during spring tides. This means that in the lower part of the estuary, flow velocities and sediment transport potential during this event were not even as high as during spring tides. It seems that a flood with a significantly greater return period would be required to affect large scale scouring of the sandbanks in the lower Goukou Estuary.

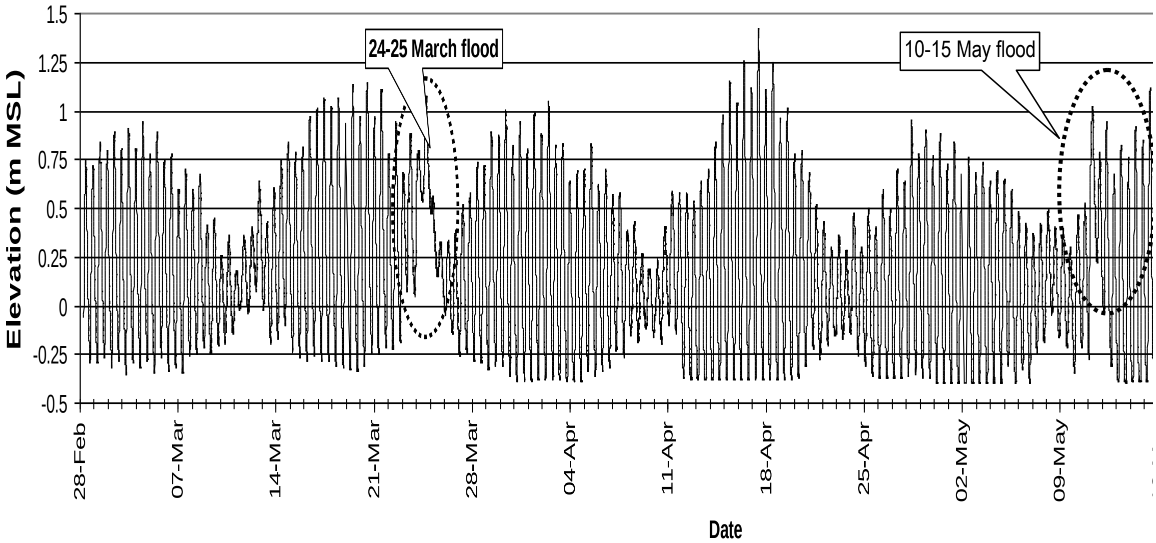

Figure A1.6 Water levels recorded in the Goukou Estuary during two river flood periods in 2003

A.2.4 Hydraulics of sediment transport processes

Field investigations have been conducted at the Goukou Estuary, which focussed on the hydraulics of sediment transport processes through the estuary during the tidal cycle (Theron *et al*., 2002; Theron, 2004; Beck *et al.*, 2004). The fieldwork basically involved the measurement of sediment transport related parameters, flow velocities and water levels at various locations in the estuary during the tidal cycle. An initial joint field exercise (by the University of Stellenbosch, the Department of Water Affairs and the CSIR) was conducted at the Goukou Estuary over a few spring tidal cycles from 19 to 21 July 2001 (**Figure A1.7**).

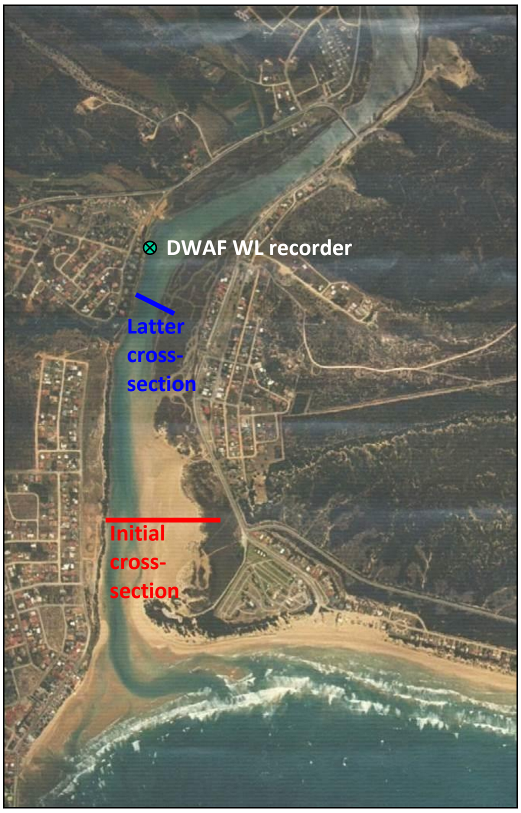

Figure A1.7 Aerial view of Goukou Estuary and location of cross-sections

During the 2001 campaign, extensive field measurements were done and a cross-section was covered representatively (on fixed horizontal and vertical grid points). Data were recorded over about $3^1/_2$ complete spring tidal cycles. A synopsis of captured field data is shown in **Figure A1.8**, which indicates measured water levels, as well as current velocities and directions. (Also shown are predictions of these parameters taken from Theron, 2004.)

Figure A1.9 shows a plot of the measured water levels, averaged flow velocities and sediment flux over a period of nearly four tidal cycles, determined in the above manner. It can be seen that in this case, there is a net upstream sediment flux through the cross-section (The upstream direction means inland, i.e. away from the mouth and towards the river.) The field data therefore shows aclear nett marine sediment ingress through this particular cross-section over this particular time period (However, due to the limited amount of data and the assumptions that had to be made in the calculations, the confidence placed in the absolute value of nett transport is relatively low).

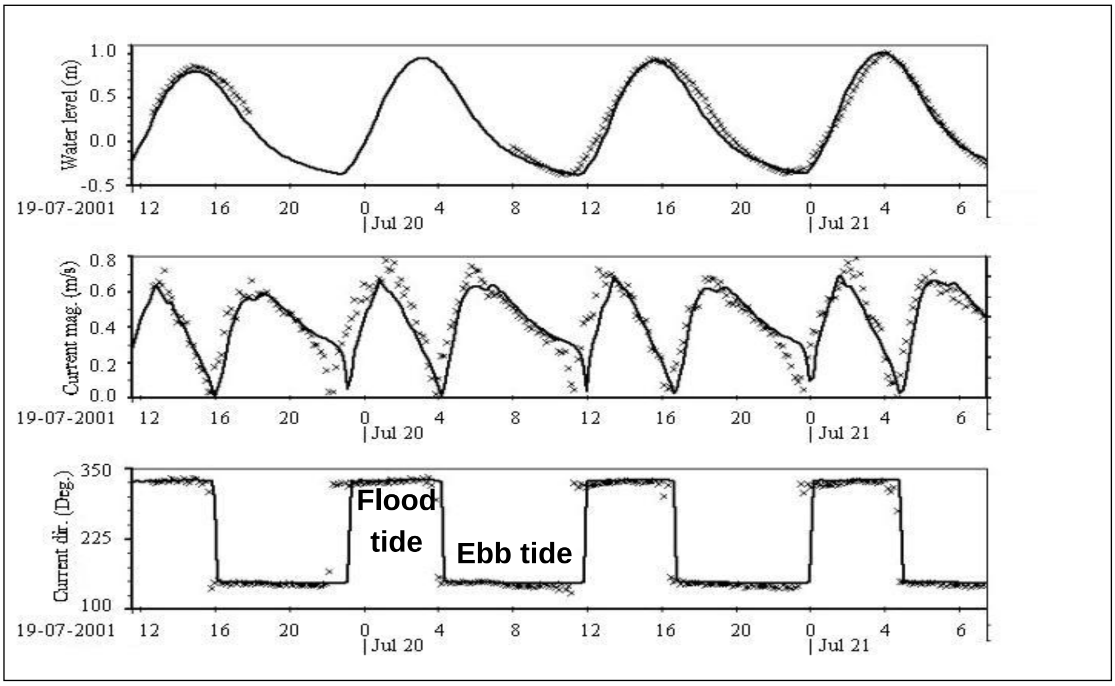

Figure A1.8 Measured (xxx) and predicted (—) hydrodynamics

A second joint field exercise by the University of Stellenbosch and the CSIR was conducted at the Goukou Estuary in March 2003. The purpose of this field exercise was mainly to obtain data through a complete neap tide to spring tide cycle, and for verification of a 2D computational model. Fixed "continuously" recording instruments were deployed during the neap tide and recovered one week later during spring tide. In addition, extensive field measurements were conducted during a few spring tidal cycles.

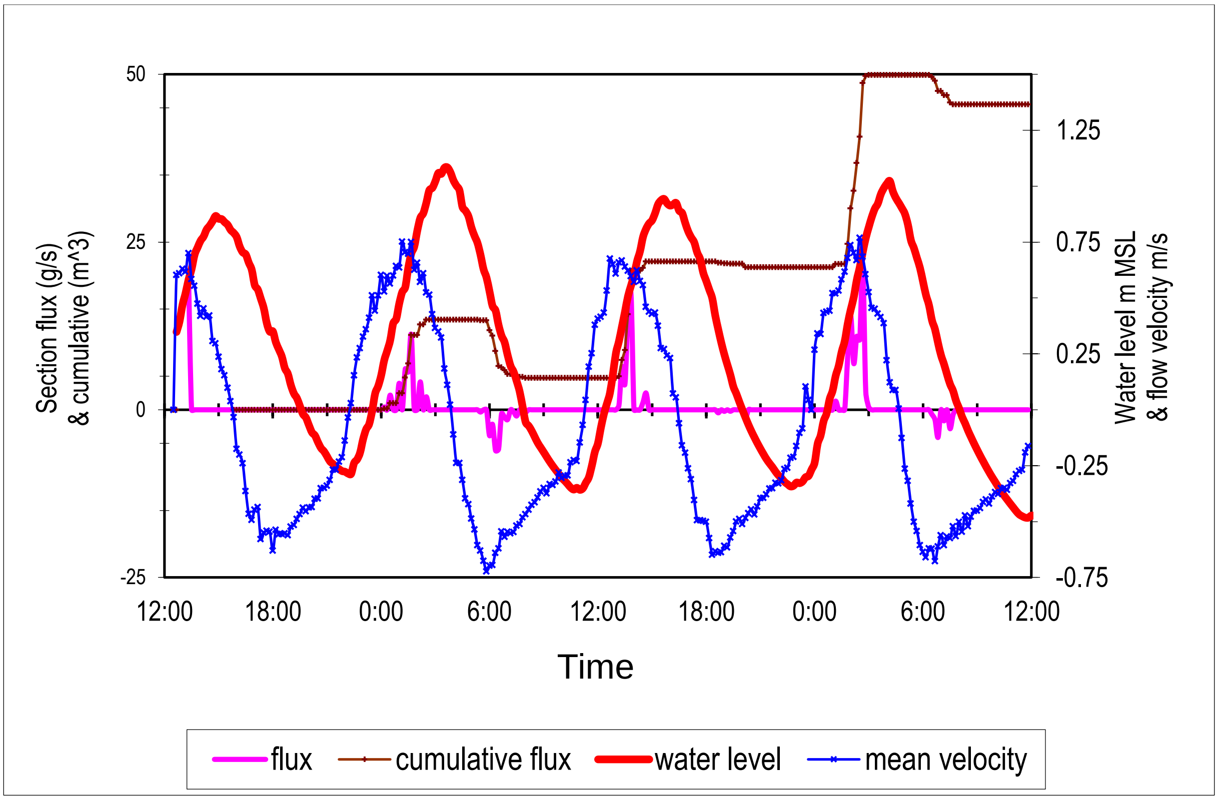

Figure A1.9 Calculated flux through the cross-section ~0,5 km from mouth

By using a logarithmic velocity distribution through the water column and parabolic suspended sediment concentrations (SSC) distribution through both in the vertical and horizontal (across the section), the total sediment transport (flux) could be integrated through the cross-section. **Figure A1.10** shows a plot of the measured water levels, averaged flow velocities and sediment flux over a period of about 1 week, determined in the above manner, through a cross-section about 1.3 km from the mouth. The blue line indicates flow velocity, while the black line indicates net sediment transport through the cross-section. Positive values mean upstream flow/velocities and net transport, while negative values mean downstream flow and transport. Clearly, during neap tides maximum velocities are low with very little transport, while both velocities and transport increase towards spring tides. It can be seen that in this case, there is again a net upstream sediment flux through the cross-section. The result is that in this case the nett upstream transport is estimated to be in the order of about 30 m^3 after this particular 7-day neap to spring tidal cycle. The field data therefore clearly show a nett marine sediment ingress through this particular cross-section over this particular time period. As before, the confidence placed in the absolute value of nett transport is relatively low, but due to the longer recording period and better calibration of the OBS, the accuracy is probably better. The result should, however still rather not be used for the ultimate quantification of the long-term sediment balance in the estuary. If there is a long-term net ingress of marine sediment (which is likely), then the only plausible way for a long-term equilibrium to be established, is if large river floods would on occasion flush out this sediment.

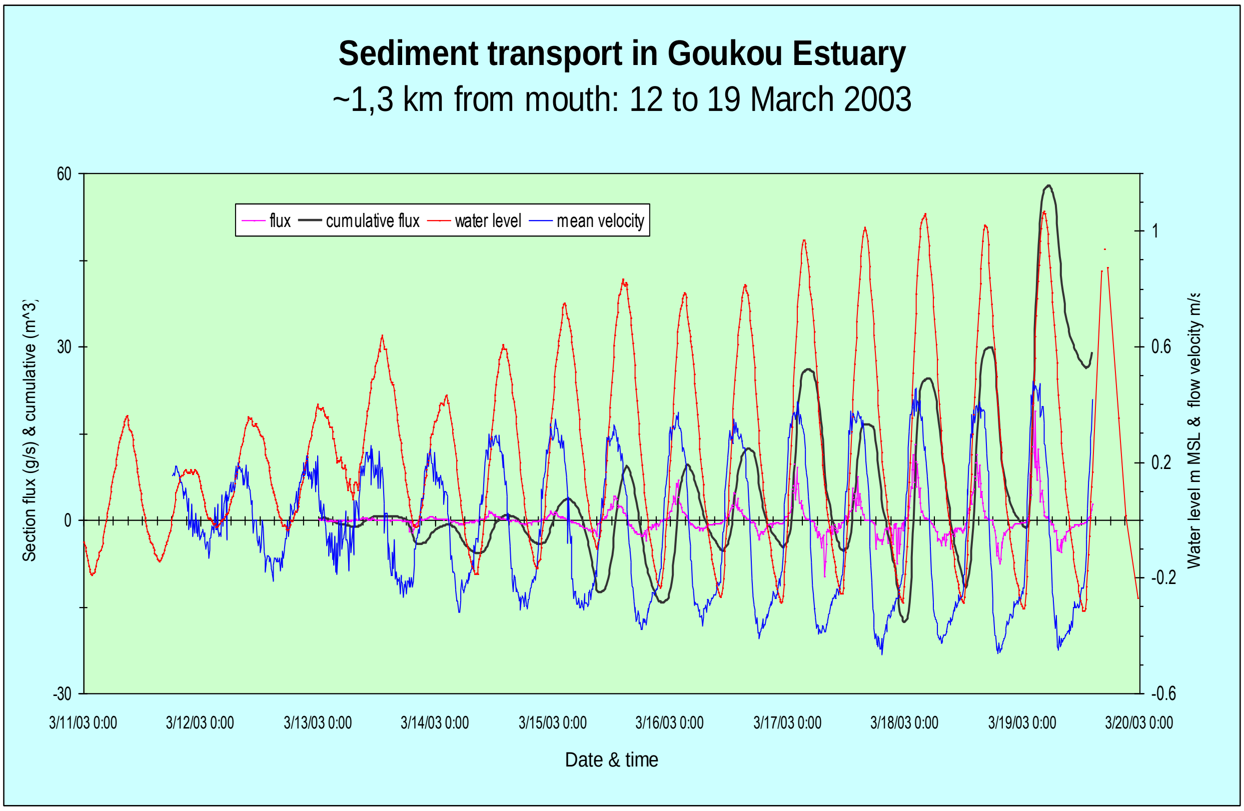

Figure A1.10 Calculated flux through the cross-section ~1,3 km from mouth

A.2.5 Bathymetry and cross-sections

Surveying of cross-sections in estuaries by standard land surveying techniques is time consuming and expensive. For this reason an alternative method, using a ski boat and echo sounder were developed, allowing reasonably accurate surveys of the cross-sections below the water level to be undertaken within a short time at much reduced costs. A boat mounted digital echo sounder and a laser rangefinder was used. The rangefinder was used to determine the positions of the soundings (usually recorded as *distance [in m] from left bank*) across a section. The position of each cross-section was usually verified using geographical position fixing systems (GPS). At the time of the survey, the water level was also recorded at the mouth so as to correct the data to MSL. Although the survey by ski boat and echo sounder covers only the deeper parts of the estuary which are accessible by boat, these are usually the main areas where changes in sedimentation and erosion take place.

The vertical accuracy of the depths measured with the echo sounder was within 0.1 m, provided that bottom material is hard enough to provide a proper echo. Vertical inaccuracies are also introduced by the reduction of the echo sounder reading to a depth referred to MSL. This, in turn, depends on the accuracy of the water level readings taken from the gauge plate, which is of the order of 0.01 m, as well as the accuracy with which the actual water level at the echo sounder position can be corrected based on the gauge plate readings. For this reason, accuracies in readings close to the location of the gauge plate will be in the order of 0.02 m, while at greater distances the accuracy will be of the order of 0.1 m, depending on the accuracy with which the phase differences of tidal variation can be determined. These errors will be minimal at small tidal variations and for this reason these type of surveys are generally undertaken during *neap tides*. The total degree of inaccuracy for these surveys is therefore estimated at 0.1 m near the gauge plate and 0.2 m further away from the gauge plate.

The position of each cross-section was pre-determined on an ortho-photo map. The cross-section was then surveyed in the field at the approximate location (**Figure A1.11**). The cross-section positions are given in **Figure A1.12**.

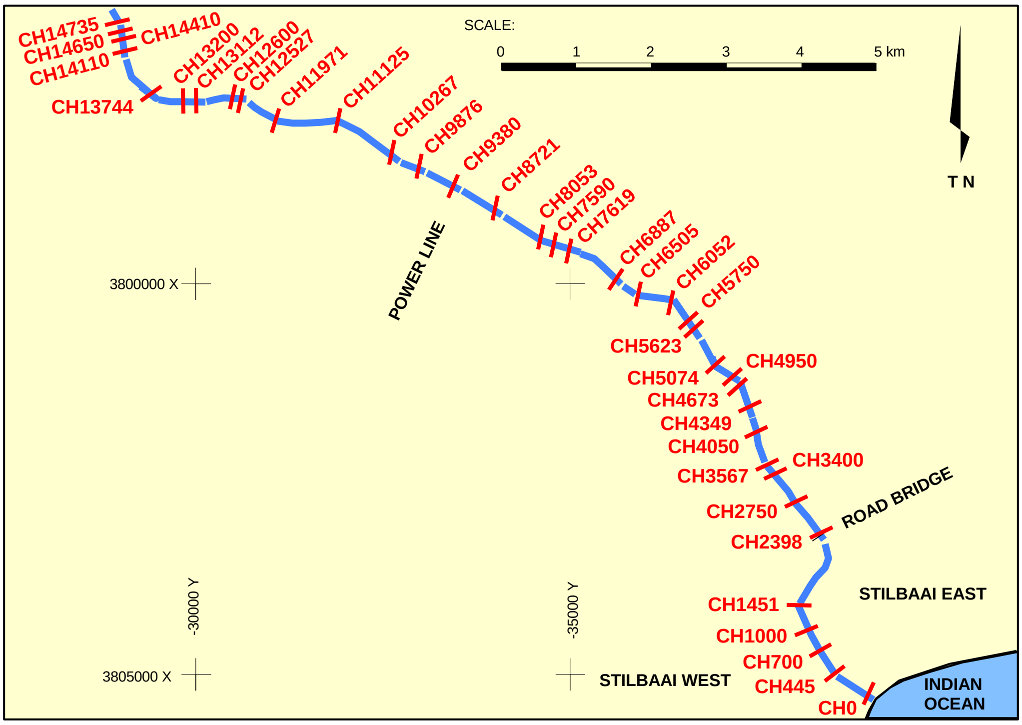

Figure A1.11 Location of cross-section profiles taken in the Goukou Estuary

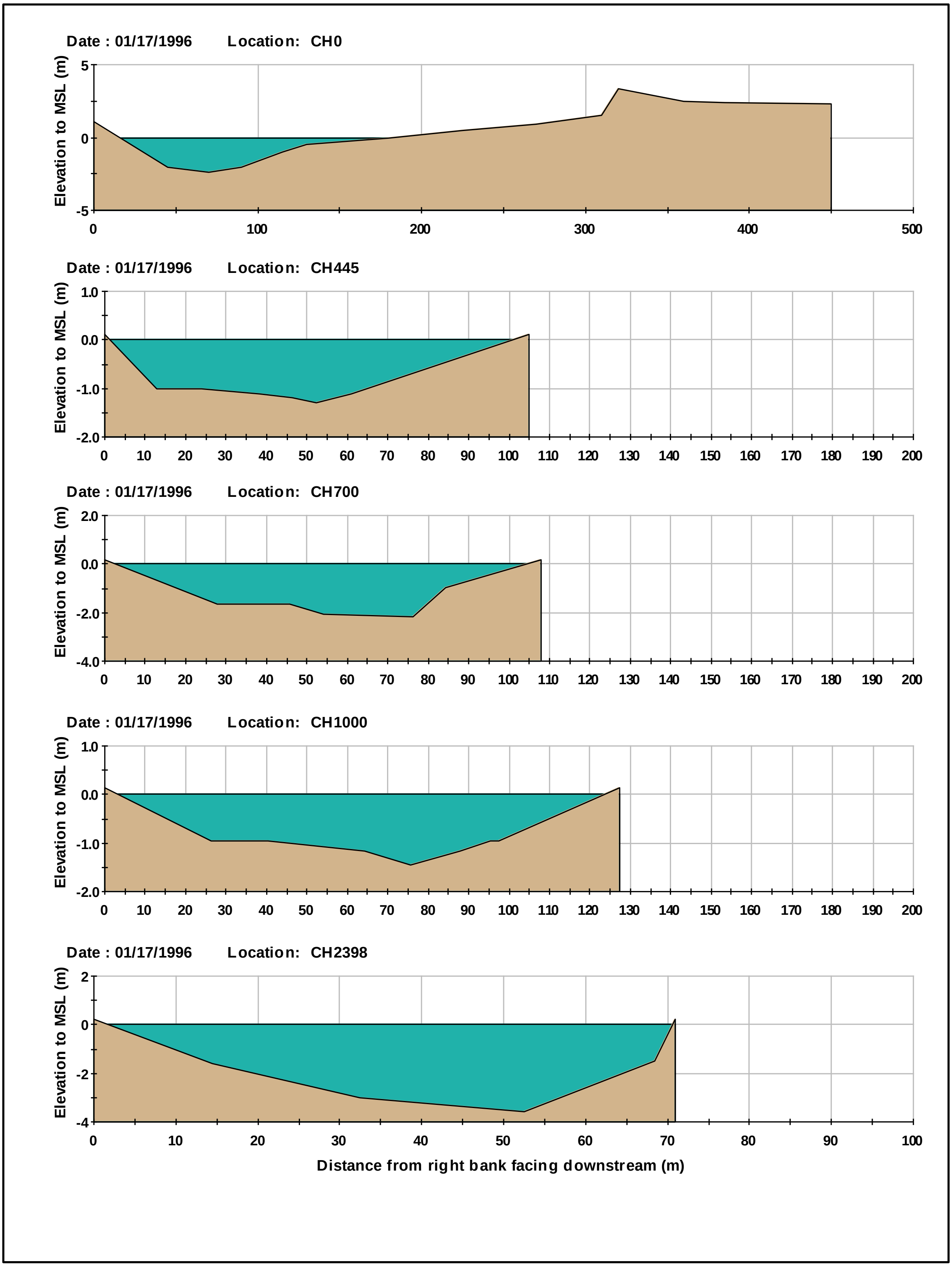

Figure A1.12 Goukou Estuary: Cross-section profiles – 17 January 1996

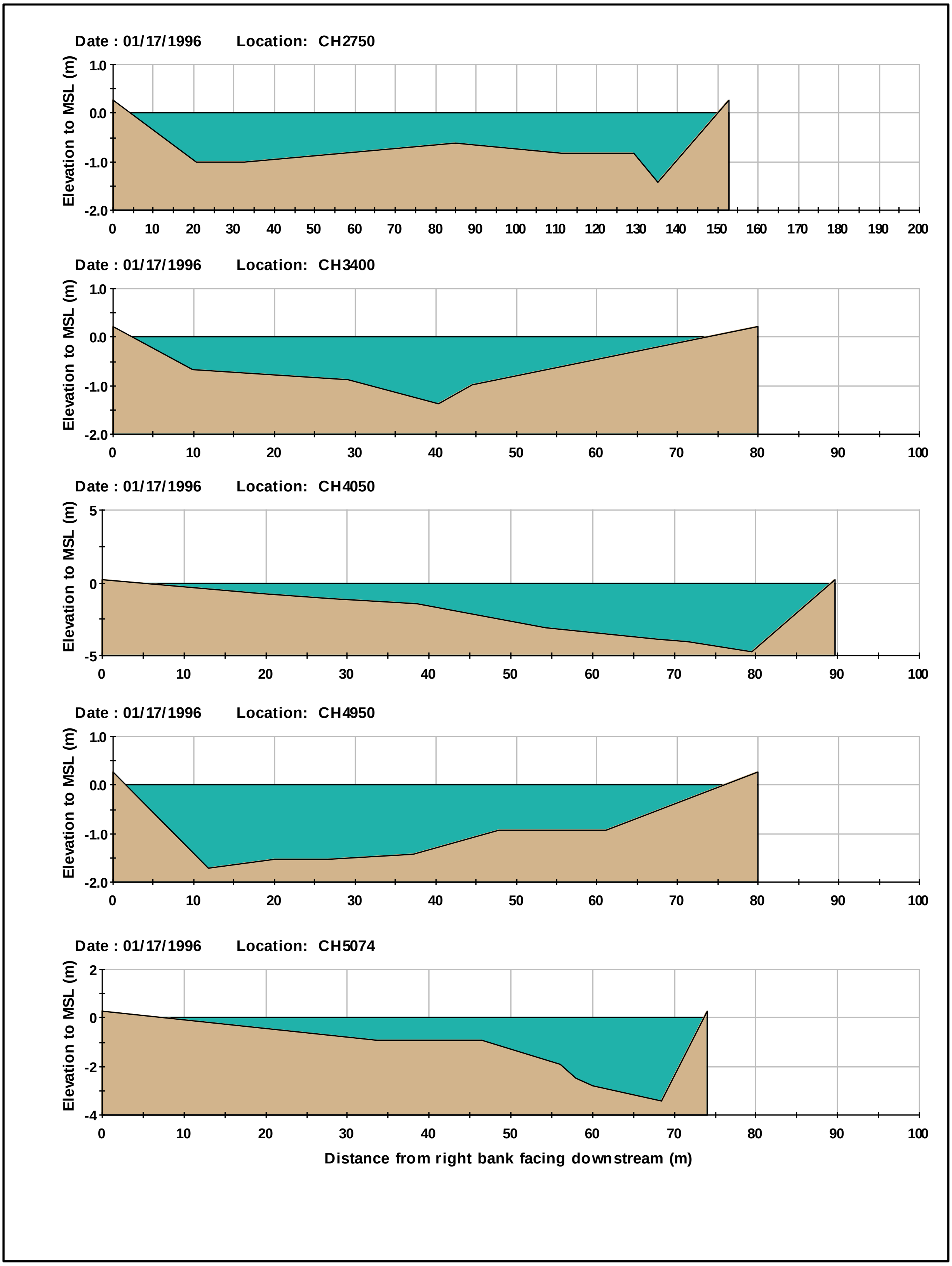

Figure A1.12 Goukou Estuary: Cross-section profiles – 17 January 1996 (continued)

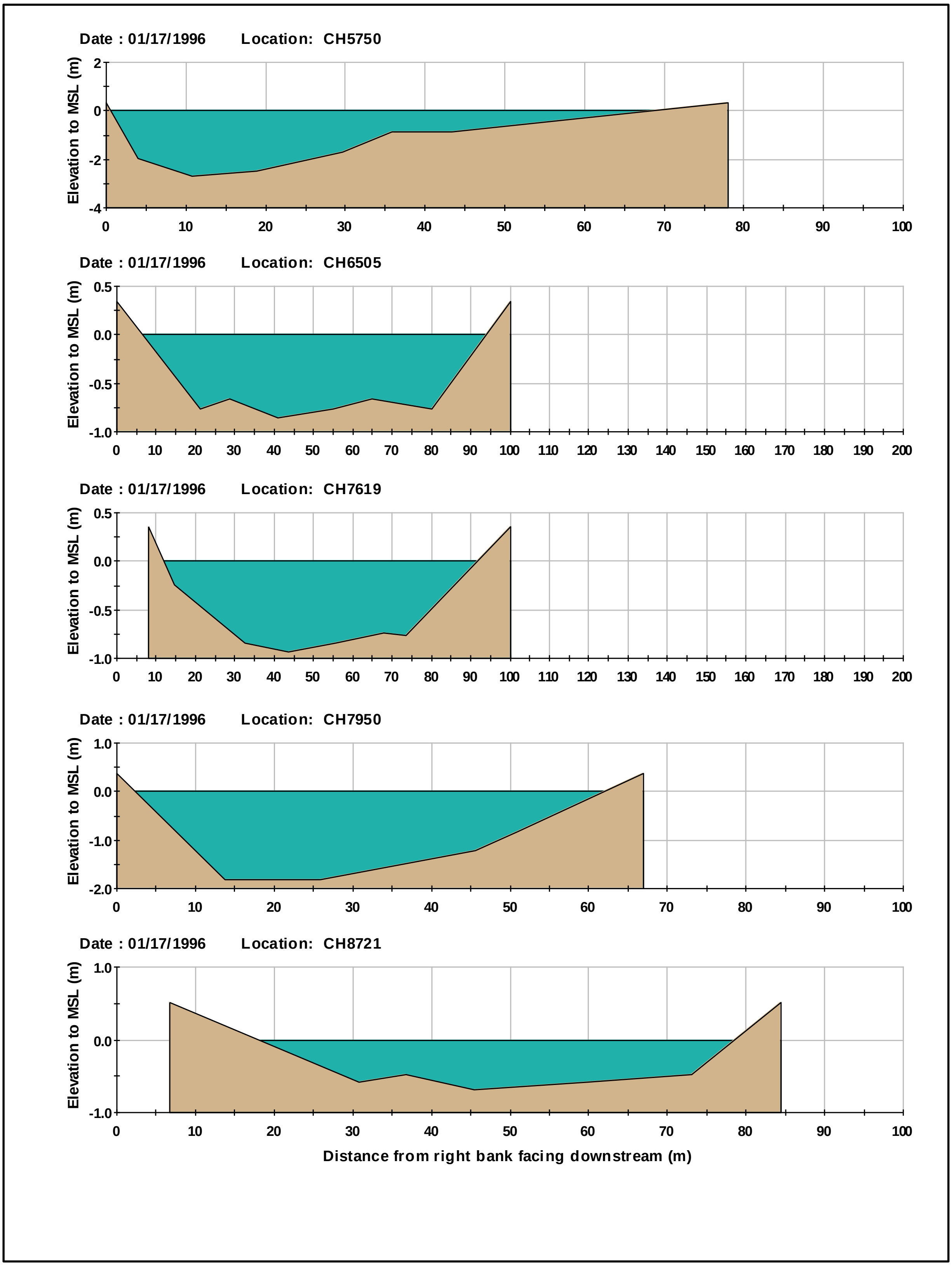

Figure A1.12 Goukou Estuary: Cross-section profiles – 17 January 1996 (continued)

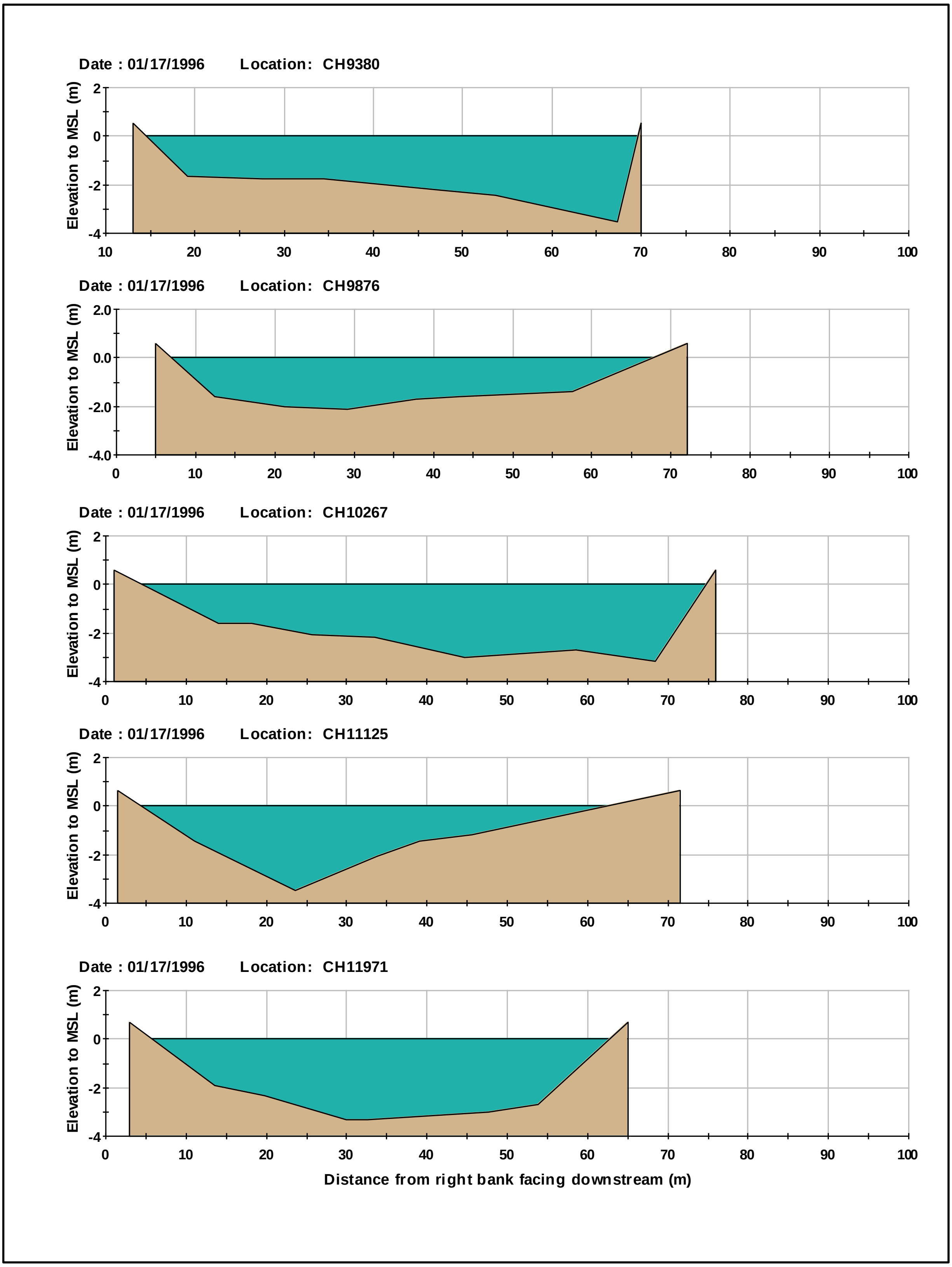

Figure A1.12 Goukou Estuary: Cross-section profiles – 17 January 1996 (continued)

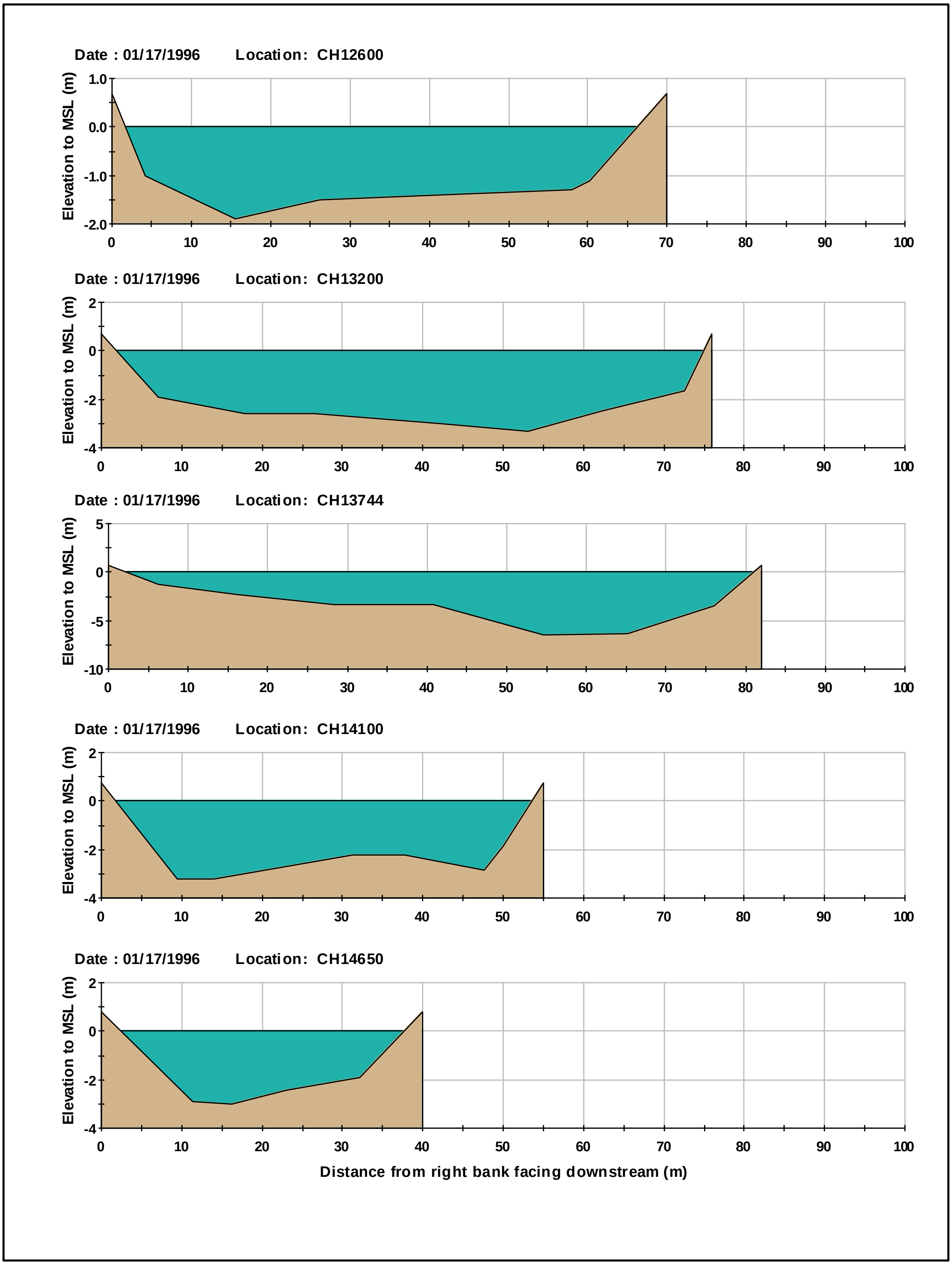

Figure A1.12 Goukou Estuary: Cross-section profiles – 17 January 1996 (continued)

Comparative surveys (Jan 1996 vs May 2004, **Figure A1.14**) at about the narrowest point in the mouth (0) and 90 m upstream of the mouth (**Figure A1.13**) shows little difference in the deepest point (almost at -2,5 m MSL).

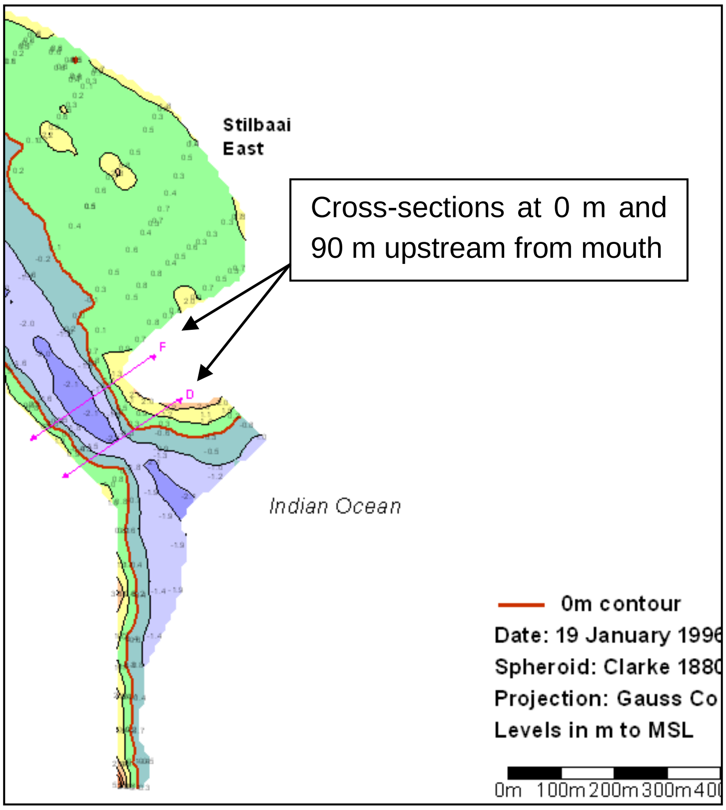

Figure A1.13 Locations of surveyed cross-sections at Goukou Mouth

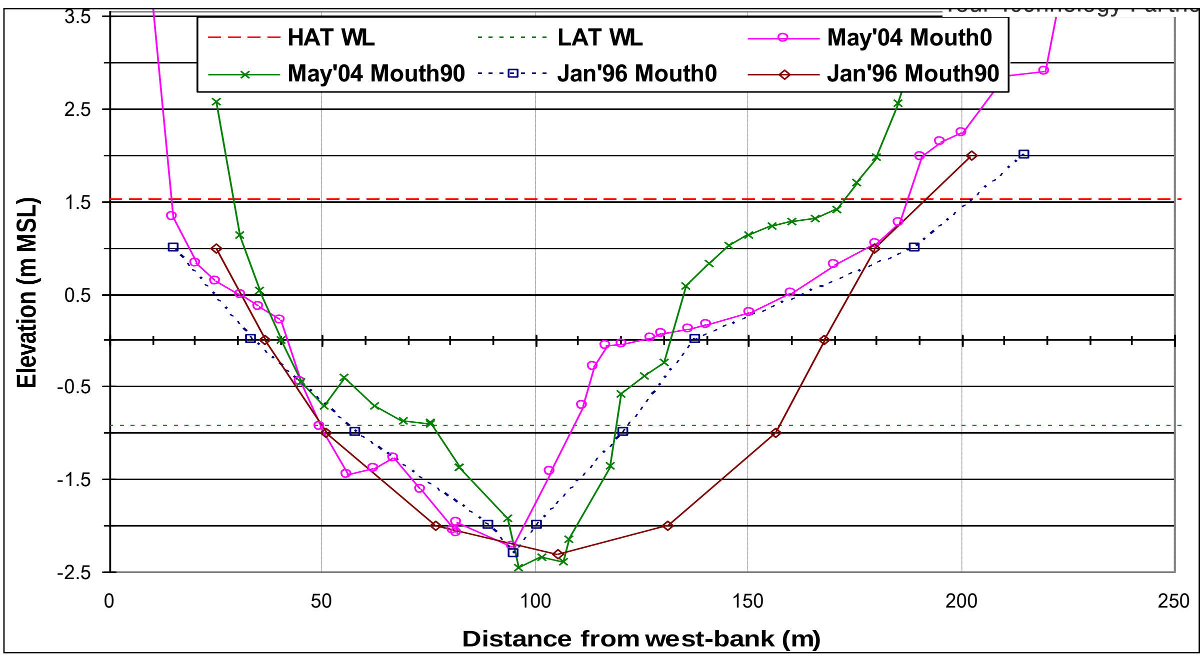

Figure A1.14 Surveyed cross-sections through Goukou Mouth

The mouth width in May 2004 appears somewhat narrower than that measured in Jan 1996. However, it should be kept in mind that the sandy eastern bank of the mouth is highly dynamic and constantly changing in response to tidal flows through the mouth, wave action and even wind action.

The survey carried out in May 2004 across a point 1451 m upstream of the mouth (just downstream of the boat launch site, **Figure A1.11**) shows that the sandbank reaches a level of just over 0,5 m above MSL and that the river channel is about 120 m wide at 0,0 m MSL, 45 m wide at -1,0 m MSL and up to 3 m deep on the western side of the river **(Figure A1.15**).

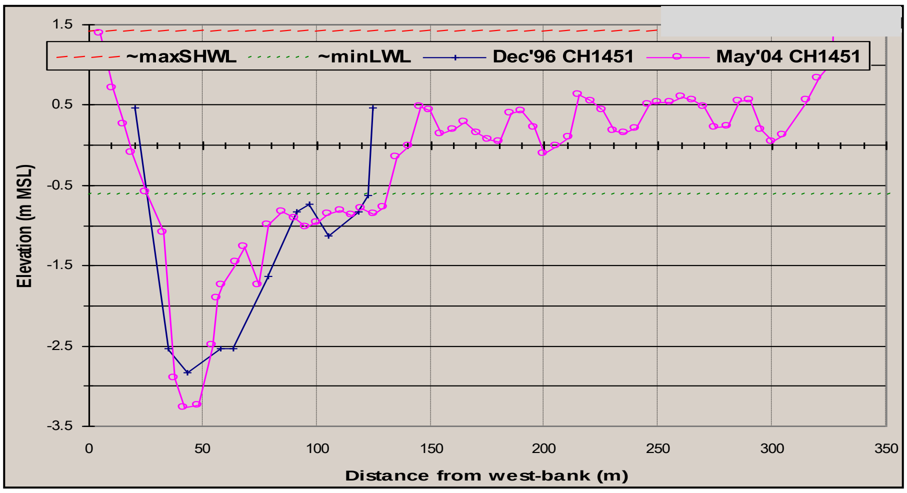

Figure A1.15 Surveyed cross-sections through Goukou: Chainage 1451

The 1996 cross-section appears to be relatively similar, even slightly shallower through the deep western channel (it should be kept in mind that the 1996 cross-section is much less detailed).

A.3 WATER QUALITY

Water quality sampling stations for the December 2013 survey are depicted in **Figure A2.1.**

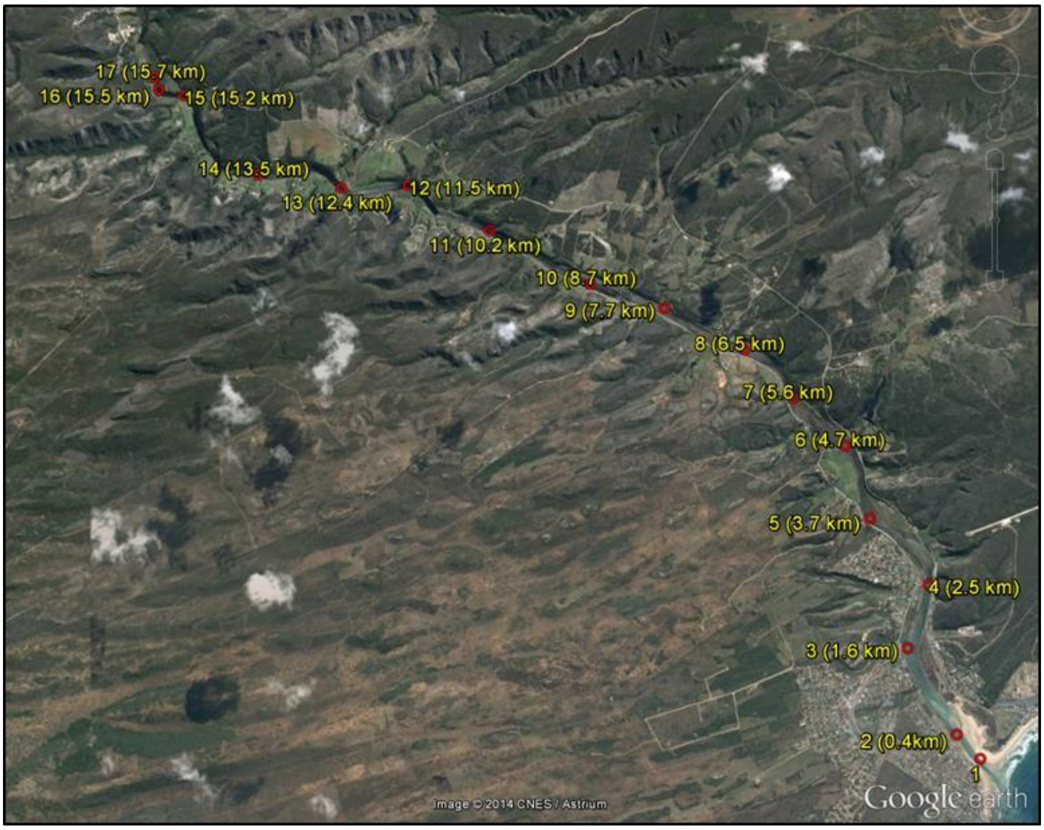

Figure A2.1 Water quality sampling stations (December 2013) and zones identified for the Goukou Estuary (for location of zones in estuary refer to Figure 3.2 in main report)

A.3.1 Salinity

The Goukou Estuary experiences significantly different salinity conditions during the low and high flow periods. The differences in inflow is further amplified by the bathymetry of the estuary, with the deeper middle reaches (2.5 – 6 km from the mouth) and upper reaches (9 –16 km from the mouth) acting as high retention areas, which is segregated by a very shallow middle section (at some places less than a metre deep) that flushes easily and acts as a barrier to salinity penetrations under normal river flow conditions.

During high flow periods, freshwater from the catchment only allows for partial salinity penetration into the lower and middle reaches of the estuary. For example, during May 2003, salinity penetration was only recorded in the lower 8 km of the system. While during the low flow period, saline water penetrates all the way to the top of the estuary **(Figure A2.2a**).

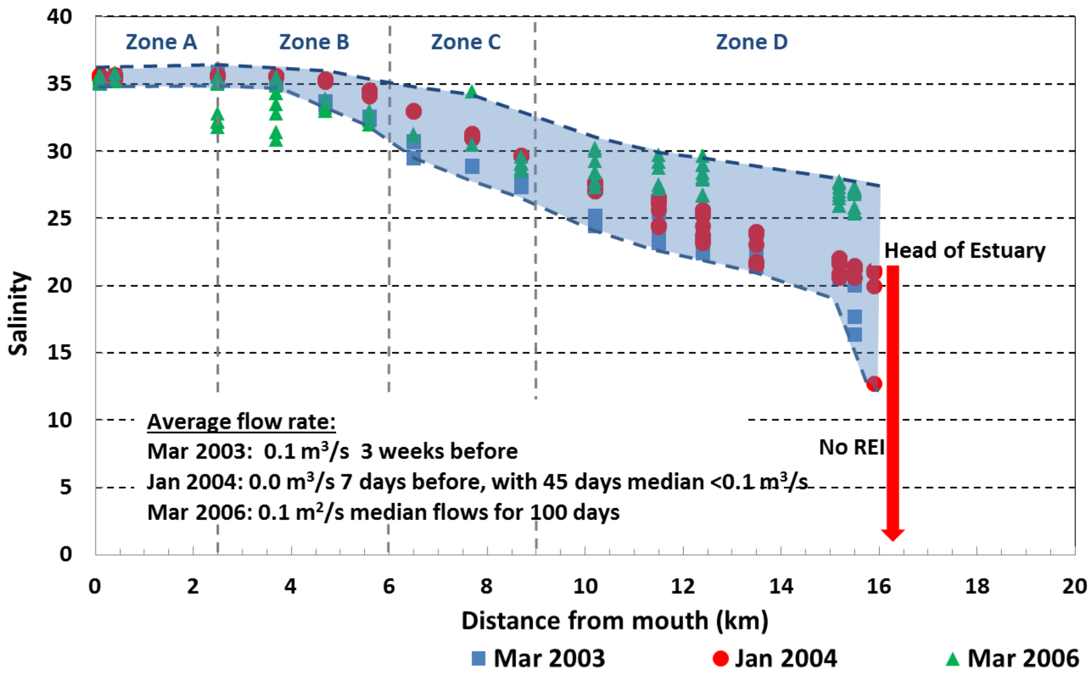

Figure A2.2a Salinity penetration in the Goukou Estuary under extreme low flow conditions

Under very low flow conditions (≤ 0.1 m^3/s) there is no River Estuarine Interface (REI) zone in the Goukou Estuary. Salinity in the lower reaches to about 6 km upstream from the mouth (Zone A and B) are 35 to 30. Then from about 6 to 9 km (Zone C) salinity varies between 30 and 25, with the upper reaches (Zone D) about 25 to 15. Under this flow range is in no stratification present in the system.

At river inflow between 0.5 and 1 m^3/s (**Figure A2.2b**), a limited REI zone starts to develop in the upper 4 km of the sytem (Zone D), with surface salinity between 0 and 10 and the bottom waters about 15. Salinity in the lower reaches (Zone A) are 35 to 30. From the bridge to about 6 km salinity ranges between 35 and 20 (Zone B), while from about 6 to 9 km (Zone C) salinity varies between 25 and 15, with the upper reaches (Zone D) about 25 to 15. Under this flow range there in no significant stratification present in the system, with only a limited statification present in Zone D.

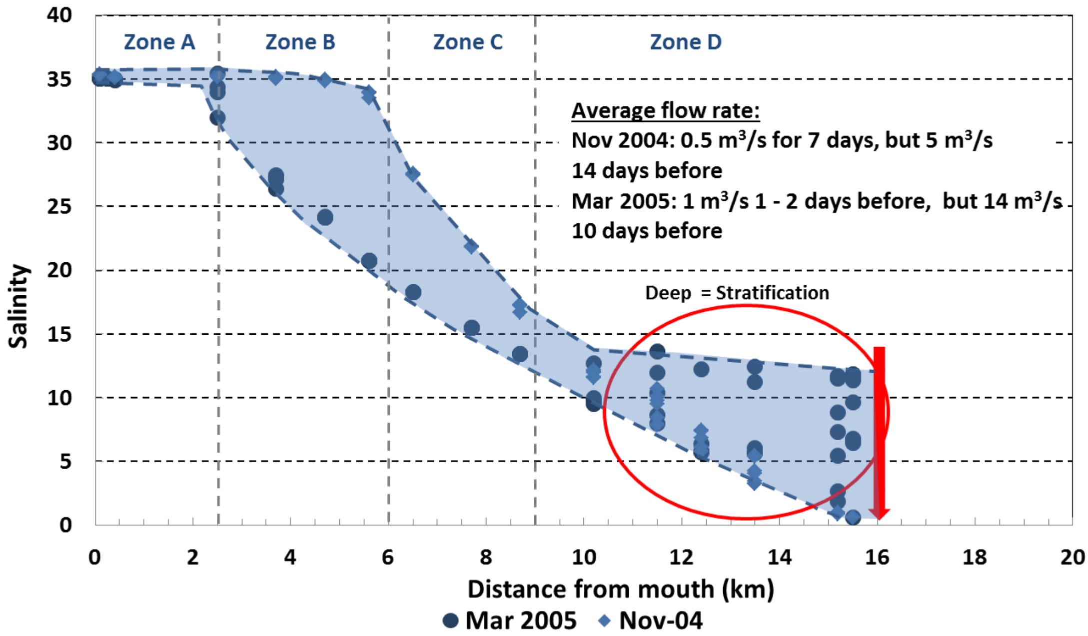

Figure A2.2b Salinity penetration in the Goukou Estuary under low flow conditions

At river inflow between 1 and 5 m^3/s (**Figure A2.2c**) a full salinity gradient develops in the Goukou Estuary. Salinity in the lower reaches (Zone A) varies between 35 to 25, with some tidal pumping expected beteen low and high tide. From the bridge to about 6 km (Zone B) salinity ranges between 35 and 10, while from about 6 to 9 km (Zone C) salinity varies between 15 and 0. The upper reaches (Zone D) range from 0 to 5, depending on the duration of the flow.

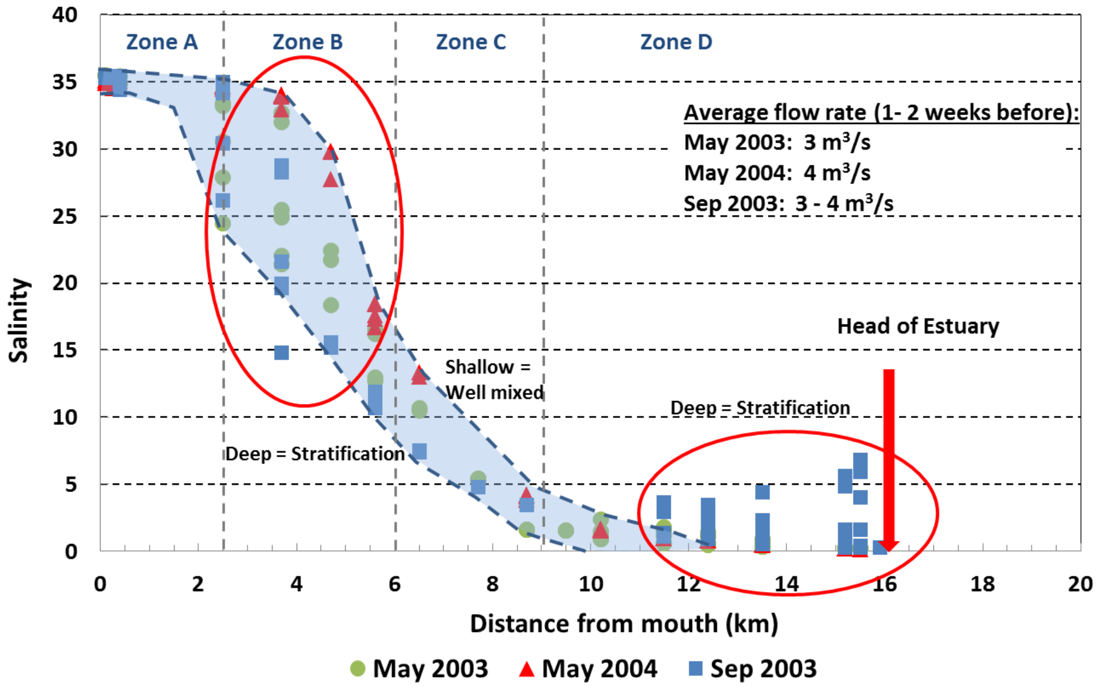

Figure A2.2c Salinity penetration in the Goukou Estuary under intermediate flow conditions

At this flow range strong statification develop in the deeper parts (> 2 m deep) of the estuary (Zone B and D), e.g. 20 diffrance between surface and bottom waters in Zone B. If the inflow presist for a significant period, Zone D will flush completely.

At higher inflows (**Figure A2.2d**), between 10 and 20 m^3/s salinity penetration are mostly confined to the lower 6 km of the system. Salinity in the lower reaches (Zone A) vary between 35 and 10, with significant differance between low and high tide. From the bridge to about 6 km (Zone B) salinity ranges between 20 and 2, while from about 6 to 9 km (Zone C) salinity varies between 3 and 0. Some statification can develop in the deeper parts (> 2 m deep) of the estuary in Zone B.

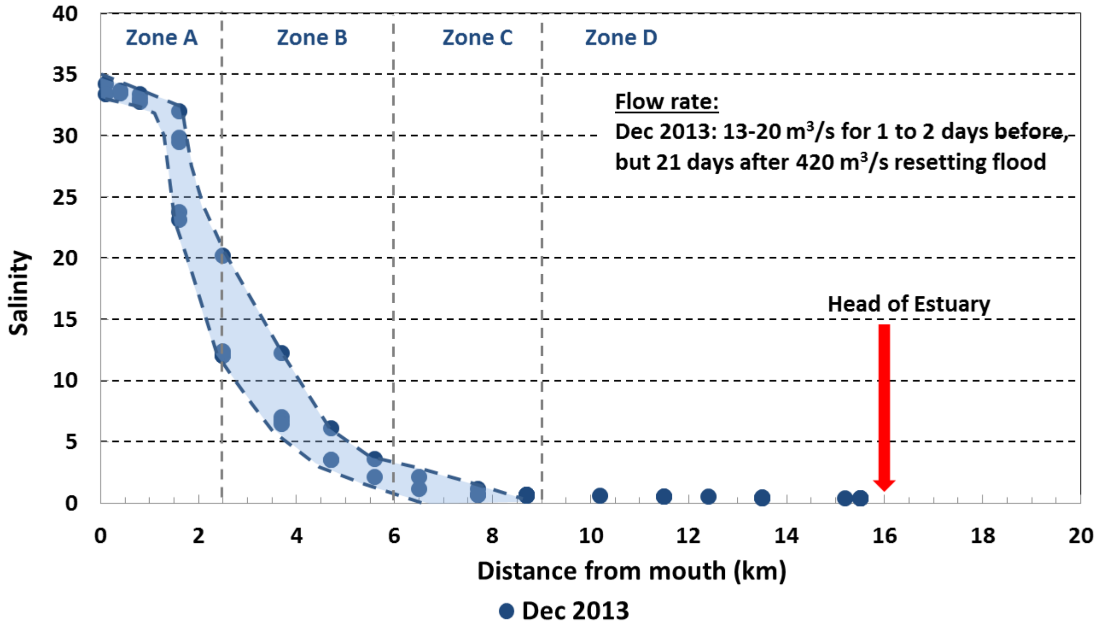

Figure A2.2d Salinity penetration in the Goukou Estuary under high flow conditions

A.3.2 Temperature

Temperature measurements collected in the Goukou Estuary during surveys in March and August 1985, March and May 2004 and December 2013 are presented in **Figure A2.3** (Carter and Brownlie, 1990; DAFF, unpublished data this study).

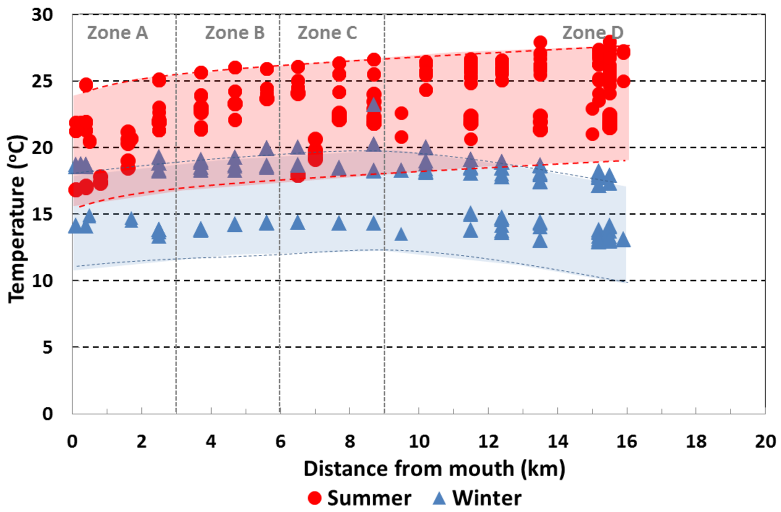

Figure A2.3 Temperature measured against along length of estuary (right) in the Goukou Estuary during summer and winter (Sources: Carter and Brownlie, 1990 and DAFF, unpublished data; this study)

Results show strong seasonal signals with highest temperature during summer (red shading) and lowest during winter (blue shading). During the summer survey, temperature increased with decrease in salinity, showing the influence of colder (15-25°C) seawater in the lower reaches. Such temperature can be significantly lower during upwelling in summer when cold water (< 5 °C) is introduced to the estuary. Temperature during the winter ranged between 14 and 20 °C. Water temperature in the system therefore is primarily influenced by atmospheric conditions and seawater temperature (lower reaches).

A.3.3 pH

Variability in pH measured in the Goukou River (approximately 40 km from the mouth [H9H005]) is presented **Figure A2.4**.

Median annual pH levels tended to increase since the 1990, ranging between 7.2 and 8,2 Agricultural activities possibly contributed to the shift in pH. pH levels measured in the Goukou Estuary generally increased with increase in salinity (Figure A2.5) and ranged between 7 and 8,2. This is expected as pH in seawater is generally higher (8.0-8.2) compared with freshwater (< 8.0). This pattern was also reflected along the length of the estuary as the system becomes fresher moving upstream.

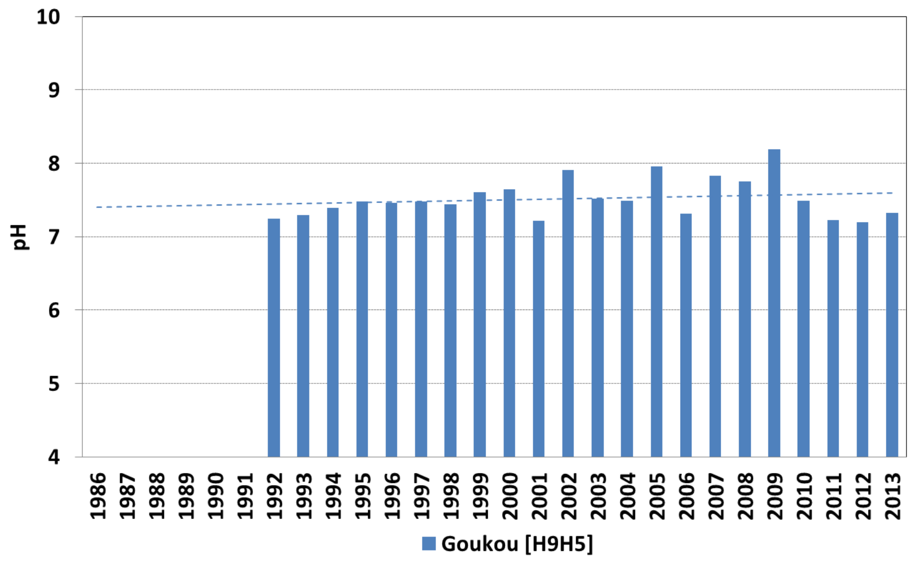

Figure A2.4 Median annual pH levels measured in the Goukou River (H9H005) (Source: www.dwaf.gov.za/iwqs/wms/data/WMS_pri_txt.asp)

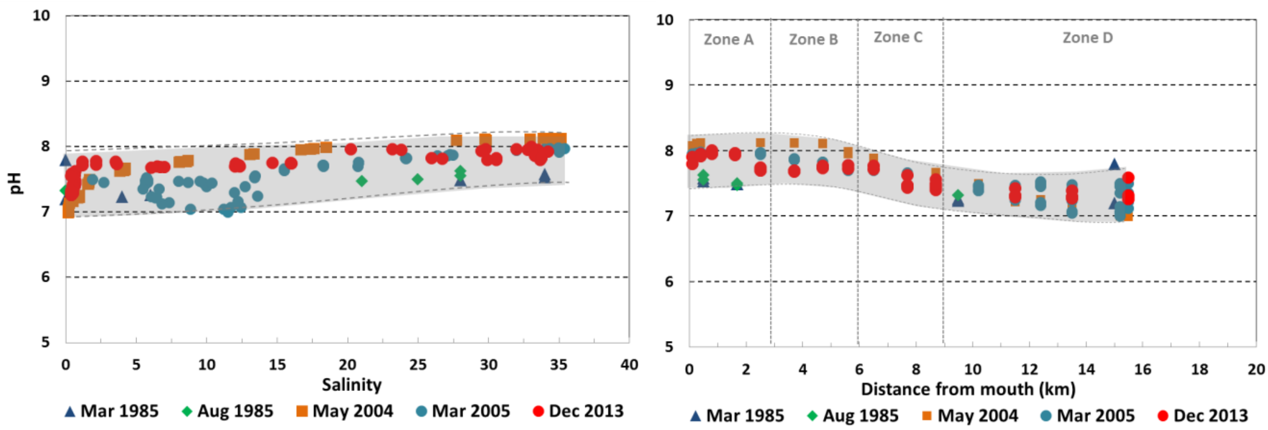

Figure A2.5 pH levels measured against salinity (left) and along length of estuary (right) in the Goukou Estuary during March 1985, August 1985, March 2004, May 2004 and December 2013 (Sources: Carter and Brownlie, 1990 and DAFF, unpublished data; this study)

A.3.4 Dissolved oxygen

Dissolved oxygen (DO) concentrations in the Goukou Estuary reflect well-oxygenated conditions (**Figure A2.6**).

In estuaries dissolved oxygen (DO) concentrations are dependent on the prevailing salinity and temperature regimes. Under saturation or near-saturated, dissolved oxygen concentrations are higher in fresher and/or colder waters compared with saline and/or warmer waters. The relationship between DO and salinity in December 2013 for the Goukou Estuary suggested the opposite, However, comparing the DO and temperature results for that survey (see **Figure A2.1**) the dominant driver in DO patterns were most likely the temperature, i.e. saline waters in the lower estuary had significantly lower temperatures compared with fresher waters moving upstream

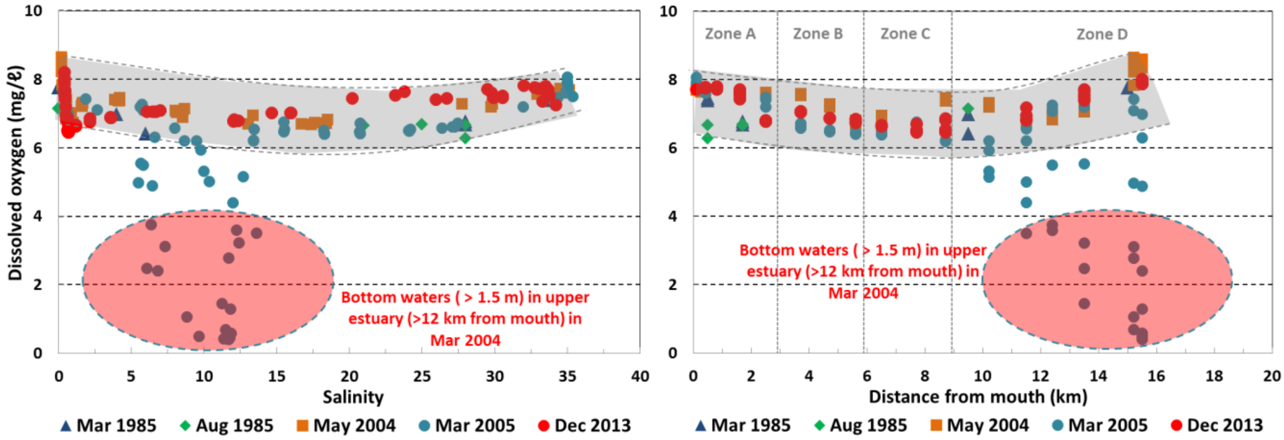

Figure A2.6 Dissolved oxygen measured against salinity (left) and along length of estuary (right) in the Goukou Estuary during March 1985, August 1985, March 2004, May 2004 and December 2013 (Sources: Carter and Brownlie, 1990 and DAFF, unpublished data; this study)

DO concentrations were usually above 6 mg/ℓ, even in bottom waters (4-6 m water depth). However, during the March 2005 survey, bottom water (deeper than 1.5 m) in the upper estuary (above 12 km from the mouth) indicated hypoxia. Deep stratification in these sheltered upper areas prevented effective wind mixing resulting in a drop in dissolved oxygen. Organic build-up in these areas may also have contributed to reduced oxygen levels, especially under the Present State.

A.3.5 Turbidity (Suspended solids)

Turbidity levels measured in the Goukou Estuary are presented in **Figure A2.7a**. Turbidity generally decreased with increase in salinity, suggesting that the river was introducing more turbid waters into the system, compared with the sea. March 2004 corresponded with a relatively low flow period, hence the lower turbidity throughout. During May 2004 medium high river inflow introduced relatively high turbidity into the fresher areas of the estuary (~40 NTU). During the December 2013 survey there was a marked decrease in turbidity in waters with salinity below 2-3 (corresponding to waters 6 km upstream of the mouth and beyond). A possible reason for this pattern is that the character of freshwater already mixed into estuarine waters in the lower reaches of the estuary was different from the fresh water present in the middle and upper reaches at the time of the survey. Just prior to the survey in December 2013, the system experienced a significant flood event (when higher turbidity would be expected). However, at the time of the December survey river flow was again lower (when turbidity levels are expected to drop again). Extrapolating from the property-salinity plot, it is estimated that turbidity levels during the high flow event were around 40 NTU (similar to concentrations measured during May 2004 – medium high flow period).

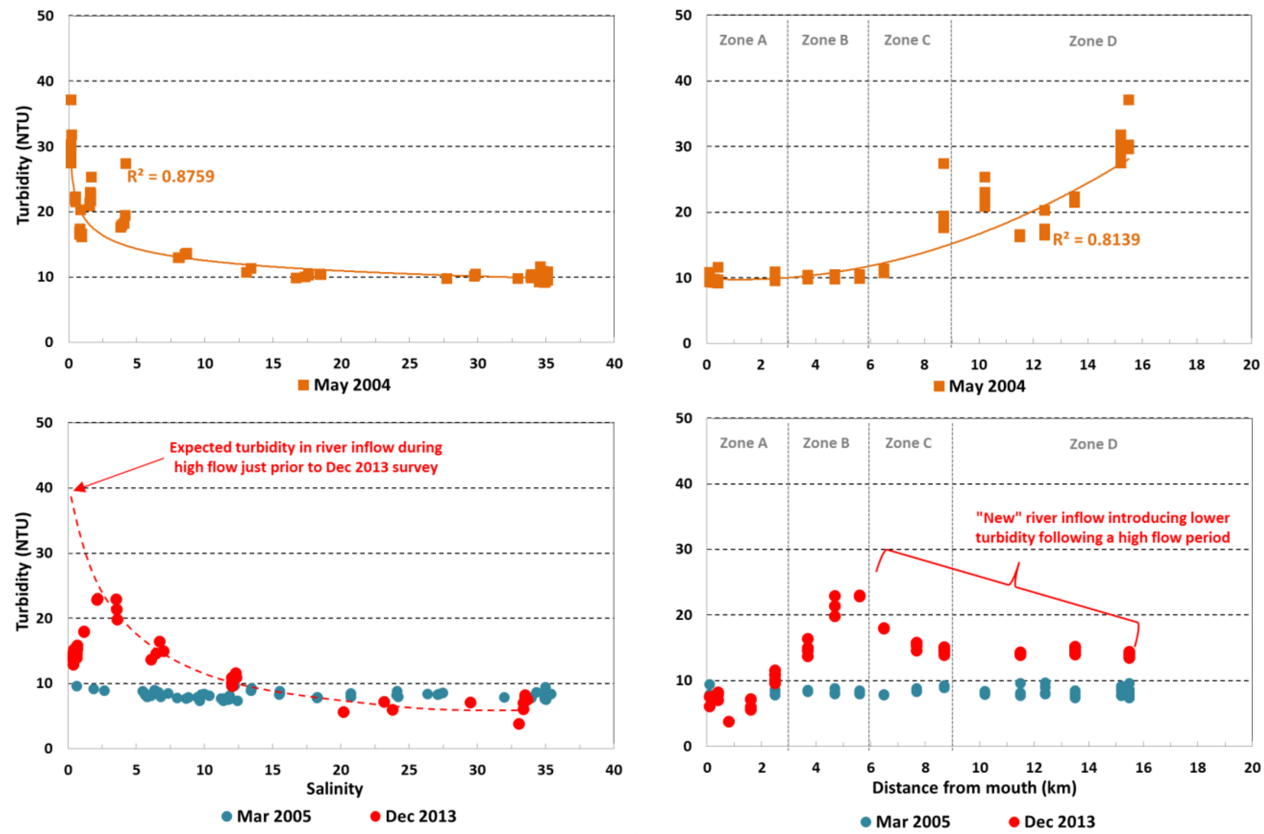

Figure A2.7a Turbidity measured against salinity (left) and along length of estuary (right) in the Goukou Estuary during March 2004, May 2004 and December 2013 (Sources: DAFF, unpublished data; this study)

Suspended solid concentrations were only measured in December 2013 and showed a weak positive linear relationship with turbidity (r^2 = 0,5) reflecting a similar patterns, i.e. concentrations decreasing in waters below salinity 2-3 (although the shift along the length of the estuary already occurred 2 km upstream of the mouth) (**Figure A2.7b**).

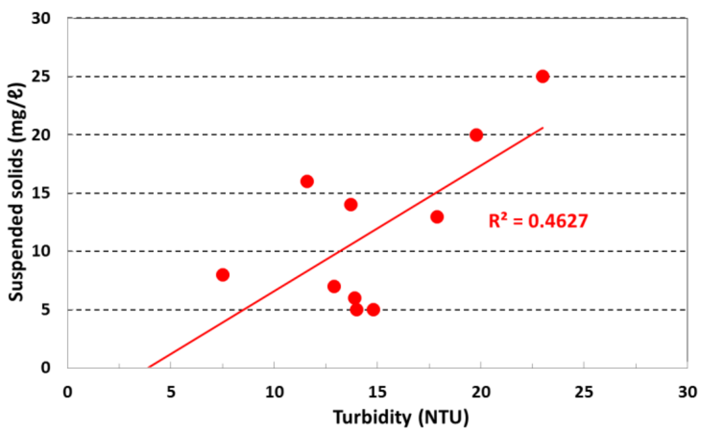

Figure A2.7b Relationship between turbidity and suspended solid in the Goukou Estuary (December 2013)

A similar motivation, related to the shift in character of freshwater inflow, would hold for suspended solids as for turbidity. Extrapolating from the property-salinity plot, it is estimated that suspended solid concentrations during the high flow event were around 30 mg/ℓ.

A.3.6 Dissolved inorganic nutrients

Variability in dissolved inorganic nutrients measured in the Goukou River (approximately 40 km from the mouth [H9H5]) is presented in **Figure A2.8**, as well as concentrations measured in the Duiwenhoks River close to the head of the estuary [H8H1].

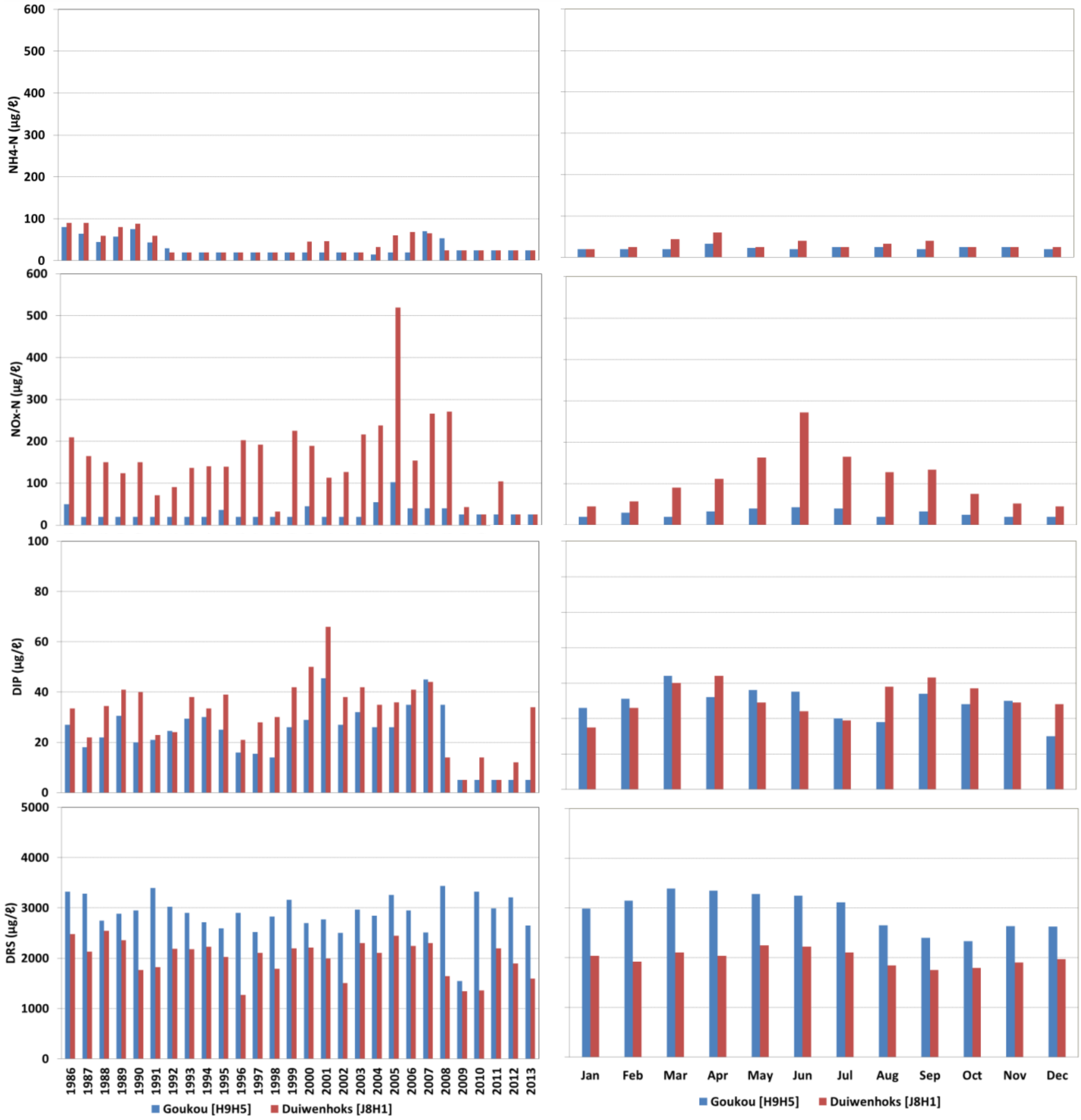

Figure A2.8 Median annual (left) and median monthly (right) dissolved inorganic nitrogen (NH_4-N, NO_x-N), dissolved inorganic phosphate-P (DIP) and dissolved reactive silicate-Si (DRS) measured in the Goukou River (H9H5), also comparing concentrations in the lower Duiwenhoks River (H8H1) (Source: www.dwaf.gov.za/iwqs/wms/data/WMS_pri_txt.asp)

The Duiwenhoks data are included as the data from the Goukou River, some 40 km upstream of the estuary may not be representative of river inflow to the estuary. As agricultural practices in the lower Goukou catchment are similar to that in the in the lower Duiwenhoks, the Duiwenhoks data may be more representative of the quality of river inflow into the Goukou Estuary.

Dissolved inorganic nitrogen

Median annual and median monthly concentrations of dissolved inorganic nitrogen (NH_4-N and NO_x-N) measured in the Goukou River (H9H5) suggests that concentrations were mostly below detection (20 µg/ℓ) (**Figure A2.8**). Also of note is that the Riversdal WWTW (approximately 3.3 km downstream of H9H5) can influence the estuary during malfunctioning, e.g. as reflected by NH_4-N concentrations in WWTW effluent during 2009 to 2012 (**Figure A2.9**). This is expected to alter river water quality entering the estuary especially during low flow periods (when the volume of effluent becomes a significant fraction of flow) or when a pulse of higher river flow pushes pools of nutrient enriched water into the estuary (i.e. not properly flushing such water out to sea). Further, agricultural activities downstream of the river sampling point are also expected to further alter river water quality. As a result measurements at station H9H5 (upper Goukou catchment) are underestimating river water quality into the estuary. As a result the lower Duiwenhoks data are probably more representative of DIN concentrations in river inflow to the Goukou Estuary.

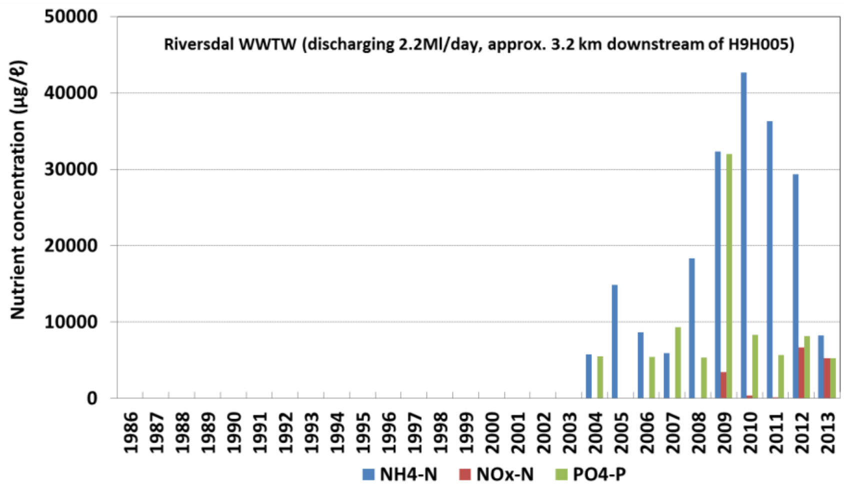

Figure A2.9 Median annual) dissolved inorganic nitrogen (NH_4-N, NO_x-N), dissolved inorganic phosphate-P (DIP) and dissolved reactive silicate-Si (DRS) measured in the Riversdal WWTW effluent (Source: www.dwaf.gov.za/iwqs/wms/data/WMS_pri_txt.asp)

De Villiers and Thiart (2007) estimated natural concentrations of DIN in these types of river systems to be ~50 µg/ℓ which suggest anthropogenic enrichment under the Present State compared with reference. Estimated DIN concentrations along this part of the coast are expected to be relative low - 50-100 µg/ℓ - except during upwelling (e.g. DWAF, 1995).

DIN concentrations in the Goukou Estuary (dominated by NO_x-N), generally increased with a decrease in salinity moving upstream, suggesting the river as major DIN source to the system (**Figure A2.10**), except during March 2013 when concentrations were low throughout the system.

During December 2013 there was a marked decrease in DIN in waters with salinity below 2-3 (corresponding to waters 6 km upstream of the mouth and beyond). The support the earlier motivation for turbidity in that the character of freshwater already mixed into estuarine waters in the lower reaches of the estuary was different from the fresh water present in the middle and upper reaches at the time of the survey. Just prior to the survey in December 2013, the system experienced a significant flood event. However, at the time of the December survey river flow was again lower. Extrapolating from the property-salinity plot, it is estimated that DIN levels during the high flow event were ~350 µg/ℓ.

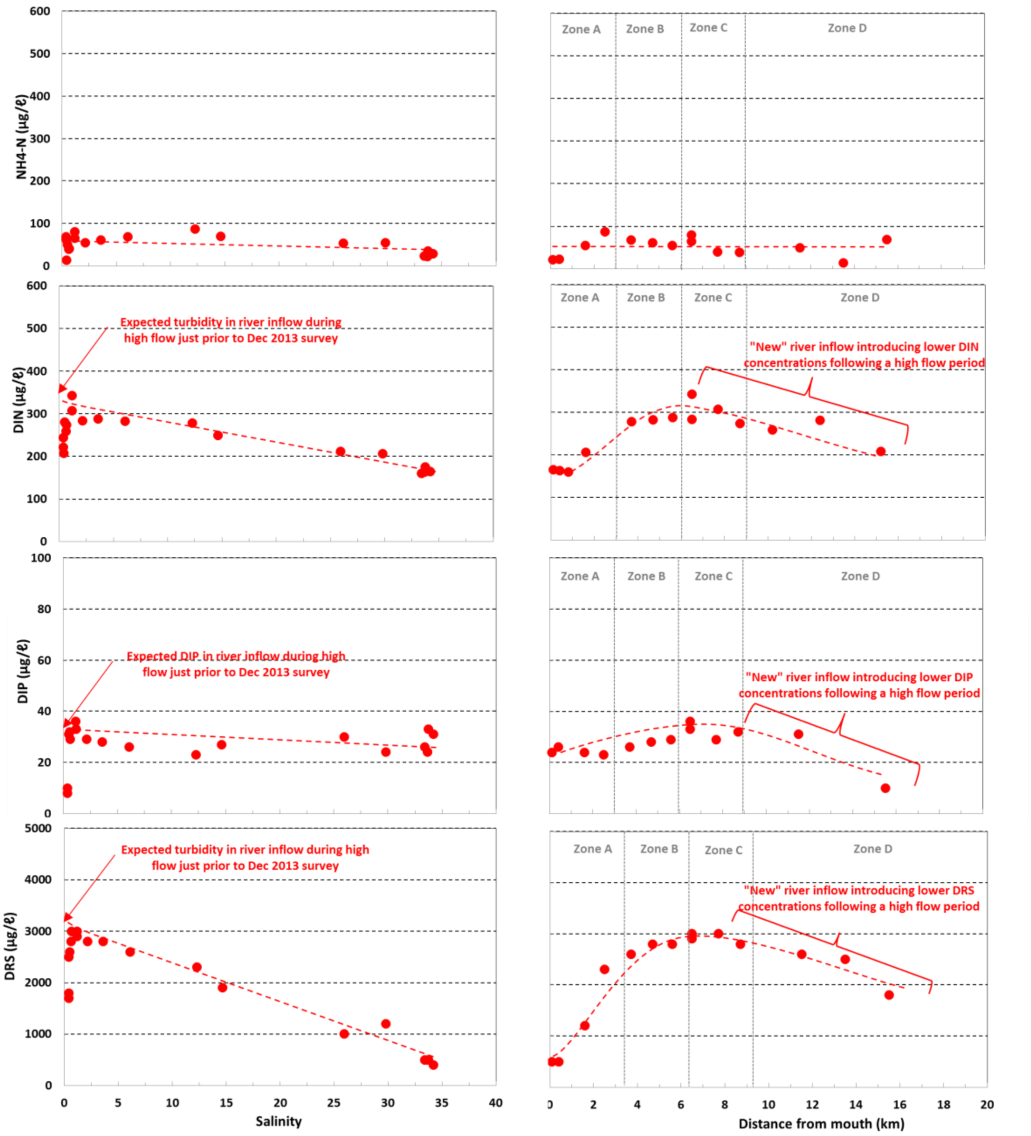

Figure A2.10 Dissolved inorganic nitrogen-N (NH4-N, NOx-N, DIN), dissolved inorganic phosphate-P (DIP) and dissolved reactive silicate-Si (DRS) measured in Goukou Estuary

Dissolved inorganic phosphate

Median annual and median monthly concentrations of dissolved inorganic phosphate (DIP) measured in the Goukou River (H9H5) suggests a gradual increase in concentration form 1980 to mid-2000s (from 20 to 40 µg/ℓ), but concentrations decreased to below detection (5 µg/ℓ) since 2009 (**Figure A2.8**). Concentrations reflected a similar pattern as observed in the lower Duiwenhoks River [H8H1]. These results suggest that activities in the lower Goukou largely introduce DIN to river inflow with DIP remaining similar to that in the upper catchment. Also of note is that the Riversdal WWTW (approximately 3.3 km downstream of H9H5) can influence the estuary during malfunctioning, e.g. as reflected by DIP concentrations in WWTW effluent during 2009 to 2012 (**Figure A2.9**).

De Villiers and Thiart (2007) estimated natural concentrations of DIP in these systems to be about 10 µg/ℓ, which suggest anthropogenic enrichment of the system during higher river flows under the Present State compared with reference. Estimated DIP concentration in seawater along this part of the coast is expected to be relative low, approximately 10-20 µg/ℓ (e.g. DWAF, 1995).

DIP concentrations in the Goukou Estuary generally increased with a decrease in salinity moving upstream, suggesting the river as major DIP source to the system. During December 2013, there was a marked decrease in DIP in waters with salinity below 2-3 (corresponding to waters 6 km upstream of the mouth and beyond) (**Figure A2.10**). The support the earlier motivation for DIN and turbidity in that the character of freshwater already mixed into estuarine waters in the lower reaches of the estuary was different from the fresh water present in the middle and upper reaches at the time of the survey. Just prior to the survey in December 2013, the system experienced a significant flood event. However, at the time of the December survey river flow was again lower. Extrapolating from the property-salinity plot, it is estimated that DIN levels during the high flow event were ~35 µg/ℓ.

Dissolved reactive silicate

Median annual and median monthly concentrations of dissolved reactive silicate (DRS) measured in the Goukou River (H9H5) shows concentrations in river inflow between 2 500 and 3500 µg/ℓ, significantly higher than in the Duiwenhoks River (**Figure A2.8**). These high concentrations are expected for fluvial systems linked to catchment geological characteristics (Eagle and Bartlett, 1984). Median annual concentrations over the period 1986 to 2013 did not show any marked trends.

As expected DRS concentrations in the Goukou Estuary generally increased with a decrease in salinity moving upstream, suggesting the river as major source of DRS to the system. As with DIN and DIP, DRS also showed a marked decrease in waters with salinity below 2-3 (corresponding to waters 6 km upstream of the mouth and beyond) during the December 2013 survey (**Figure A2.10**). This strengthens earlier motivations presented for turbidity and DIN and DIP, namely that the character of freshwater already mixed into estuarine waters in the middle and lower reaches was different from the fresh water present in the upper reaches at the time of the survey.

A.3.7 Toxic substances

No data was available on levels of toxic substances in the Goukou Estuary. Considering extensive agricultural activities in the catchment and the influence of fertilizers on inorganic nutrient levels (see above), it is expected that these activities also introduced toxic substances such as herbicides and pesticides. However, it is not expected for metal concentrations to be high in this system as there is no major industrial or urban development along the banks of the estuary or in the catchment that would be most likely sources of metal pollution.

Annexure A1: Water quality data collected in the Goukou Estuary on 3 December 2013

Time	Stn	X Cordinates	Y Coordinates	Depth (m)	Distance from mouth	Temp	Salinity	pH	NTU	SS (mg/l)	DO (mg/l)	DO (%)	NO2-N (µg/l)	NH4-N (µg/l)	NOX-N (µg/l)	DIN (ug/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tot P (µg/l)
16:50	SEA			0.0		17.3	34.2	7.9	21.2		7.3	93	2	29	136	165	31	400	
12:00	1	34 22 39.1	21 25 20.1	1.6	0.1	16.8	33.4	7.9	6.1		7.7	97							
12:00	1	34 22 39.1	21 25 20.1	0.0	0.1	16.8	33.7	7.8	7.5	8	7.7	98	1	22	141	163	24	500	<25
12:14	2	34 22 29.3	21 25 09.2	2.5	0.4	17.1	33.5	8.0	8.2		7.8	99							
12:14	2	34 22 29.3	21 25 09.2	1.0	0.4	17.1	33.5	7.9	7.9		7.8	99							
12:14	2	34 22 29.3	21 25 09.2	0.0	0.4	17.0	33.4	7.9	7.0		7.8	98	3	23	137	160	26	500	
12:20	2A	34 22 19.6	21 25 00.7	1.7	0.8	17.3	33.1	8.0	3.8		7.7	98							
12:20	2A	34 22 19.6	21 25 00.7	1.0	0.8	17.5	32.8	8.0			7.8	99							
12:20	2A	34 22 19.6	21 25 00.7	0.0	0.8	17.8	32.0	8.0	17.1		7.8	99							
12:30	3	34 21 54.2	21 24 47.3	2.8	1.6	18.4	29.8	8.0		10	7.6	97	3	55	151	206	24	1200	<25
12:30	3	34 21 54.2	21 24 47.3	2.0	1.6	19.0	29.5	7.9	7.1		7.7	98							
12:30	3	34 21 54.2	21 24 47.3	1.5	1.6	20.3	23.8	8.0	6.0		7.6	98							
12:30	3	34 21 54.2	21 24 47.3	1.0	1.6	20.6	23.2	8.0	7.2		7.5	96							
12:30	3	34 21 54.2	21 24 47.3	0.0	1.6	21.2	20.2	8.0	5.6		7.4	94							
12:53	4	34 21 28.6	21 24 59.3	4.1	2.5	22.0	12.1	7.7	9.6		6.8	84							
12:53	4	34 21 28.6	21 24 59.3	3.0	2.5	22.0	12.0	7.7	10.1		6.8	84							
12:53	4	34 21 28.6	21 24 59.3	2.0	2.5	21.9	12.0	7.7	10.9		6.8	83							
12:53	4	34 21 28.6	21 24 59.3	1.0	2.5	21.9	12.4	7.7	10.9		6.8	83							
12:53	4	34 21 28.6	21 24 59.3	0.0	2.5	21.9	12.3	7.7	11.6	16	6.8	83	3	87	191	278	23	2300	<25
13:15	5	34 21 01.2	21 24 31.5	1.8	3.7	22.6	7.0	7.7	15.0		7.1	85							
13:15	5	34 21 01.2	21 24 31.5	1.5	3.7	22.8	6.7	7.7	16.4		7.1	85							
13:15	5	34 21 01.2	21 24 31.5	1.0	3.7	23.0	6.5	7.7	14.6		7.1	85							
13:15	5	34 21 01.2	21 24 31.5	0.0	3.7	23.0	6.1	7.7	13.7	14	7.1	85	4	68	215	283	26	2600	<50
13:30	6	34 20 31.0	21 24 21.1	1.8	4.7	23.3	3.6	7.8	22.9		6.9	83							
13:30	6	34 20 31.0	21 24 21.1	1.0	4.7	23.3	3.6	7.7	21.4		6.9	83							
13:30	6	34 20 31.0	21 24 21.1	0.0	4.7	23.3	3.6	7.7	19.8	20	6.9	82	4	61	227	288	28	2800	<50
13:40	7	34 20 10.8	21 23 56.0	1.3	5.6	23.7	2.1	7.8	22.8		6.9	82							
13:40	7	34 20 10.8	21 23 56.0	0.0	5.6	23.7	2.2	7.7	23.0	25	6.8	81	4	55	229	284	29	2800	<50
13:50	8	34 19 49.9	21 23 32.6	1.2	6.5	24.1	1.2	7.8	17.9	13	6.7	80	4	80	263	343	36	3000	<50
13:50	8	34 19 49.9	21 23 32.6	0.0	6.5	24.1	1.2	7.7	18.0		6.6	80	4	65	242	307	33	2900	
14:00	9	34 19 31.6	21 22 52.9	2.6	7.7	22.1	0.7	7.6	15.8		6.5	75							
14:00	9	34 19 31.6	21 22 52.9	2.0	7.7	22.1	0.7	7.5	15.8		6.5	74							
14:00	9	34 19 31.6	21 22 52.9	1.0	7.7	22.6	0.7	7.4	15.3		6.5	75							
14:00	9	34 19 31.6	21 22 52.9	0.0	7.7	22.4	0.7	7.5	14.6		6.7	80	4	40	234	274	29	3000	
14:20	10	34 19 20.6	21 22 15.8	7.0	8.7	21.8	0.6	7.6	13.9		6.6	75							
14:20	10	34 19 20.6	21 22 15.8	6.0	8.7	21.8	0.6	7.5	14.5		6.5	74							
14:20	10	34 19 20.6	21 22 15.8	5.0	8.7	21.8	0.6	7.4	14.6		6.5	74							
14:20	10	34 19 20.6	21 22 15.8	4.0	8.7	21.8	0.6	7.4	14.5		6.5	74							
14:20	10	34 19 20.6	21 22 15.8	3.0	8.7	22.1	0.6	7.4	15.0		6.5	75							
14:20	10	34 19 20.6	21 22 15.8	2.0	8.7	22.3	0.6	7.4	15.1		6.5	75							
14:20	10	34 19 20.6	21 22 15.8	1.0	8.7	22.9	0.6	7.4	15.1		6.5	76							
14:20	10	34 19 20.6	21 22 15.8	0.5	8.7	23.5	0.6	7.5	14.7		6.8	80							
14:20	10	34 19 20.6	21 22 15.8	0.0	8.7	24.0	0.6	7.5	14.8	5	6.9	83	5	39	220	259	32	2800	<50

Time	Stn	X Cordinates	Y Coordinates	Depth (m)	Distance from mouth	Temp	Salinity	pH	NTU	SS (mg/l)	DO (mg/l)	DO (%)	NO2-N (µg/l)	NH4-N (µg/l)	NOX-N (µg/l)	DIN (ug/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tot P (µg/l)
14:30	12	34 18 36.7	21 20 44.4	2.9	11.5	21.8	0.5	7.4	14.1		6.8	78							
14:30	12	34 18 36.7	21 20 44.4	2.0	11.5	21.8	0.5	7.3	14.3		6.8	78							
14:30	12	34 18 36.7	21 20 44.4	1.0	11.5	22.1	0.5	7.3	14.0		7.0	80							
14:30	12	34 18 36.7	21 20 44.4	0.0	11.5	22.4	0.5	7.3	13.9	6	7.2	84	4	50	231	281	31	2600	<50
	13	34 18 37.0	21 20 10.2		12.4														
14:45	14	34 18 30.4	21 19 27.9	3.9	13.5	21.3	0.4	7.4	15.2		7.4	84							
14:45	14	34 18 30.4	21 19 27.9	3.0	13.5	21.4	0.4	7.3	15.1		7.5	85							
14:45	14	34 18 30.4	21 19 27.9	2.0	13.5	21.4	0.4	7.3	14.8		7.6	86							
14:45	14	34 18 30.4	21 19 27.9	1.0	13.5	21.9	0.4	7.3	14.4		7.7	89							
14:45	14	34 18 30.4	21 19 27.9	0.0	13.5	22.4	0.4	7.3	14.0	5	7.7	89	7	14	194	208	83	2500	<50
15:00	16	34 17 52.8	21 18 37.4	7.1	15.5	21.5	0.4	7.6	14.4		7.9	89							
15:00	16	34 17 52.8	21 18 37.4	6.0	15.5	21.5	0.4	7.3	14.2		7.9	82							
15:00	16	34 17 52.8	21 18 37.4	5.0	15.5	21.7	0.4	7.3	13.9		7.9	90							
15:00	16	34 17 52.8	21 18 37.4	4.0	15.5	21.8	0.4	7.3	13.9		8.0	91							
15:00	16	34 17 52.8	21 18 37.4	3.0	15.5	21.9	0.4	7.3	13.8		8.0	91							
15:00	16	34 17 52.8	21 18 37.4	2.0	15.5	22.1	0.4	7.3	13.8		8.0	62							
15:00	16	34 17 52.8	21 18 37.4	1.0	15.5	22.3	0.4	7.3	13.5		8.0	93							
15:00	16	34 17 52.8	21 18 37.4	0.0	15.5	22.5	0.4	7.3	13.6		7.9	93	6	69	175	244	10	1800	
15:20	RIVER			0.0		22.3	0.4	7.6	12.9	7	8.2	95	5	62	159	221	8	1700	<50
15:44	9	34 19 31.6	21 22 52.9	2.4	7.7	22.2	16.0	7.7	32.0		7.0	88							
15:44	9	34 19 31.6	21 22 52.9	1.0	7.7	22.2	16.0	7.8	21.5		7.0	88							
15:44	9	34 19 31.6	21 22 52.9	0.0	7.7	22.4	14.6	7.8	13.7		7.0	88	3	70	179	249	27	1900	
16:00	8A	34 20 0.38	21 23 5.31	4.7	7.0	19.1	30.6	7.8	9.0		7.5	97							
16:00	8A	34 20 0.38	21 23 5.31	3.0	7.0	19.2	30.6	7.8	7.8		7.5	97							
16:00	8A	34 20 0.38	21 23 5.31	2.0	7.0	19.5	29.9	7.8	7.6		7.5	97							
16:00	8A	34 20 0.38	21 23 5.31	1.0	7.0	19.8	26.7	7.8	7.8		7.5	96							
16:00	8A	34 20 0.38	21 23 5.31	0.0	7.0	20.6	26.0	7.8	7.0		7.4	96	3	53	159	212	30	1000	
16:10	8	34 19 49.9	21 23 32.6	2.2	6.5	17.9	33.3	7.9	8.5		7.4	95							
16:10	8	34 19 49.9	21 23 32.6	1.0	6.5	17.9	33.7	7.8	7.5		7.5	97							
16:10	8	34 19 49.9	21 23 32.6	0.0	6.5	17.9	33.8	7.8	5.1		7.5	97	3	35	140	175	33	500	

Annexure A2: Sediment grain size and TOM data collected on 3 December 2013 in the Goukou Estuary (stations Figure A2.1 approximately mid channel)

	Station location		1	2	3	4	4	6	7	8	9	11	12	13	14	15	16	17
	% Loss on Ignition *	%	3.1	14.9	3.4	1.8	1.8	2.8	3.1	1.2	1	3.6	5.8	0.3	0.4	0.5	0.5	0.8
	Gravel as % *	%	0.1	0	0	1.9	0	0	0	0	0	0	0.4	0	0	0	0	0
	Sand as % *	%	99.9	100	100	98.1	100	100	100	100	100	100	99.5	100	100	99.9	99.9	100
	Mud as % *	%	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0.1	0.1	0
Sediment size fractions	>4000µ	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	>2000µ	%	0.1	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
	>1140µ	%	0.3	0.0	0.0	0.7	0.0	0.1	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.3
	>1000µ	%	0.6	0.4	0.4	1.0	0.2	0.0	0.1	0.1	0.1	0.5	0.7	0.2	0.3	0.0	0.2	0.5
	>710µ	%	2.7	1.1	0.4	0.7	0.3	1.3	0.2	0.5	1.1	0.1	2.2	2.1	0.5	0.1	0.4	2.3
	>500µ	%	25.2	19.7	0.7	2.6	2.2	12.6	0.5	8.8	13.5	0.5	17.3	29.3	4.3	1.1	2.0	29.3
	>300µ	%	56.7	20.5	2.1	8.4	15.7	40.8	5.5	44.5	50.6	19.5	39.7	51.3	33.7	17.4	12.9	51.7
	>250µ	%	13.2	35.5	31.9	46.9	61.0	36.5	54.3	40.1	29.2	55.7	26.9	14.3	44.7	53.6	52.4	15.1
	>212µ	%	0.6	12.2	34.4	23.5	15.6	3.9	27.7	3.5	4.2	15.1	5.0	1.7	11.9	17.8	23.8	0.6
	>180µ	%	0.2	4.7	17.1	7.8	3.8	4.2	7.5	1.3	0.8	5.5	2.5	0.7	2.8	6.2	5.3	0.2
	>150µ	%	0.2	5.2	11.3	4.9	1.1	0.4	3.9	0.7	0.4	2.7	2.4	0.2	1.3	2.9	2.5	0.1
	>125µ	%	0.2	0.7	1.5	1.4	0.1	0.1	0.3	0.3	0.0	0.1	0.7	0.0	0.5	0.5	0.3	0.0
	>90µ	%	0.0	0.1	0.4	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.8	0.0	0.0	0.1	0.1	0.0
	>63µ	%	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.1	0.6	0.1	0.0	0.2	0.1	0.0
	<63µ	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0

APPENDIX B: MICROALGAE SPECIALIST REPORT

Prepared by GC Snow
Department of Botany, Nelson Mandela Metropolitan University, Port Elizabeth/University of the Witwatersrand, Johannesburg

B.1 AVAILABLE DATA

Microalgae data requirements for Intermediate level assessment (DWAF, 2008), as well as availability of data for this study is presented below:

Data required	Availability	Reference
Phytoplankton: For biomass chlorophyll a at the surface and 0.5 m depth intervals. Cell counts (at 400 x magnification) on dominant phytoplankton species to establish species distribution and composition. Collect data during high and low flow period (and closed state for temporality open estuaries)	Limited historical data Summer (Dec 2013)	Carter and Brownlie (1990) This study
Benthic microalgae biomass: For biomass collect subtidal benthic samples for chlorophyll a. Record the relative abundance of dominant algal groups. Collect data during high and low flow period (and closed state for temporality open estuaries)	Summer (Dec 2013)	This study

B.2 INTRODUCTION

Microalgae, as primary producers, form the base of the food chain in estuaries. The group includes those living in the water column (phytoplankton) and those living on exposed intertidal or submerged surfaces (benthic microalgae). Phytoplankton biomass indicates the river-estuary interface zone, a brackish zone in the estuary characterised by high biomass and diversity. As freshwater inflow is reduced the extent of the river-estuary interface zone changes and the flow requirements of the estuary are set based on the acceptable change.

Phytoplankton biomass indicates the nutrient status of an estuary. For example, the Mhlanga Estuary receives sewage input and phytoplankton chlorophyll *a*, an index of biomass, exceeded 200 µg/ℓ, which is typical of a eutrophic system. Species composition also indicates the nutrient and hydrodynamic status of an estuary. Dinoflagellates are typically abundant when the estuary is nutrient-rich and stratified. They occur in the middle reaches of an estuary where salinity is > 5 whereas cyanophytes (blue-green algae) are common in nutrient-rich water where salinity is < 5.

Benthic diatoms are known to respond to salinity and most references describe diatoms as freshwater, brackish or marine species (Bate *et al*., 2013). In addition, diatoms have proven to be useful indicators of trophic status, particularly in freshwater ecosystem studies (Taylor *et al*., 2007). As such, knowledge of diatom ecology is a vital component of estuarine management it is therefore imperative that they, and phytoplankton, are included in Resource Directed Measures (RDM) studies.

The only record of phytoplankton occurrence in the Goukou Estuary is the data obtained during the previous surveys and J Grindleys 1969 records of diatoms (Carter and Brownlie, 1990). During the 1985 summer and winter surveys the flows were similar with saline water penetrating just upstream of the 9.5 km site. Nitrate and orthophosphate concentrations were only slightly elevated, ranging from 1.52 to 14.86 µM and from 0.13 to 0.81 µM respectively. Phytoplankton chlorophyll *a* was generally low and ranged from 0.35 to 2.16 µg/ℓ in summer and from 0.30 to 1.08 µg/ℓ in winter.

Data collection for the Goukou Estuary took place on 03 December 2013 under high flow conditions and during the open mouth phase at five equally distributed sites along the length of each estuary (**Figure B.1**).

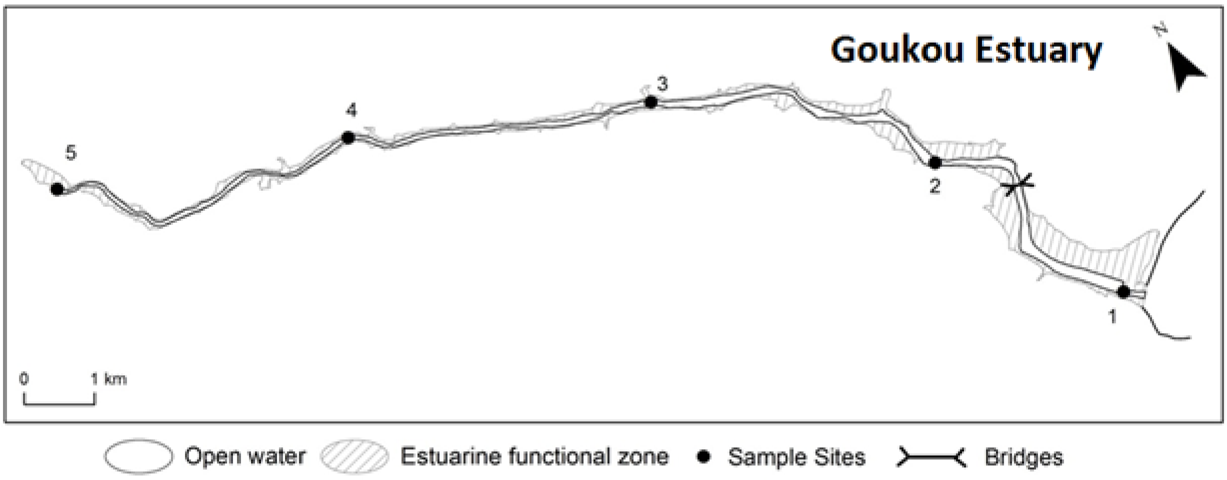

Figure B.1 Study site map indicating the positions of sampling stations within the Goukou Estuary (Distance from mouth: 1 =0.03 km; 2 = 3.7 km; 3 = 7.7 km; 4 =11.5 km; 5 = 15.5 km)

B.3 MATERIALS AND METHODS

B.3.1 Phytoplankton

Phytoplankton biomass

Phytoplankton biomass (measured chlorophyll *a* concentration as an index) was measured by collecting water samples using a weighted pop-bottle at depths of 0, 0.5, 1.0 and then at 1 m intervals to the bottom at each site. The samples were then gravity-filtered through glass-fibre filters (Whatman© GF/C) and frozen until laboratory analysis. Chlorophyll *a* was extracted by placing the frozen filters into glass vials containing 10 ml of 95% ethanol (Merck 411). After extraction for 24 h in a cold (*ca*. 1 – 2°C), dark room, spectrophotometric determinations of chlorophyll *a* were performed according to Nusch (1980).

Absorbance before and after (only when absorbance ≥ 0.2) acidification of extracts with 1N HCl were read using a UV/VIS spectrophotometer at 665 nm. Chlorophyll *a* biomass was then calculated using the following equation:

$$Chl\ a\ (\mu g\ l^{-1}) = (E_{b665} - E_{a665})\ x\ 29.6\ x\ \left(\frac{v}{(V\ x\ l)}\right)$$

Where: E_{b665} = Absorbance at 665 nm before acidification

E_{a665} = Absorbance at 665 nm after acidification

v = Volume of solvent used for extraction (ml)

V = Volume of sample filtered (litres)

l = Path of spectrophotometer cuvette (cm)

29.6 = Constant calculated from the maximum acid ratio (1.7) and the specific absorption coefficient of chlorophyll *a* in ethanol (82 g l^{-1} 10 mm^{-1})

Phytoplankton community composition

Water samples of 200 ml were collected from each site and preserved using two drops of undiluted glutaraldehyde. The Coulon and Alexander (1972) method was used to settle the samples overnight in 26.5 mm diameter settling chambers. Two drops of Rose Bengal were added to 50 ml of preserved water samples and then allowed to settle for 24 hours before identification.

Once settled, a Zeiss IM 35 inverted microscope was used to count and identify the microalgal groups at a magnification of 630X during which either a minimum of 200 frames or 200 cells were counted. The cells were classified according to different algal groups, i.e. diatoms, flagellates, dinoflagellates, cyanobacteria (blue-green algae), and chlorophytes (green algae). Cell density (cells ml^{-1}) was calculated using the following equation (Snow, 2008);

$$Cells\ ml^{-1} = \left(\frac{(\pi r^2)}{A}\right) x \left(\frac{C}{V}\right)$$

Where: R = Radius of the settling chamber (mm)

A = Area of each frame (mm^2)

C = Number of cells in each frame

V = Volume of sample in settling chamber (ml)

B.3.2 Benthic microalgae

Microphytobenthos chlorophyll a and sediment characteristics

Sediment samples for microphytobenthic chlorophyll *a* determination were collected using a perspex twin-corer of 20 mm internal diameter. Four 1 cm deep intertidal and subtidal sediment cores were collected from each site, frozen and kept in the dark before being freeze-dried in the Secfroid Lausanne Suisse freeze-drier overnight (*ca*. 12 hours) (Snow, 2008). The process of freeze-drying removes interstitial water that improves pigment extraction. Thereafter, 15 ml of 95% ethanol was added to each of the freeze-dried samples and placed into a fridge to allow for chlorophyll *a* extraction for 6 hours (Brito *et al*., 2009). The extract was then cleared of sediment by filtering it through glass fibre filters (Whatman GF/C), and subsequently the chlorophyll *a* concentrations of the microphytobenthos were determined using the spectrophotometric method described by Nusch (1980). The chlorophyll *a* biomass was expressed as mg m^{-2} for comparative purposes (Underwood, 2010). The sediment used to extract chlorophyll *a* was then dried at 105°C for 24 h and weighed. Lastly, the sediment was placed in an ashing oven at 550°C for 12 hours in order to determine the organic fraction (%). The microphytobenthos chlorophyll *a* biomass was calculated using the following equation:

$$Chorophyll\ a\ (mg\ m^{-2}) = (E_{b665} - E_{a665})\ x\ 29.6\ x \left(\frac{v}{(A\ x\ l)}\right) x\ 10$$

Where: E_{b665} = Absorbance at 665 nm before acidification

E_{a665} = Absorbance at 665 nm after acidification

v = Volume of solvent used for extraction (ml)

A = Total area of cores (cm^2)

l = Path of spectrophotometer cuvette (cm)

29.6 = Constant calculated from the maximum acid ratio (1.7) and the specific absorption coefficient of chlorophyll *a* in ethanol (82 g l^{-1} 10 mm^{-1})

Benthic diatoms

The method used for epipelic diatom identification is an adaptation of that described by Bate *et al*. (2013). Samples for the identification of epipelic diatoms were collected by scraping the surface of both the intertidal and subtidal zones at each site along each estuary, and subsequently placing the sediment slurry into Petri dishes. In a field laboratory, the sediment in the Petri dishes was allowed to settle overnight before sucking off excess water using clean glass pipettes. Four glass cover slips, covering *ca*. 30% of the sediment surface, were then placed on top of the wet sediment early in the morning. The sediment and cover slips were then left in diffuse natural light conditions until mid-afternoon before carefully removing the cover slips with forceps. The cover slips were then placed in sealed containers until analysis could commence.

To begin the preparation of permanent slides for diatom identification, 2 mℓ of saturated potassium permanganate and 2 ml of hydrochloric acid (10 M) were added to the cover slips. This solution was then heated on a hotplate at *ca*. 60°C until the solution cleared. All the acid-cleaned samples were then washed with distilled water using five consecutive spins at 2000 rpm for 10 minutes. Next, the supernatant was drawn off and a 1.5 ml sample placed in a plastic microfuge tube for storage.

Permanent light microscopy slides were made using 2 drops of the diatom 'digest' placed onto a cover slip and allowed to air-dry overnight. Once the cover slip was completely dry, a small amount of Naphrax mounting medium was placed onto a glass microscopy slide and the cover slip placed over it. Any air trapped under the slide in the Naphrax was removed by heating the slide at *ca*. 60°C. The slide was then allowed to dry for a week, before being analysed using a microscope at a magnification of 1000x.

Diatom species diversity within each community was determined using the Shannon Diversity Index (Shannon and Weaver, 1949). This index is useful as it accounts for both species richness and evenness (relative abundance). The following equation was used to calculate the index score:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where: H' = Shannon Diversity Index

S = Total number of species in the community (richness)

p_i = Proportion of *S* made up by the *i*th species (relative abundance of each species)

Furthermore, Shannon's equitability (E_H) was used to determine the species evenness at each site. This was calculated using the following equation:

$$E_H = \frac{H'}{\ln S}$$

Equitability (E_H) assumes a value between 0 and 1, with 1 representing complete evenness of species distribution.

B.3.3 Data analysis

Data were analysed using Statistica© Version 12 (StatSoft Inc., 2013). The data were tested for normality using the Shapiro-Wilks test. The parametric one-way ANOVA and two-way ANOVA were used to test for intra-system and inter-system comparisons of the numerous variables used as indicators. When data were non-parametric these tests were done using the Kruskal-Wallis ANOVA. In certain circumstances, the parametric Student's t-test was used to test for differences between systems. Analyses were either done at $\alpha = 0.05$ or $\alpha = 0.001$. Lastly, all contour plots depicting standard water quality parameters were created using Grapher™ Version 6, Golden Software, Inc.

B.4 RESULTS

B.4.1 Phytoplankton biomass

In the Goukou Estuary (**Figure B.2**), phytoplankton biomass was significantly lower ($H = 15.12$; $P < 0.05$; $n = 38$) in the upper reaches (15.5 km) compared to the rest of the water column. The most productive section of the Goukou Estuary (i.e. bloom conditions) was in the middle to upper reaches (11.5 km). The median phytoplankton chlorophyll *a* concentration for the estuary was 5.92 µg/ℓ, which is regarded as medium (3.5 to 8.0 µg/ℓ) based on the classification scheme of Snow (2008).

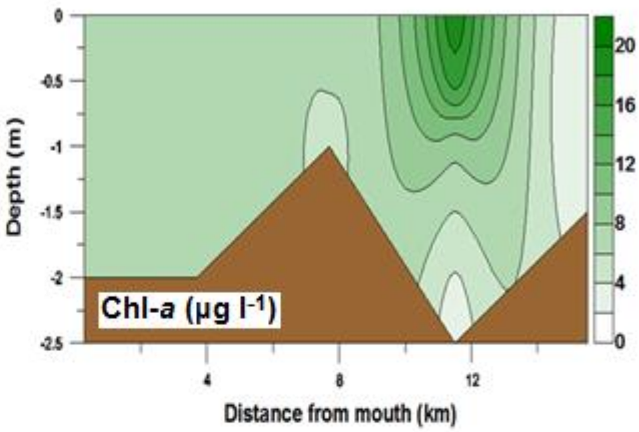

Figure B.2 Distribution of phytoplankton chlorophyll *a* (µg/ℓ) in the Goukou Estuary (3 December 2013)

A comparison of phytoplankton chlorophyll a for the different estuaries within the Gouritz WMA showed that biomass was significantly higher ($H = 151.09$; $P < 0.001$; $n = 288$) in the Hartenbos Estuary. Furthermore, by excluding Hartenbos from the analyses, it was found that Goukou had significantly higher ($H = 108.78$; $P < 0.001$; $n = 268$) phytoplankton biomass than the Duiwenhoks, Klein Brak, Great Brak, Gwaing and Goukamma estuaries. Lastly, the Gouritz and Kaaimans estuaries had elevated ($P < 0.05$) phytoplankton biomass compared to the Duiwenhoks, Klein Brak and Goukamma estuaries.

B.4.2 Phytoplankton community composition

In the Goukou Estuary the flagellate group dominated (> 50% RA) the phytoplankton community in the middle to lower reaches (0.3 and 7.7 km), with chlorophytes (*Sphaerocystis* sp.) dominant throughout the middle to upper reaches (11.5 and 15.5 km). The only exception was at 3.7 km, where blue-green algae (*Symplocastrum* sp.) were dominant (78% RA) (**Figure B.3**). It is worthwhile noting that the blue-green algae were confined to the incoming saline water (i.e. from the lower reaches) in the stratified section of the water column. Vertically averaged phytoplankton cell density was lowest in the middle reaches (7.7 km) and peaked in the upper reaches (15.5 km); 177 and 38034 cells/ml respectively (**Table B.2**). The middle to upper reaches (11.5 and 15.5 km) exceeded the suggested cell density threshold for bloom conditions; however the phytoplankton chlorophyll *a* at these sites was low. The disjunction between cell density and phytoplankton chlorophyll *a* could possibly be attributed to the presence of *Sphaerocystis* sp. as they possess a small biovolume (diameter < 5 µm) and therefore negligible amounts of chlorophyll *a*.

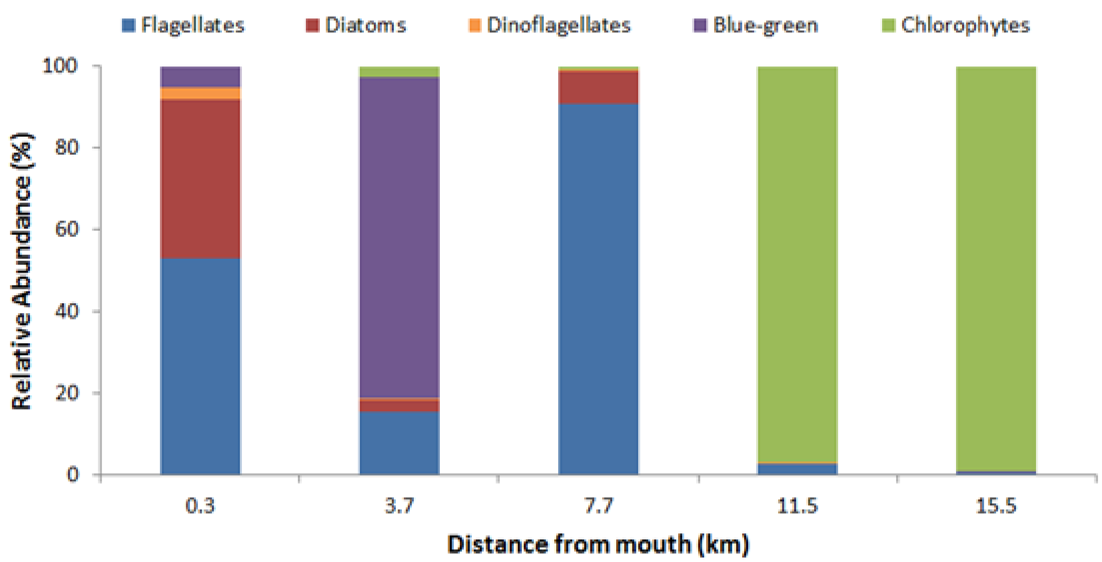

Figure B3 Phytoplankton community composition in the Goukou Estuary (3 December 2013)

B.4.3 Benthic microalgal biomass

Average benthic chlorophyll *a* in the Goukou Estuary ranged from 0 to 45.2 mg/m^2 and was significantly lower ($F = 28.25$; $P < 0.001$; df = 4) in the middle to upper reaches (Site 11.5 and 15.5 km) compared to the rest of the system (**Figure B.4**). The average organic content of the sediment within the estuary (ranging from 0.34 to 5.9%) was significantly elevated ($H = 14.84$; $P < 0.05$; $n = 20$) in the lower reaches (0.3 km) compared to the mid to upper reaches (7.7 and 11.5 km) (Table

B3). No significant ($P > 0.05$) variations were observed between the subtidal and intertidal zones for any of the above parameters.

The median intertidal chlorophyll *a* concentration was 24.0 mg/m^2 in the Goukou Estuary, which is regarded as high (23 to 42 mg/m^2) based on the classification scheme of Snow (2008). When compared to other estuaries within the Gouritz WMA the benthic microalgal biomass in the Goukou Estuary was relatively low; inter-system comparisons showed significantly elevated MPB biomass concentrations ($H = 91.83$; $P < 0.001$; $n = 180$) in the Hartenbos Estuary compared to the all the other estuaries, with the Great Brak and Gwaing being the only exceptions.

Table B.2 Summary of phytoplankton indicators within estuaries of the Gouritz WMA (cells shaded green represent potential bloom conditions; cell density >10 000 cells ml-1 or chlorophyll a > 20 µg l-1) (Lemley, 2015)

Estuary	Distance from mouth (km)	Vertically averaged cell density (ml^{-1})	Average chl-*a* biomass (µg/ℓ ± se)	Dominant group
Duiwenhoks	0.2	172	0	Flagellates
	3.8	60	0	Flagellates
	8.5	40575	0.6 ± 0.4	Chlorophytes
	11.8	44930	0	Chlorophytes
	16.2	32797	0	Chlorophytes
Goukou	0.3	219	6.7 ± 0.8	Flagellates
	3.7	751	6.7 ± 0.7	Blue-green
	7.7	177	5.7 ± 0.3	Flagellates
	11.5	15071	12.7 ± 3.5	Chlorophytes
	15.5	38034	2.4 ± 0.5	Chlorophytes
Gouritz	0.3	535	3.1 ± 0.4	Diatoms
	3.2	274	3.9 ± 0.5	Flagellates
	5.3	763	5.8 ± 1.1	Diatoms
	8.5	568	11.7 ± 0.6	Diatoms
	11.4	733	3.0 ± 0.4	Chlorophytes
Hartenbos	0.37	7440	68.7 ± 30.9	Flagellates
	0.82	13530	104.4 ± 2.5	Flagellates
	1.78	18323	130.5 ± 3.9	Flagellates
	2.37	17635	133.8 ± 14.6	Flagellates
	2.7	5850	69.9 ± 7.1	Flagellates
Klein Brak	0.7	283	0	Flagellates
	1.86	342	0	Flagellates
	3.42	530	1.8 ± 0.8	Flagellates
	4.48 (BR)	234	8.4 ± 3.5	Flagellates
	4.45 (MR)	205	0.4 ± 0.4	Flagellates
Great Brak	1.43	875	0	Flagellates

Estuary	Distance from mouth (km)	Vertically averaged cell density (ml^{-1})	Average chl-*a* biomass (µg/ℓ ± se)	Dominant group
	2.2	1137	0.4 ± 0.3	Flagellates
	3.59	1671	3.0 ± 1.2	Flagellates
	4.99	2221	6.7 ± 3.2	Flagellates
	6.15	3251	21.5 ± 5.6	Flagellates
Gwaing	0.29	282	1.8 ± 0.6	Flagellates
	0.48	536	1.0 ± 0.6	Flagellates
	0.77	649	2.4 ± 0.3	Flagellates
	0.92	380	2.6 ± 0.5	Flagellates
	1.12	509	1.8 ± 0.6	Flagellates
Kaaimans	0.33	732	8.9 ± 0.6	Flagellates
	0.71	1097	7.1 ± 1.2	Flagellates
	1.13	1092	5.5 ± 0.7	Flagellates
	1.58	885	2.2 ± 0.9	Flagellates
	2.27	797	0	Flagellates
Goukamma	0.98	1089	0	Flagellates
	2.64	1121	0.3 ± 0.2	Chlorophytes
	4.33	2310	2.5 ± 1.7	Blue-green
	6.3	4745	17.6 ± 7.1	Chlorophytes
	7.96	12516	0	Chlorophytes

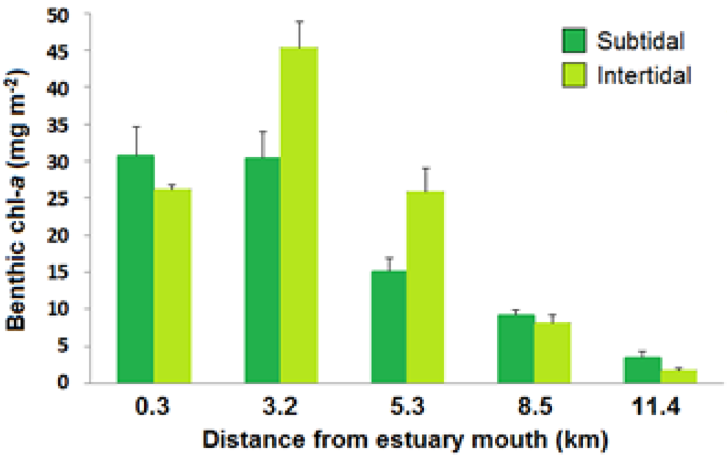

Figure B.4 Benthic chlorophyll a in the Goukou Estuary, 3/12/2013

Table B.3 Benthic microalgal chlorophyll a and organic content in the Goukou Estuary (3 December 2013)

Zone	Distance from mouth (km)	Benthic chl-*a* (μg/ℓ) (± SE)	Organic content (%) (± SE)
Intertidal	0.3	26.15 ± 0.71	4.43 ± 0.36
	3.7	45.23 ± 3.53	3.21 ± 0.08
	7.7	25.79 ± 3.18	1.15 ± 0.03
	11.5	8.13 ± 1.06	0.62 ± 0.14
	15.5	1.77 ± 0.35	1.07 ± 0.07
Subtidal	0.3	30.74 ± 3.89	4.86 ± 0.03
	3.7	30.39 ± 3.53	5.90 ± 2.94
	7.7	15.19 ± 1.77	0.34 ± 0.00
	11.5	9.19 ± 0.71	0.58 ± 0.17
	15.5	3.53 ± 0.71	0.84 ± 0.07

B.4.4 Benthic diatom community composition

Based on the Masters study by Lemley (2015), the lower reaches of the Goukou Estuary (0.3 and 3.7 km) were dominated (>10% relative abundance) by *Amphora jostesorum* and *A. subacutiuscula*. Both are marine or brackish species with no described tolerances for pollution. The middle reaches of the estuary (7.7 and 11.5 km) were dominated by *Hantzschia distinctepuncta*, *Achnanthidium minutissimum*, *Navicula cincta*, *Navicula rostellata* and *Nitzschia clausii*. Achnanthidium minutissimum typically occurs in well-oxygenated, clean water in contrast to the cosmopolitan *N. cincta*, *N. clausii* and *N. rostellata* species that are found in fresh to brackish eutrophic waters (tolerant of heavy pollution). The upper reaches of the estuary (15.5 km) was dominated by *Navicula erifuga*, *Nitzschia palea*, *Navicula gregaria* and *Aulacoseira ambigua*. The first three species are cosmopolitan, tolerant of brackish conditions and tolerate eutrophic environments (tolerate critical levels of pollution). *Aulacoseira ambigua* is typically found in the benthic sediments of eutrophic rivers and lakes. Based on the index information of the majority of dominant benthic diatoms (Lange-Bertalot 2000; Bate *et al.*, 2004; Taylor *et al.*, 2007), the estuary could be regarded as eutrophic.

The benthic diatom species richness score (**Table B.4**) for the Goukou Estuary was 2.35 ± 0.15 (Lemley, 2015), and the evenness score 0.74 ± 0.04. These scores are relatively high when compared to other estuaries in the Gouritz WMA.

Table B4 **Indices of community structure based on the benthic diatom communities along the length of selected estuaries in the Gouritz WMA (Average ± SE) (Lemley, 2015)**

Estuary	Species richness (*S*)	Shannon diversity index (*H'*)	Species evenness (*J'*)
Duiwenhoks	23 (±2)	2.26 (±0.13)	0.74 (±0.04)
Goukou	25 (±3)	2.35 (±0.15)	0.74 (±0.04)
Gouritz	26 (±4)	2.06 (±0.23)	0.65 (±0.05)
Hartenbos	18 (±2)	1.52 (±0.13)	0.55 (±0.04)
Klein Brak	42 (±6)	3.07 (±0.14)	0.84 (±0.02)
Great Brak	29 (±3)	2.45 (±0.15)	0.73 (±0.03)
Gwaing	18 (±2)	1.73 (±0.20)	0.61 (±0.05)
Kaaimans	22 (±3)	1.96 (±0.16)	0.65 (±0.03)
Goukamma	11 (±3)	1.49 (±0.26)	0.64 (±0.06)

B.5 CONCLUSIONS

The Goukou River flooded approximately two weeks prior to sampling on 3 December 2013 and the river flow was still high during the once-off study. This resulted in saline water of marine origin (salinity >1) only penetrating as far as the middle reaches of the estuary (between 3.7 and 7.7 km from the mouth). Nutrient concentrations were elevated but water residence time in the estuary was low so it was expected that the phytoplankton biomass would be low (< 5 µg/ℓ). However, the average chlorophyll *a* was 6.9 µg/ℓ with a distinct peak of 21.9 µg/ℓ, nine kilometres from the mouth of the estuary in the fresh upper reaches. Vertically averaged phytoplankton cell density ranged from low (177 cells/ml; 7.7 km) to very high (38034 µg/ℓ; 15.5 km). Chlorophyll *a* measurements exceeding 20 µg l^{-1} and cell densities exceeding 10 000 cells ml^{-1} are typical of phytoplankton blooms and are indicative of eutrophication, either within the estuary or from a point source. Flagellates and diatoms dominated the water column (> 50% relative abundance) in middle-lower reaches (Zones 1 and 2), and chlorophytes (*Sphaerocystis* sp.) the middle-upper reaches (Zone D). At 3.7 km the blue-green algae (*Symplocastrum* sp.) was dominant (78%); blue-greens were confined to the stratified lower reaches.

Benthic chlorophyll *a* in the estuary was relatively high, reaching a maximum of 45.2 mg/m^2. The median intertidal benthic chlorophyll *a* was 24.0 mg/m^2, which is high when compared to other permanently open estuaries along the south coast of South Africa. Dominant benthic diatoms in the middle and upper reaches were typically brackish and tolerant of pollution suggesting that the Goukou Estuary could be regarded as eutrophic. The benthic diatom species richness was 2.35 ± 0.15 and the evenness score 0.74 ± 0.04. These scores are relatively high, indicating higher biodiversity when compared to other estuaries in the Gouritz WMA. Based on the once-off sampling trip during relatively high flows the results of the phytoplankton and benthic microalgae suggest that the estuary is fairly eutrophic and conditions are likely to be worse at lower river flows when residence time is more optimal for growth. It is strongly recommended that further studies be conducted to accurately determine the estuarine health.

APPENDIX C: MACROPHYTE SPECIALIST REPORT

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C.1 AVAILABLE DATA

Macrophyte data requirements for Intermediate level assessment (DWAF, 2008), as well as availability of data for this study, are presented below:

Data required	Availability	Reference
Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the Present State, as well as the Reference Condition (earliest year available)	The lower reaches of the estuary were remapped in this study using SPOT 5 2013 satellite and Google Earth imagery. GIS vegetation map was produced for the lower reaches from 1942 aerial photographs. Other photographs consulted for changes over time were 1963, 1974 1975, 1981.	This study This study
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.	Yes The estuary was sampled in November 2012. Field survey to ground truth in December 2013	Veldkornet unpublished; incorporated in this report 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 measured in duplicate quadrats (1 m^2).	Yes The estuary was sampled in November 2012. Field survey to ground truth in December 2013	Veldkornet unpublished; incorporated in this report This study

C.2 METHODS

C.2.1 Habitat mapping

The estuarine functional zone (estuarine habitat area) was digitized using the most recent (2013) Spot 5 imagery combined with 2014 Google Earth images. Earliest aerial photographs (1942) that could be obtained were also digitised and estuarine open water areas mapped. Macrophyte habitats were described for past conditions using additional available information i.e. vegetation reports, species lists or oblique photographs. By comparing earlier vegetation maps with more recent maps, changes over time can be documented and the extent of change determined. Past aerial photographs only covered the lower reaches and mouth of the estuaries and so a high confidence of overall past estuarine macrophyte habitat area cannot be made. These mapping data together with descriptions of the abiotic environment under natural / Reference Conditions were used to predict changes over time. All maps were digitised in ArcGIS™ Version 10.2.

C.2.2 Species data

Vegetation was analysed along five transects (**Table C.1**). Vegetation cover was measured as average percentage cover in duplicate quadrats (1 m^2) placed at 5 m intervals along each transects. Transects were chosen where there was a transition from salt marsh to terrestrial vegetation and where there was as little disturbance as possible. Taxon names follow Germishuizen and Meyer (2003), and Mucina and Rutherford (2006). Voucher specimens are housed in the Ria Oliver Herbarium (PEU) of the Nelson Mandela Metropolitan University. Different zones sampled were intertidal salt marsh, supratidal salt marsh, fringe and terrestrial vegetation. Transects 1 and 2 were adjacent to Blombos Strandveld (coastal vegetation) while Transects 3-5 occurred near Southern Cape Valley Thicket (thicket vegetation) (**Table C1**). Transects 1 and 2 were located in the salt marsh on the east bank near the mouth whereas Transects 3, 4 and 5 were located in the middle reaches.

Table C.1 GPS locations of transects in the Goukou Estuary

Transect 1	34.371362° S ; 21.421745°E
Transect 2	34.371528° S ; 21.422017°E
Transect 3	34.339563° S; 21.402944°E
Transect 4	34.339417° S; 21.402716°E
Transect 5	34.339297° S; 21.402496°E

C.2.3 Groundwater and sediment analysis

Along each transect, depth to groundwater was determined by manually auguring down to the water table. Water table readings were taken at the same sites from where the sediment samples were collected. In each of the vegetation zones, sediment samples were collected for analyses in the laboratory. Analyses included sediment moisture and organic content as well as sediment electrical conductivity, following the methods of Black (1965 – sediment moisture content), Briggs (1977 – sediment organic matter) and The Non-Affiliated Sediment analyses Working Committee (Barnard 1990 – sediment electrical conductivity). In situ measurements of the groundwater salinity and electrical conductivity were conducted using an YSI handheld multiprobe.

C.3 RESULTS

C.3.1 Habitat area

Previous estimates of the total estuarine area for the Goukou Estuary were restricted to the lower reaches of the estuary with an estimate of 108 ha (Carter and Brownlie, 1990), with large areas of sand and mud banks, and more recent estimates (Harrison *et al.*, 2000) only refer to the total open water surface area (154.8 ha). If all the area is included below the 5 m contour line to denote the functional estuarine zone, then the total estuarine area is 372 ha (NBA, 2012). Fine-scale mapping of the Goukou Estuary for this report (**Figure C.1**), measured the total estuarine area at 418 ha, which is higher than the 372 ha reported in the NBA report.

Open water surface, however, is significantly higher (206 ha) than in previous estimates and may be dependent on tidal conditions at the time of photography (i.e. from which the maps were digitised) (**Table C.2**). Tidal inundation would also explain the smaller measured area of sand and mud banks (35 ha). Salt marsh area however, changed little between the 2001 and this estimate (44.2 and 57 ha, respectively), while larger floodplain areas have been identified in the recent estimate (~126 ha). Although previous estimates did not quantify the area of reeds and sedges, they do occur along the shorelines of the middle and upper reaches. The 21 ha calculated in this assessment extended to 15 km upstream.

Table C.2 Macrophyte habitats in the Goukou Estuary

Habitat type	Defining features, typical/dominant species	2013 area (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	206
Sand and mud banks	Intertidal zone consists of sand/mud banks that are regularly flooded by freshwater inflows. This habitat provides a possible area for microphytobenthos to inhabit.	35
Macroalgae	Macroalgae would be attached as epiphytes to intertidal vegetation. They would also occur attached to rocky substrates.	0
Submerged macrophytes	Plants that are rooted in both soft subtidal and low intertidal substrata and whose leaves and stems are completely submerged for most states of the tide. Species recorded for the Goukou Estuary include *Zostera capensis.* Pondweed, *Stuckenia pectinata,* which is indicative of brackish conditions, was found during the field survey in November 2013.	5
Salt marsh	The following species have been recorded: *Poecilolepis ficoidea, Bassia diffusa, Cotula coronopifolia, Disphyma crassifolium, Limonium linifolium, Samolus porosus, Sarcocornia natalensis, Sarcocornia pillansii, Spartina maritima, Sporobolus virginicus Triglochin striata, buchenaui* and *Triglochin elongata.*	57
Reeds and sedges	The following species have been recorded, and belong to the families Cyperaceae, Juncaceae and Poaceae: *Juncus kraussii*, *Phragmites australis* and *Schoenoplectus scirpoideus*.	21
Floodplain	This is a mostly grassy area which occurs within the 5 m contour line. Also includes dune vegetation at the mouth and riparian vegetation along the middle and upper reaches of the estuary. Most of the area is degraded (89 ha).	37
Total estuarine area		**372**

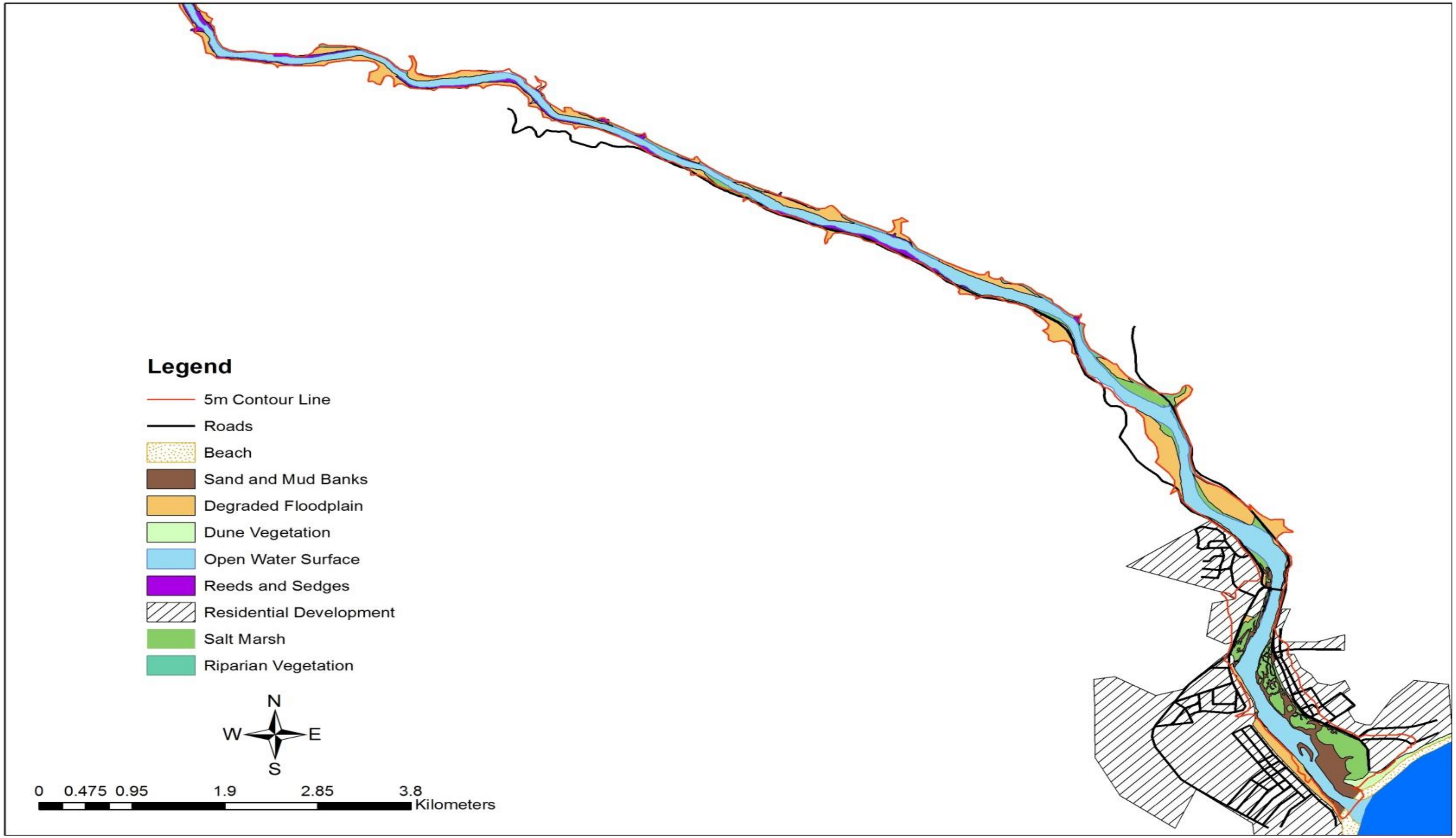

Figure C.1 Present (2013) distribution of the various macrophytes habitats within the Goukou Estuary

C.3.2 Species composition and distribution

Previous surveys (1990) indicated that *Zostera capensis* was the dominant submerged macrophyte that occurred on the sand banks and lower tidal flats of the Goukou Estuary (Carter and Brownlie, 1990). Salt marsh occurred on both banks of the system. During Carter and Brownlie's (1990) survey, the lower intertidal salt marsh was dominated by *Spartina maritima*, the upper intertidal by *Sarcocornia perennis*, *Limonium scabrum,* and *Cotula coronopifolia*, interspersed by clumps of *Salicornia meyeriana*, in disturbed areas. The supratidal salt marsh was dominated by *Juncus kraussii*. Reeds and sedges were mainly encountered upstream, with *Phragmites australis* occurring at salinities below 15, and *Typha capensis* in freshwater areas.

Veldkornet's field studies in November 2012 describe the species from the lower intertidal salt marsh community closer to the mouth as; *Spartina maritima, Triglochin buchenaui, Sarcocornia natalensis, Poecilolepis ficoidea,* and *C. coronopifolia* (**Figure C.2**). An upper intertidal salt marsh community could also be recognised that included *Bassia diffusa, L. linifolium* and *Samolus porosus.* This upper intertidal salt marsh community (with *P. ficoidea)* was also present in the middle reaches where the lower intertidal community was not present (salt marsh 3, **Figure C.3**). Vegetation distribution in the Goukou Estuary is mainly affected by elevation, with species such as *Triglochin elongata*, *Disphyma crassifolium*, *Sarcocornia pillansii* and *Sporobolus virginicus* distributed along an elevation gradient (**Figure C.2**). Other environmental factors that influenced species distribution were groundwater salinity, groundwater electrical conductivity, sediment electrical conductivity and sediment moisture content.

The field survey in December 2013 investigated the dominant species in the salt marshes from the mouth to the upper reaches of the estuary (**Figure C.2**). The salt marsh at the mouth (salt marsh 1, Figure C3) on the eastern bank had *Spartina maritima*, *Limonium linifolium*, *Sporobolus virginicus*, *Disphyma crassifolium, Bassia diffusa*, *Cotula coronopifolia* and *Samolus porosus*. Towards the mouth dune vegetation occurred closer to the water at high elevation with a marsh area behind this. The marsh area on the west bank below the mouth consisted mostly of the lower intertidal grass *Spartina maritima*. Above the bridge on the east bank the large marsh and floodplain area has been disturbed by farming (salt marsh 2, **Figure C.3**). There was clear zonation from the lower intertidal to supratidal zone with 2 m *Spartina maritima*, 1 m *Cotula coronopifolia*, 2 m *Triglochin elongata*, 10 m *Samolus porosus* with *Cotula coronopifolia* and *Limonium linifolium*. The upper intertidal species *Bassia diffusa* was followed by *Sarcocornia pillansii, Disphyma crassifolium* and *Atriplex vestita* along an elevation gradient. The terrestrial habitat was defined by the grass, *Stenotaphrum secundatum*, and where it was drier *Acacia cyclops* and *Chrysanthemoides monilifera* were abundant. Thereafter there were paddocks and a farm house.

The salt marsh area on the east bank further upstream (salt marsh 3, **Figure C.3**) has been disturbed by the road to Stilbaai. The salinity in the pools on this marsh ranged from 25-30 compared to the water column which was 5 during the December 2013 survey. *Cotula coronopifolia, S. tegetaria, S. pillansii, Triglochin* spp.*, Limonium linifolium, Samolus porosus, Bassia diffusa*, and *Juncus kraussii* occurred at this marsh. Veldkornet sampled this site in 2013 (Transects 3-5).

During the December 2013 survey the beds of *Zostera capensis* found near the mouth were patchy possibly in response to the flooding prior to sampling which would have removed some biomass.

However pondweed, *Stuckenia pectinata,* occurred (*Stuckenia* 2) opposite the large white house resort development in the middle reaches of the estuary. This is of significance as this plant grows best at a salinity of 10. *Stuckenia* was also found further downstream (*Stuckenia* 1, **Figure C.3**). This is described as Zone C in the abiotic report (Van Niekerk *et al*., 2015).

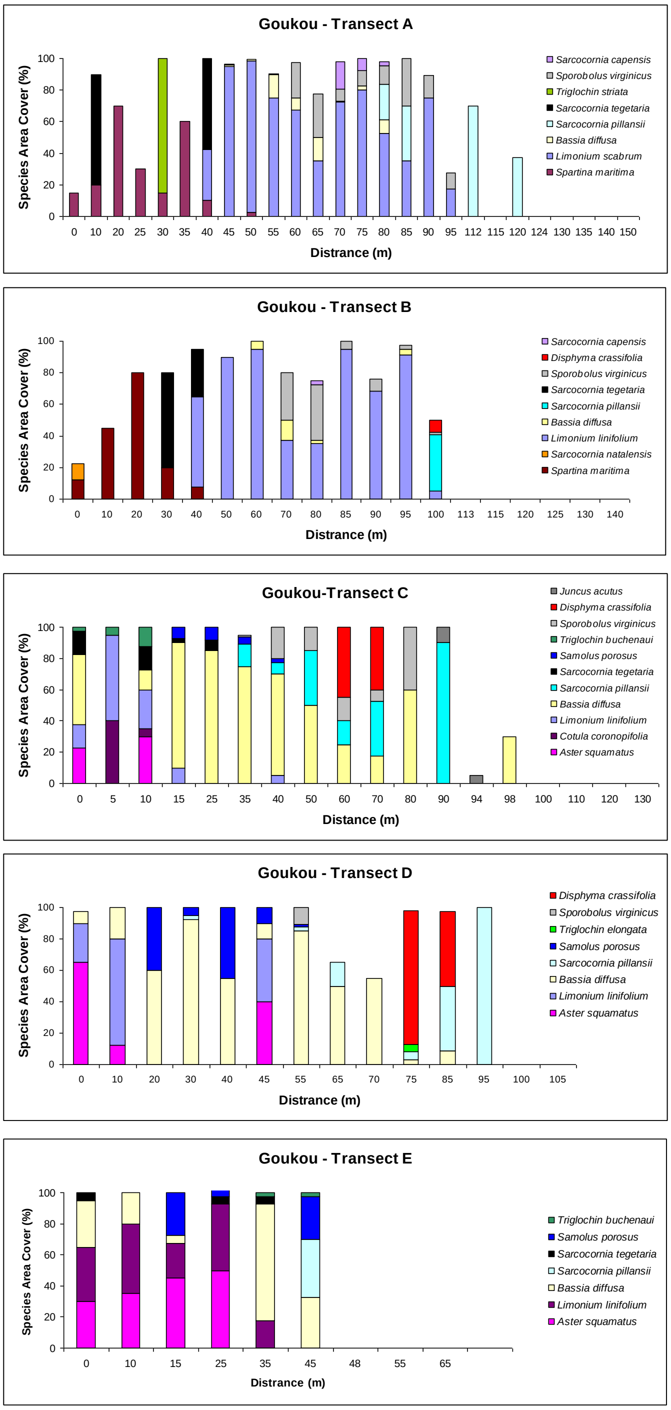

Figure C.2 Species area cover (%) for the dominant salt marsh macrophytes along transects in the lower, middle and upper reaches of the Goukou Estuary

Freshwater seepage from surrounding small fountains and seeps results in pockets of common reed *Phragmites australis* occurring at certain sites such as the launch site on the west bank in the lower reaches. The salt tolerant grass, *Spartina maritima,* grows in front of the reed. *Phragmites australis* which grows best at salinity less than 15 can survive when it is tidally inundated by seawater if its roots are in freshwater (Adams and Bate, 1995). Field studies in the Goukou Estuary showed that surface and interstitial salinity decreased from the water's edge inland which resulted in an increase in plant height. These sites of freshwater seepage create nodes of biodiversity. Van Niekerk *et al*. (2015) described these as freshwater micro-habitats dependent on the input of numerous fountains and seeps.

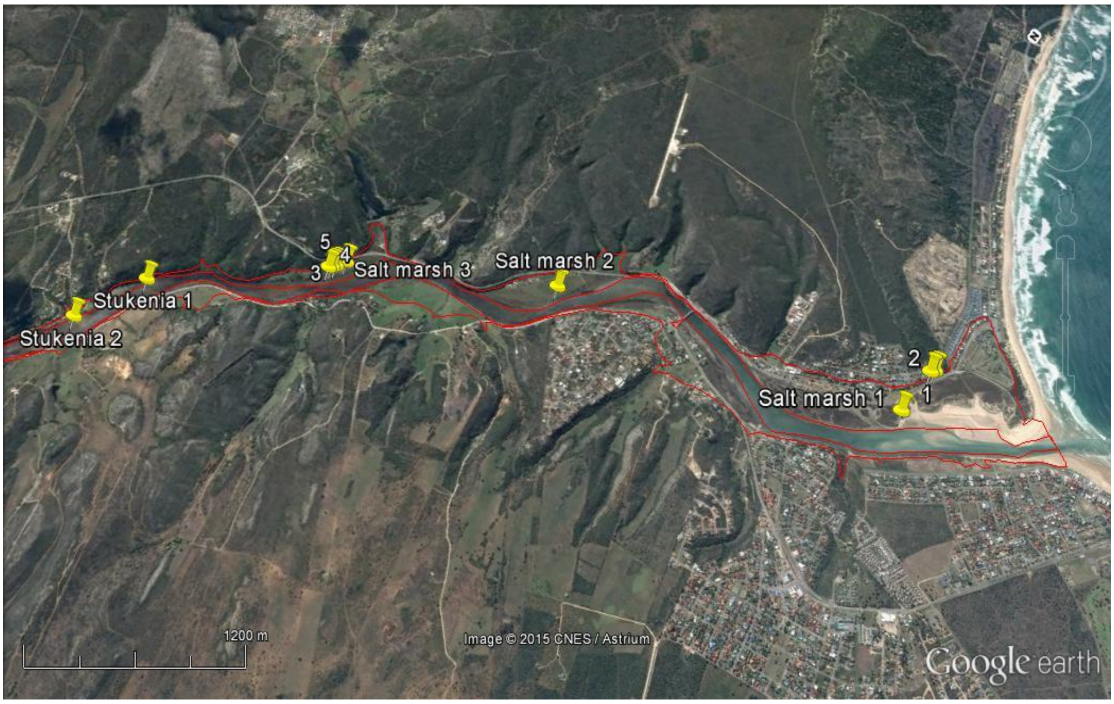

Figure C.3 Macrophyte sites indicating the location of Veldkornet's transects (1-5), *Stuckenia pectinata* (pondweed) beds and salt marsh described in the text

South African estuaries show clear zonation patterns in terms of salt marsh species distribution from the spring low water to spring high water marks. These distribution patterns are influenced by tidal inundation and salinity gradients (Adams *et al*., 1999), as well as sediment characteristics and depth to groundwater (Bornman *et al*., 2004). Salt marshes in the Goukou Estuary had clearly defined zones:

- **Subtidal**: generally exposed during spring low water and characterised by submerged macrophyte species, e.g. *Zostera capensis*.
- **Lower Intertidal salt marsh**: generally exposed during low water and characterised by the salt marsh grass *Spartina maritima.*
- **Intertidal salt marsh**: generally exposed during low water and inundated for brief periods during high tide. Characteristics species include *Sarcocornia tegetaria*, *Triglochin striata* and *Cotula coronopifolia*. *Limonium linifolium* generally occurs in the upper part of this zone together with *Bassia diffusa*.
- **Supratidal salt marsh**: generally inundated only during spring high water. Consequently the sediment tends to have high salinity due to evaporative water loss. Characteristic species include *Sarcocornia pillansii* and *Disphyma crassifolium*.

Plate 1 *Spartina maritima* salt marsh on the east bank near the mouth

Plate 2 Salt marsh in the middle reaches of the estuary

Veldkornet (unpublished data) studied the distribution and connectivity of estuarine macrophytes and sampled across the salt marsh – terrestrial habitats in the Goukou and found a specific group of species associated with the fringe habitat (**Table C.3**) The salt marsh and the terrestrial vegetation had the greatest number of species (18) across all five transects (**Table C.3**). The fringe had the lowest species richness of ten. In the lower reaches the 'terrestrial' vegetation consisted of strandveld and dune bush tick berry (bitou bush), *Chrysanthemoides monilifera*, was dominant. Transects in the upper reaches of the estuary had thicket vegetation with *Aloe pluridens*, *Sideroxylon inerme*, and *Searsia pterota*. Invasive species (*Acacia cyclops*, *Acacia longifolia* and *Opuntia ficus indica*) occurred in the terrestrial zone.

There was a steep decrease in sediment electrical conductivity from the lower intertidal salt marsh to the terrestrial vegetation. The sediment organic content was higher in the terrestrial vegetation compared to the fringe and salt marsh habitats. The salt marsh as expected (sediment moisture contents 33-41%) was wetter compared to the fringe and terrestrial habitats (26% and 10.5% respectively).

Table C.3 Species composition in the three habitats in the Goukou Estuary

Salt marsh	Fringe	Terrestrial
Bassia diffusa	*Ficinia repens*	*Acacia cyclops*
Cotula coronopifolia	*Acacia cyclops*	*Acacia longifolia*
Disphyma crassifolium	*Atriplex vestita*	*Aleo pluridens*
Frankenia capensis	*Carpobrotus muirii*	*Asparagus suaveolens*
Juncus acutus	*Chironia baccifera*	*Asparugus racemosa*
Limonium linifolium	*Chrysanthemoides monilifera*	*Buddleja saligna*
Poecilolepis ficoidea	*Helichrysum terretifolium*	*Carissa macrocarpa*
Samolus porosus	*Searsia glauca*	*Chironia baccifera*
Sarcocornia capensis	*Searsia pterota*	*Chrysanthemoides monilifera*
Sarcocornia natalensis	*Thesium fruticosum*	*Euclea crispa*
Sarcocornia pillansii		*Gymnosporia heterophylla*
Sarcocornia tegetaria		*Helicrysum* sp.
Spartina maritima		*Opuntia ficus-indica*
Spergularia media		*Searsia glauca*
Sporobolus virginicus		*Searsia longispina*
Triglochin buchenaui		*Searsia pterota*
Triglochin elongata		*Thesium fruticosum*
Triglochin striata		*Zygophyllum morgsana*

C.3.3 Environmental drivers for habitat types

Throughout the Goukou Estuary, salt marsh zonation patterns could be observed from the lower to the upper reaches of the system. Sediment analyses indicated that moisture content (%) increased with distance from the water's edge towards the supratidal salt marsh areas (**Figures C.4** to **C.6**). It should be noted that in the lower and middle reaches of the estuary, back channels were encountered that account for these elevated moisture measurements. Sediment moisture content was also highest in the upper reaches of supratidal zone at 60% saturation, which can be linked to higher sediment organic content (20%). Depth to groundwater increased in the lower reaches from the lower intertidal to the supratidal as expected with increase elevation. Sediment organic content (%) ranged from 5 to 8% in the lower and middle reaches, and again increased away from the water's edge. This could indicate an increase in organic litter along the transects towards the fringe and terrestrial areas. In the upper reaches however, there was a significant increase in organic matter in the supratidal area (20%). Sediment electrical conductivity was the highest in the lower reaches, ranging from 45 mS/cm in the lower intertidal to 30 mS/cm in the supratidal salt marsh. Overall the electrical conductivity was lower in the supratidal salt marsh than in the lower intertidal (< 10 and 15 mS/cm and 20 mS/cm, respectively) in the middle and upper reaches, indicative of fresh groundwater seepage towards the main estuarine channel. According to Bornman *et al.* (2004), salt marsh species along the west coast of South Africa rely on fresh groundwater for sustained growth and reproduction. Effect of abiotic characteristics and processes, as well as other biotic components on macrophyte habitats within the Goukou Estuary are presented in **Table C.4**.

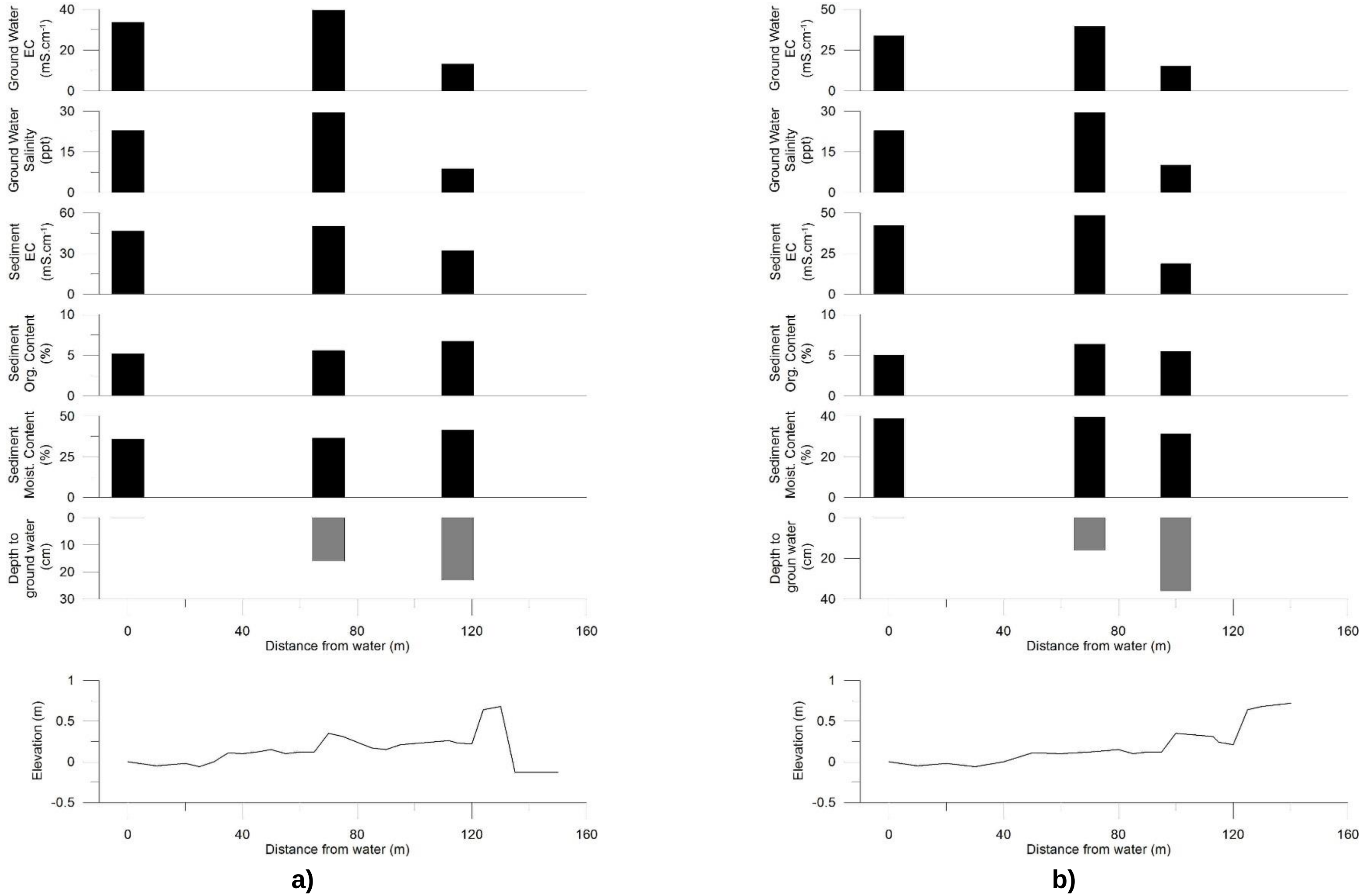

Figure C.4 Environmental variables measured along a) Transect 1 and b) Transect 2 of the lower reaches of the Goukou Estuary

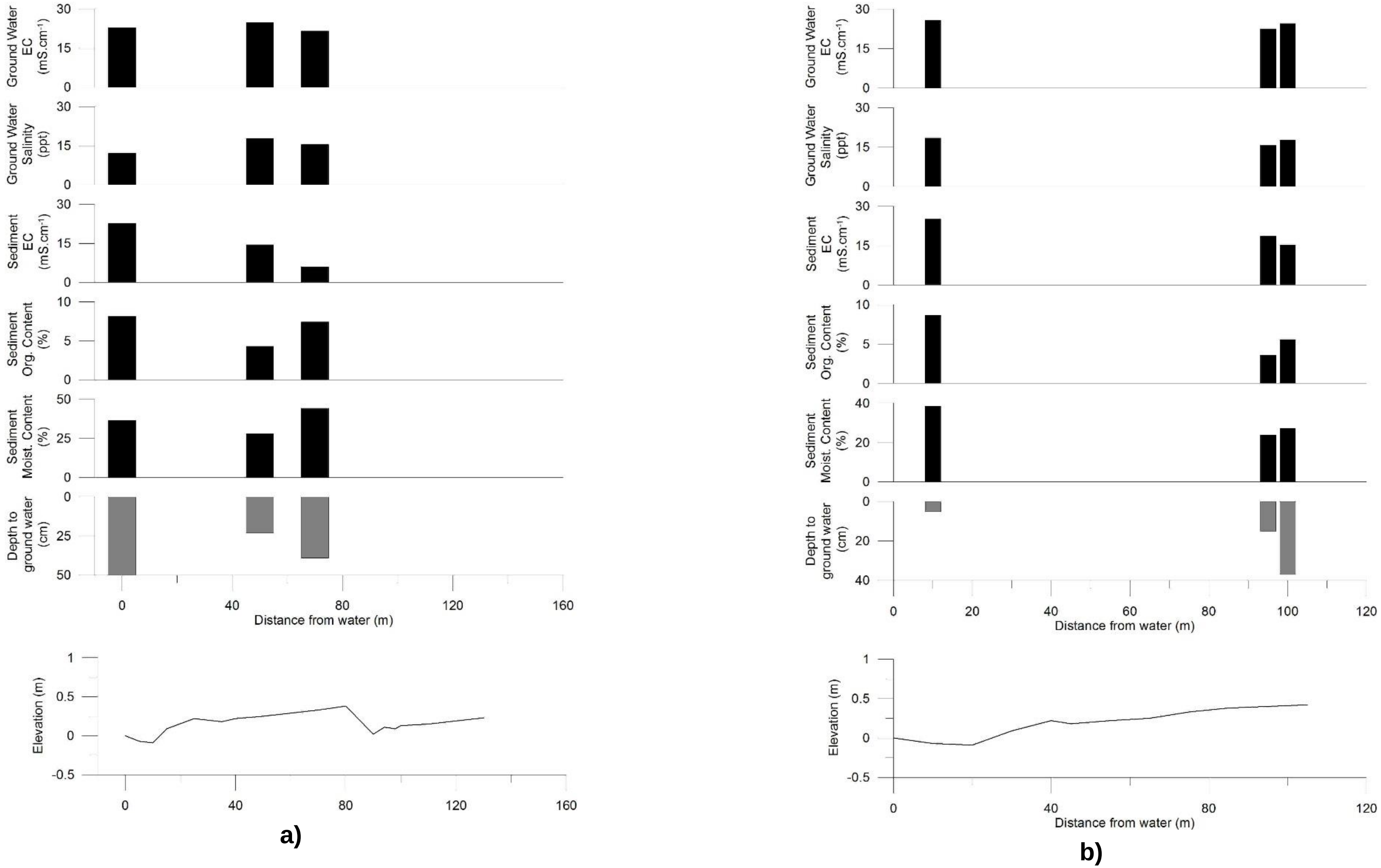

Figure C.5 Environmental variables measured along a) Transect 3 and b) Transect 4 of the middle reaches of the Goukou Estuary

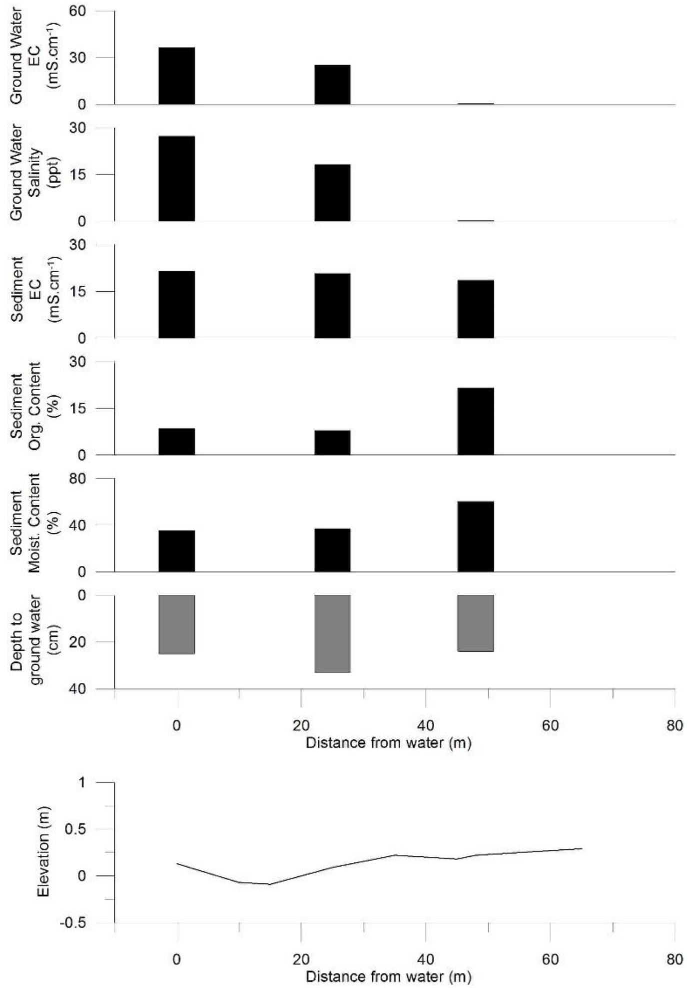

Figure C.6 Environmental variables measured along Transect 5 of the upper reaches of the Goukou Estuary

Plate 3 *Phagmites australis* (common reed) at a freshwater seepage site

Table C.4 Effect of abiotic characteristics and processes, as well as other biotic components on macrophyte habitats within the Goukou Estuary

Process	Macrophytes
Mouth condition	Open mouth conditions creates intertidal habitat. There are large areas of intertidal salt marsh on both banks of the estuary, especially on the eastern bank below the road bridge.
Flow velocities (e.g. tidal velocities or river inflow velocities)	Strong tidal flows can limit the establishment of submerged macrophytes in the lower reaches of the estuary.
Total volume and/or estimated volume of different salinity ranges	The longitudinal salinity gradient promotes species richness, different macrophyte habitats are distributed along the length of the estuary, for example salt marsh in the lower reaches and reeds and sedges in the upper reaches.
Floods	Large floods are important in flushing out salts from the salt marsh area and preventing the encroachment of reeds and sedges into the main river channel. Floods are attenuated by the various impoundments in the catchment area.
Salinity	Base flow is sufficient to maintain longitudinal salinity gradients from the mouth to head of the estuary. Different macrophytes are distributed along the longitudinal gradient in the Goukou Estuary.
Turbidity	Increase sediment load within the water column results in a reduction in the photic zone and will limit submerged macrophyte establishment and distribution, as well as phytoplankton production.

Process	Macrophytes
Dissolved oxygen	The estuary is well oxygenated.
Nutrients	Increased nutrient inputs would increase macrophyte growth particularly in areas of freshwater seepage (i.e. reeds and sedges). Inputs from septic tanks would stimulate reed growth.
Sediment characteristics (including sedimentation)	Stabilization of sand banks and dunes at the mouth has allowed a large dune / marsh area to develop.
Other biotic components	Grazing and trampling has occurred in certain sections of salt marsh. Invasive plants occur in the riparian zone.

C.3.4 Changes over time in macrophyte habitats

Figure C.8 shows a series of aerial photographs of the mouth and lower reaches of the Goukou Estuary, i.e. 1942, 1963, 1977 and 1981. Evidence of residential development is clearly visible in these photographs, firstly on the eastern shore and in later years on the western shore near the mouth. The stabilisation of the dune fields on the eastern shore by invasive vegetation is also evident, together with the subsequent expansion of salt marsh into what was previously (1942) the sand berm at the mouth of the estuary. Dune vegetation also expanded onto the stabilised berm on the eastern bank of the mouth, as can been seen by the latest aerial photographs.

Of the past floodplain area, 70 ha is developed for residential use (within the 5 m contour line used to delineate the functional estuarine zone) and 19 ha have been transformed as a result of agriculture. Salt marsh has increased from 41 ha as shown by the 1942 aerial photograph to 57 ha in the lower reaches of the estuary. This represents a 40% increase in this habitat but should be interpreted with caution as a large percentage of this change is due to an increase in area on the east bank of the mouth due to sediment deposition as a result of a change in mouth configuration and dune stabilisation. This area could easily be eroded by the next large flood. The total area of mud and sand banks has been reduced to 35 ha as a result of dune stabilisation at the eastern shore of the mouth and the subsequent establishment of salt marsh vegetation. There also appear to be a re-establishment of fringe and riparian vegetation in previous agricultural floodplain areas with an increase of 13 ha noted in the recent images. Reeds and sedges cover 21 ha in upper reaches where salinity is low.

The area covered by *Zostera capensis* is difficult to quantify as the beds are very dynamic. The high ebb flow as described in Carter and Brownline (1990) may limit growth on sand banks in the lower reaches of the estuary. Bait digging and boating would stir up sediment and also physically remove seagrass (*Zostera capensis*) which would limit their growth and distribution. The estuary was sampled after a flood in 2013 which would have removed submerged macrophytes. *Stukenia pectinata* would have covered larger areas in the upper reaches of the estuary under natural conditions compared to present day (**Table C.5**) due to lower salinity.

Poor quality aerial photography for the past macrophyte habitat mapping does not allow for fine-scale mapping of the Goukou Estuary as the different habitats could not be distinguished. However, salt marsh could be identified in the lower reaches on the eastern bank of the estuary. A relatively large area could also be identified in the 1942 aerial photograph in the middle to upper reaches. This area however, was already severely impacted by agricultural development and a road cutting across the salt marsh. Although salt marsh area increased in cover in the lower reaches of the estuary there would have been an overall loss of this sensitive habitat.

The reed and sedge area could not be distinguished in past aerial photographs (1942). These plants would have been abundant in the Reference Condition when there was no freshwater abstraction and salinity was lower. It is estimated that they covered 30 ha compared to 21 ha for present conditions (**Table C.6**).

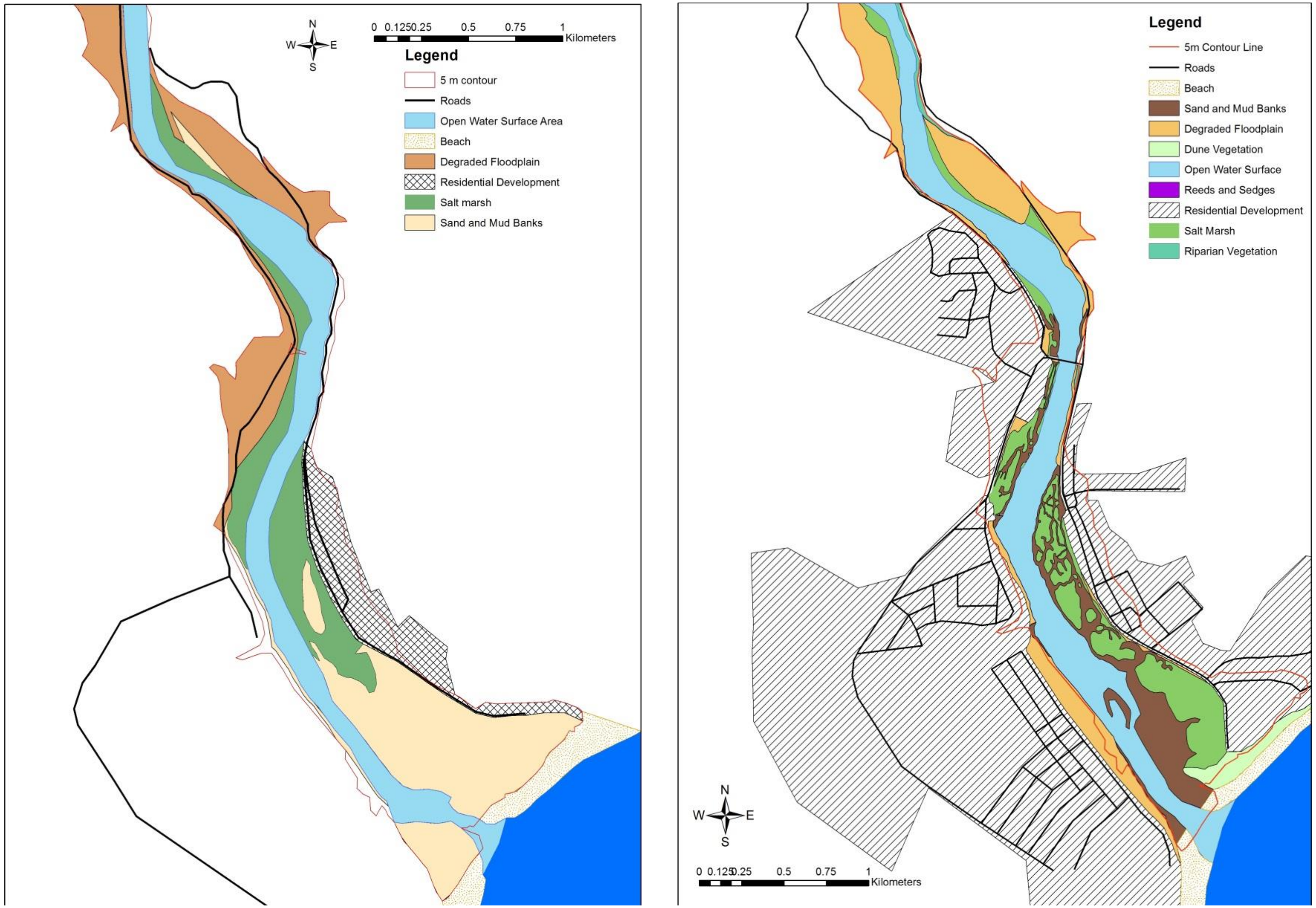

Figure C.7 Past (1942) and present (2013) distribution of macrophyte habitats in the lower to middle reaches of the Goukou Estuary

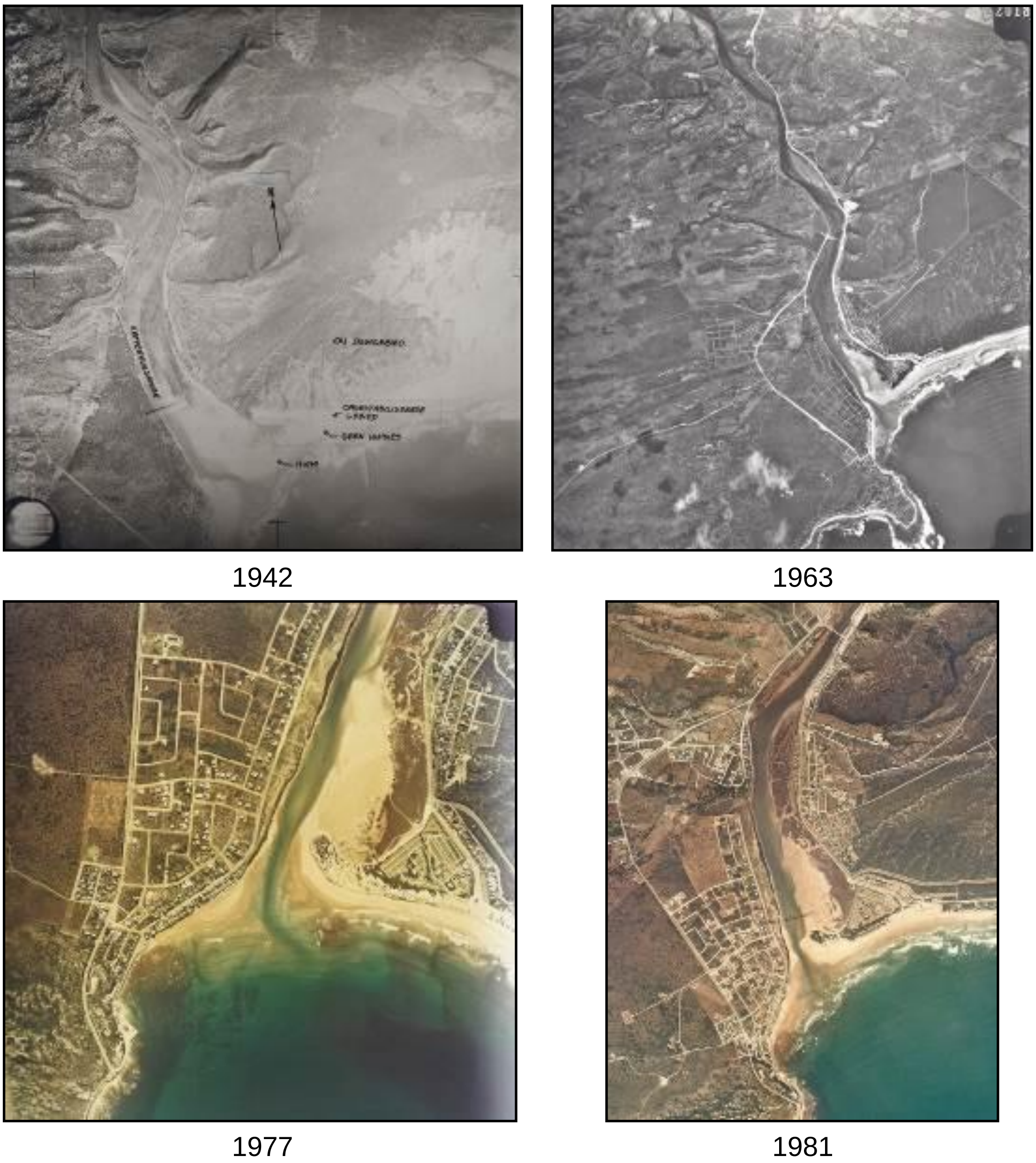

Figure C.8 Changes over time for the lower to middle reaches of the Goukou Estuary

The floodplain has been altered considerably even as early as 1942, where roads and agricultural development can be clearly seen from aerial photographs. In total 89 ha of floodplain habitat has been lost. Residential development on both banks in the lower reaches removed floodplain habitat. In the middle and upper reaches riparian vegetation has been removed to provide access to the water's edge. The banks have been artificially stabilized in some areas thus removing the natural buffering effect of the vegetation. Removal of riparian vegetation has also decreased connectivity between the aquatic and terrestrial ecosystems. Abstraction of water from the small seeps and fountains adjacent to the estuary has also reduced terrestrial-aquatic connectivity.

C.4 CONCLUSIONS

The environmental flow requirement study showed that freshwater inflow abstraction has increased salinity in the upper reaches of the estuary particularly during the summer months causing die-back of reeds, sedges and pondweed. It is estimated that reeds and sedges covered 30 ha compared to 21 ha for present conditions. Under the Reference Condition, river inflow did not decrease below 0.5 $m^{3/}$s for more than 5% of the time however flows below 0.5 m^3/s now occur for between 20 and 30% of the time. Large flood events have not changed much from reference to present conditions. These would be important in inundating salt marshes and reducing salinity as water level can increase to 3-4 m during floods. Intertidal salt marsh area has remained fairly similar from reference to present conditions mainly as a result of stabilisation and expansion in the lower reaches.

Table C.5 Area covered by different habitats in the Goukou Estuary in 2013 compared with 1942 for the lower reaches of the estuary

Habitat	Area (ha) in 1942	Comparable area (ha) in 2013
Floodplain agriculture	55	19
Floodplain developed	34	70
Floodplain undisturbed	-	13
Salt marsh	41	57
Submerged macrophytes	-	-
Reeds and sedges	-	-
Mud and sandbanks	73	35
Open water surface area	70	82
Total functional estuarine area	**273**	**276**

Table C.6 Estimate of the area (ha) covered by the different macrophyte habitats for reference and present (2013) conditions

Habitat	Reference	Present (2013)
Floodplain agriculture and development	0	89
Floodplain natural	126	37
Salt marsh	60	57
Reeds and sedges	30	21
Submerged macrophytes (pondweed)	10	5
Mud and sandbanks	73	35
Open water surface area	206	206
Total area	**505**	**366**

Floodplain agriculture and low-lying infrastructure such as roads, bridges and jetties have removed floodplain habitat, riparian vegetation, salt marsh, reeds and sedges. Artificial bank stabilization has also resulted in loss of habitat. Recreational boating stirs up sediments and physically removes submerged macrophytes. The health of the estuary can be improved by controlling these activities, by removing alien plants from riparian and floodplain areas and by rehabilitating some of the agricultural lands that occur in the estuary functional zone. Future threats to the estuary are a further decrease in freshwater inflow and encroaching development.

C.5 ACKNOWLEDGEMENTS

Some of the data used in this report come from Mr Dimitri Velkornet's ongoing PhD research on "Distribution and connectivity of estuarine species and habitats" funded by the Applied Centre for Climate and Earth Systems Science (ACCESS). This research was planned with a focus on the Gouritz WMA so that it could provide data to inform this study.

APPENDIX D: INVERTEBRATE SPECIALIST REPORT

Prepared by T Wooldridge, Nelson Mandela Metropolitan University, Port Elizabeth and N Thwala, National Research Foundation, Pretoria

D.1 AVAILABLE DATA

Invertebrate data requirements for Intermediate level assessment (DWAF, 2008), as well as availability of data for this study are presented below:

Data required	Availability	Reference
Zooplankton: Collect quantitative samples using a flow meter after dark, preferably during neap tides (mid to high tide) Alternatively, use a benthic D-net to do a transect across the estuary at different station. Daytime midwater and suprabenthic samples at three stations using a WP-2 (90 mm mesh) and a hyperbenthic D-Net sledge (200 mm mesh) respectively. One survey in summer/spring and 1 survey in winter, recording the abiotic state of estuary.	Limited historical data Summer survey (Dec 2013)	Carter and Brownlie (1990) This study
Benthic invertebrates: Collect (subtidal) samples using a Van Veen or Zabalocki-type Eckman grab sampler with 5-9 randomly placed grabs (replicates) at each station. One survey in summer/spring and 1 survey in winter, recording the abiotic state of estuary. For temporarily open estuaries, one survey during stable open and table closed phases.	Summer survey (Dec 2013)	This study
Macrocrustaceans (hyperbenthos): Quantitative sampling for macrocrustaceans conducted during neap tides (mid to high tide), at the same stations used for zooplankton. One survey in summer/spring and 1 survey in winter, recording the abiotic state of estuary. For temporarily open estuaries, once survey during stable open and table closed phases.	Limited historical data Summer survey (Dec 2013)	Carter and Brownlie (1990) This study

Documented information on invertebrates from the Goukou Estuary is limited, although Montoya-Maya and Strydom (2009) included zooplankton information in a broader study of south coast estuaries. Other information on invertebrates from the estuary is broadly descriptive and non-quantitative. Carter and Brownlie (1990) noted 19 taxa of plankton and the presence of mud prawns (*Upogebia africana*), sand prawns (*Callichirus kraussi*) and pansy shells (*Echinodiscus bisperforatus*). Zooplankton data were originally collected by Grindley in 1969 and described in Carter and Brownlee (1990). These data are listed in **Table D.1**. During the survey, 17 zooplankton taxa were recorded. Mean biomass was 135.3 mg DW/m^3 and although relatively high, results were elevated by a high concentration of zooplankton in the mouth area (N=5 sites).

Table D.1 Zooplankton species collected by Grindley (1969) and listed in Carter and Brownlee (1990).

NEMATODA	species not identified
ANNELIDA	polychaete larvae
OSTRACODA	species not identified
COPEPODA	*Acartia natalensis* Harpacticoids Hemicyclops sp. not identified *Pseudodiaptomus hessei* Nauplii larvae
MYSIDACEA	*Mesopodopsis africana* (identification probably incorrect)
ISOPODA	*Cirolana* sp. *Leptanthura laevigata*
AMPHIPODA	*Austrochiltonia subtenuis*
INSECTA	Chironomid larvae
MOLLUSCA	Lamellibrabch larvae

Four species of bait organisms were also collected from the estuary during the Carter and Brownlie (1990) survey. These are listed in **Table D.2**, together with other macrozoobenthic organisms present in the estuary at the time.

Table D.2 Macrozoobenthic species recorded from the estuary (Carter and Bownlie, 1990)

Species	Comments
NEMERTIA	
Unidentified species	On a sandbank 300 m from the mouth
ANNELIDA	
Arenicola loveni	Locally common in areas of coarse sand
Glycera convoluta	Present in lower estuary
Lumbrinereis tetraura	Present in lower estuary
Orbinia sp	Present in lower estuary
ARTHROPODA	
Balanus elizabethea	Sparse on rocks in lower stuary
Chthalamus denteatus	Present in lower estuary
Urothoe sp.	Sandbanks in lower stuary
Alpheus crassimanus	Near *Zostera* beds
Penaeus japonicus	Near *Zostera* beds

Species	Comments
Diogenes brevirostris	Throughout lower estuary

D.2 METHODS

D.2.1 Hyperbenthos

Hyperbenthic animals were sampled at all sites in the two estuaries using a sled mounted on broad skids. Two replicates were collected at each site. The rectangular opening to the sled measured 75 x 70 cm. Attached to this frame was a 500 µm mesh net. A calibrated flowmeter mounted in the entrance quantified water volume passing through the net. Animals collected were then stored in 500 ml plastic bottles and preserved in 10% formaldehyde solution. In the laboratory animals were identified to species level under a microscope and final abundance expressed as average numbers per m^3 of water calculated from the two samples collected at each site. Animals captured in sled samples are usually fairly large, measuring up to 1-2 centimetres. Most of the smaller organisms such as copepods escape through the mesh and were therefore not enumerated or identified in sled samples, although their presence was noted.

D.2.2 Benthos

Subtidal benthic invertebrates were collected during daylight from the deck of the flat-bottomed boat using a Van Veen type grab. Five sites were sampled in each estuary. Six replicates were collected at each site and the contents of each sieved through a 500 µm mesh screen bag. The grab sampler had a 564 cm^2 bite that penetrated the sediment down to about 10 cm depth. Animals retained by the sieve were stored in 500 ml plastic bottles and preserved with 10% formaldehyde solution for further analysis in the laboratory.

A sediment sample collected at each station provided information on particle size distribution and percent organic content. Dry samples (dried at 60^oC for 48 h and then weighed) were incinerated at 550^oC for 12 h to burn off the organic matter. The difference in weight of the sample after incineration provided information on organic content, expressed as a percentage. Three replicates from each sediment sample were used to obtain a final value. Samples were then soaked in distilled water for 24 h to remove salts. Excess water was carefully siphoned off and the sample again dried at 60^oC for 72 h. Dried sediment was then vibrated through a series of metal test sieves (2 mm, 1 mm, 500 µm, 355 µm, 250 µm, 180 µm, 125 µm, 90 µm, 63 µm and <63 µm).

Physoco-chemical information was collected at each site, focusing on water temperature, salinity, oxygen content of the water. Dater were collected at the surface ant at 0.5 m depth intervals

Analysis of biological samples was completed in the laboratory. Final abundance was expressed as the average number of each species per m^2 of substratum at each site, determined from the six replicates respectively. Invertebrates were identified to species level wherever possible and the data analysed using multivariate statistics from the statistical package, PRIMER V.6 (Plymouth Routines in Multivariate Ecological Research). If multivariate techniques were not appropriate, other packages using MS Excel or Statistica for Windows were used.

D.3 RESULTS AND DISCUSSION

D.3.1 Physico-chemical readings

Physico-chemical data were collected on a strong out-going tide when sampling commenced at Station 1 (**Figure D.1**). A strong south-easterly wind was also blowing, particularly at the mouth. Results are shown in **Table D.3** for all parameters measured and in **Figure D.2** for water temperature and salinity collected at two levels in the water column (near the surface and just above the substrate).

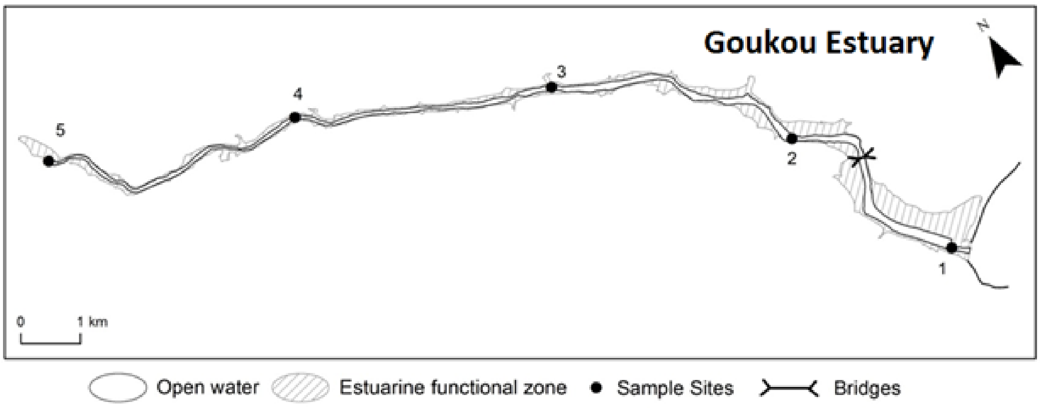

Figure D.1 Location of invertebrate stations sampled in the Goukou Estuary

Table D.3 Physico-chemical readings recorded in the Goukou Estuary on the 3 December 2013

Station	Depth (m)	Temp (°c)	Salinity	Do %	Do mg/l	Ph	Secchi (cm)
Station 1	0	20.94	19.62	87.9	6.99	7.87	
	0.5	20.91	19.65	88	7	7.88	
	1	20.9	19.71	88	7	7.89	
	1.5	20.9	19.74	88.1	7.01	7.88	
	2	20.88	19.79	88.3	7.2	7.58	93
Station 2	0	23.89	2.59	82.1	6.81	8.03	
	0.5	23.86	2.6	82.4	6.85	8.06	
	1	23.85	2.62	82.3	6.84	8.08	
	1.5	23.85	2.62	83	6.87	8.12	
	2	23.83	2.64	83.9	6.96	8.18	55
Station 3	0	24.53	0.76	78.5	6.52	7.98	
	0.5	24.51	0.77	78.5	6.51	8.01	
	1	24.46	0.76	78.9	6.55	8.04	54
Station 4	0	25.18	0.55	86.8	7.13	7.68	
	0.5	25.18	0.55	85.1	7.01	7.67	
	1	23.67	0.55	77.6	6.54	7.68	

Station	Depth (m)	Temp (^oc)	Salinity	Do %	Do mg/l	Ph	Secchi (cm)
	1.5	23.17	0.59	74.7	6.35	7.7	
	2	23.09	0.59	76.2	6.5	7.72	
	2.5	23.08	0.6	75.9	6.48	7.75	58
Station 5	0	23.58	0.38	96.4	8.16	7.66	
	0.5	23.57	0.38	96.1	8.14	7.68	
	1	23.57	0.38	95.6	8.1	7.68	
	1.5	23.57	0.38	94.9	8.03	7.7	50

Near surface and near bottom water temperatures and salinity (**Figure D.2**) suggested a well-mixed water column, although near-bottom temperatures were over 2^{o}C cooler relative to surface layers at Station 4. At 2.5 m, this was the deepest station sampled. Oxygen concentration differences (between near surface and bottom layers) were also greatest at this station (> 10% difference) (**Table D.1**). Water temperatures indicated a trend of increasing values upstream, with Station 5 being > 2.5^{o}C warmer compared to the lower estuary (**Figure D.2**).

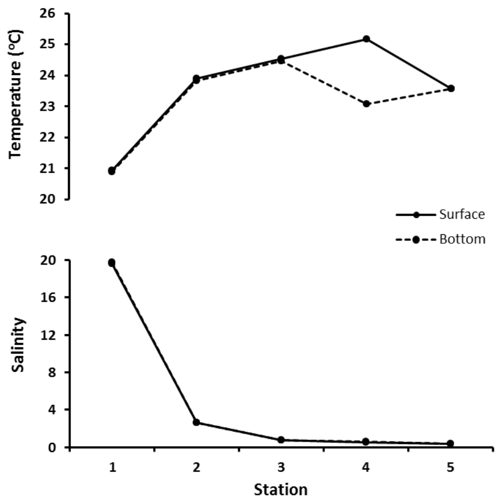

Figure D.2 Temperature and salinity readings measured just below the water surface and near the substrate at five stations in the Goukou Estuary. Station positions shown in Figure D.1)

Except for Station 1, the estuary can be described as oligohaline over much of its length at the time of the current study. Salinity values above Station 3 were < 1.0. Near the mouth salinity was probably still decreasing as the tide continued to ebb at the time of sampling.

The above information on the estuary contrasts with the study undertaken by Montoya-Maya and Strydom (2009), who described the estuary as freshwater deprived and predominantly euhaline (Salinity 30.0-35.9) throughout. Six sites were investigated and involved four visits to the estuary between June 2003 and March 2004. Montoya-Maya (2009) reported salinity distribution along the estuary in more detail, providing summer (December 2003) and autumn (March 2004) values > 21 in the upper estuary. In winter (June 2003) and spring September 2003), values were <5 at the same sites (refer to **Table D.4).** In another investigation, Harrison (2004) reported an average salinity of 23.33 along the estuary (N = 7 samples) during a once-off study.

In terms of sediment particle size distribution, fine to medium sand dominated the entire estuary at the time of sampling (**Table D.4**). Fine mud (< 0.065 μm particle size) contributed < 3%, as did organic matter content of the sediment.

Table D.4 Sediment particle size distribution at five stations in the Goukou Estuary. Size distribution grouped into three categories and expressed as percentage contribution of that category to the whole sample. Organic content of the sediment (expressed as percentage) shown in the last column

Station	< 0.500 - 0.125 μm	< 0.125 - 0.065 μm	< 0.065 μm	Organic matter (%)
1	40.98	58.68	1.19	0.66
2	8.10	91.39	1.39	1.36
3	38.14	58.39	2.33	1.29
4	3.41	96.36	1.05	0.90
5	41.12	56.64	2.10	1.30

D.3.2 Zooplankton

Information on the zooplankton based on four field visits and provided by Montoya-Maya and Strydom (2009) supports the conclusion that in the present study, water column invertebrates were in a recovery phase after floods had passed through the estuary. While species composition was similar when compared to the study carried out by Grindley and reported in Carter and Brownlee (1990), abundance levels were relatively high in the report by Montoya-Maya and Strydom (2009). This information is summarized in **Table D.5**, extracted from the original dissertation by Montoya-Maya (2009).

Table D.5 Physico-chemical readings and dominant zooplankton taxa reported by Montoya-Maya (2009). Fieldwork (four visits) was undertaken in 2003-2004

Salinity	**Lower estuary**	**Range along the estuary**
Summer	>30	35.0 – 19.8
Winter	>30	34.4 – 0.0
Temperature (^{o}C)		
Summer	21.6 – 22.5	21.6 – 24.3
Winter	15.6 – 16.2	16.2 – 13.2
Dominant zooplankton taxa		
Copepoda	**Average density (ind m3) for four visits**	
Acartia spp	6000	
Pseudodiaptomus hessei	<1000	
Mysidacea		
Gastrosaccus brevifissura	50	
Mesopodopsis wooldridgei	80	

Decapod larvae were also important contributors to zooplankton density (13.2% of total zooplankton taxa present) in the Goukou Estuary (Montoya-Maya 2009), but no specific details were reported.

D.3.3 Hyperbenthos

Fifteen taxa were recorded in hyperbenthic samples. However, abundance values shown in **Table D.4** are low compared to other temperate estuaries and are probably a reflection of oligohaline conditions over much of the estuary at the time. Floods were experienced a few weeks previously and populations were probably in a recovery phase. Data for the copepod *Pseudodiaptomus hessei* must also be viewed with caution as adults remain close to or on the substrate during daylight.

Amphipods (*Copophium triaenonyx* and *Grandidierella lignorum*) were the most common taxa (**Table D.6, Figure D.3**) and their distributions along the estuary reflect tolerance to low salinity conditions (Wooldridge and Deyzel 2009, Masikane *et al.,* 2014). Although mysid shrimps are often the most abundant taxa in the hyperbenthos, numbers in the Goukou were orders of magnitude lower compared to other temperate estuaries probably as a consequence of low salinity conditions at the time of sampling.

Table D.6 Abundance of hyperbenthic organisms (ind/m^{-3}) in the Goukou Estuary (data represent mean values of two replicates collected on 3 December 2013 at five sites)

Station	1	2	3	4	5
Copepoda					
Pseudodiaptomus hessei	0.0	0.0	0.0	694.0	0.0
Mysidacea					
Gastrosaccus brevifissura	0.0	10.0	1.0	0.0	0.0

Station	1	2	3	4	5
Mesopodopsis wooldridgei	2.0	0.0	0.0	0.0	0.0
Rhopalophthalmus terranatalis	0.0	2.0	0.0	0.0	0.0
Cumacea					
Iphinoe truncata	0.0	2.0	0.0	0.0	0.0
Isopoda					
Anthurid sp.	0.0	1.0	1.0	2.0	0.0
Corallana africana	0.0	0.0	0.0	4.0	0.0
Amphipoda					
Amphipod sp.	0.0	0.0	1.0	0.0	0.0
Corophium triaenonyx	0.0	0.0	0.0	4.0	78.0
Grandidierella lignorum	0.0	0.0	1.0	17.0	8.0
Caridea					
Carid larvae	0.0	3.0	0.0	0.0	0.0
Palaemon capensis juvs	0.0	0.0	0.0	7.0	0.0
Anomura					
Callichirus kraussi	0.0	0.0	0.0	1.0	0.0
Brachyura					
Hymenosoma orbiculare juvs	0.0	0.0	0.0	5.0	0.0
Hymenosoma orbiculare larvae	0.0	3.0	3.0	0.0	0.0

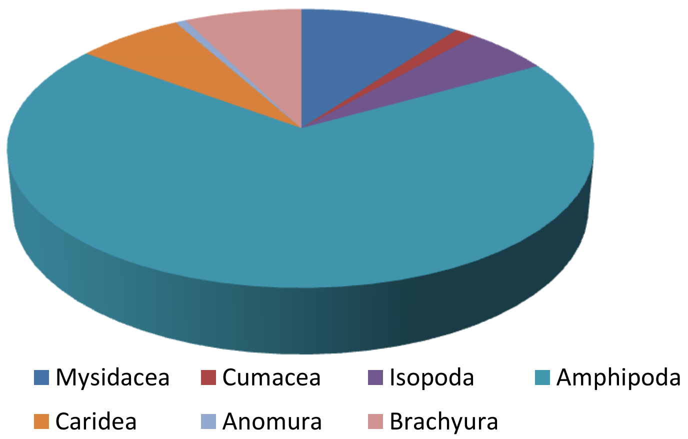

Figure D.3 **Pie diagram of the most abundant hyperbenthic taxa in the Goukou Estuary. Values represent their total abundance at all sites in the estuary (see Table D.6) and expressed as percentage contribution of each group**

D.3.4 Benthos

A total of 17 species belonging to 10 different taxonomic groups was recorded. The mysid shrimp *Gastrosaccus brevifissura* occurred at all sites and numerically dominated the benthic community (**Table D.7 and Figure D.4**). Although *Gastrosaccus brevifissura* has limited physiological ability to adapt to lower salinities (Marshall *et al.*, 2003) compared to other estuarine species, it is well adapted to regulate its spatial distribution along the estuary (Schlacher and Wooldridge, 1994), even under conditions of relatively strong water flow. This strategy probably aided population recovery following the flood that occurred before the sampling programme commenced.

The low species richness and abundance levels recorded in the current study were probably indicative of loss of organisms due to the flood that passed through the estuary weeks previously. *Ceratonereis keiskama* and *Grandidierella lignorum* were fairly abundant in samples and were amoung the few estuarine taxa usually associated with upper estuarine sites where oligohaline conditions prevail (Schlacher and Wooldridge 1996). Salinity values dropped throughout the estuary following the flood, thus favouring these species even in the lower reaches where salinity remained relatively low.

Table D.7 Abundance of macrozoobenthic species (ind. m^2) in the Goukou Estuary (data represent mean values of six replicates collected on 3 December 2013 at five sites)

STATION	1	2	3	4	5
Polychaeta					
Ceratonereis keiskama	0.0	79.8	29.6	32.5	307.3
Prionospio sp	0.0	3.0	0.0	0.0	3.0
Mysidacea					
Gastrosaccus brevifissura	159.6	44.3	8.9	481.7	3.0
Mysidacea sp.	3.0	5.9	0.0	0.3	0.0
Cumacea					
Iphinoe truncata	0.0	0.0	0.0	3.0	0.0
Tanaidacea					
Apseudes digitalis	0.0	59.1	0.0	0.0	44.3
Isopoda					
Corallana africana	0.0	0.0	0.0	0.0	3.0
Cirolana fluviatilis	0.0	0.0	0.0	5.9	3.0
Cyathura estuaria	0.0	0.0	3.0	23.6	11.8
Amphipoda					
Corophium triaenonyx	0.0	26.6	0.0	3.0	41.4
Grandidierella lignorum	0.0	109.3	0.0	5.9	153.7
Xenathura sp.	0.0	0.0	0.0	0.0	3.0
Caridea					
Carid juv.	5.9	0.0	0.0	0.0	0.0
Brachyura					
Thaumastoplax spiralis	0.0	0.0	0.0	3.0	0.0
Mollusca					

STATION	1	2	3	4	5
Bivalve spat	0.0	5.9	0.0	0.0	0.0
Modiolus capensis	0.0	0.0	0.0	0.0	53.2
Eumarcia sp.	0.0	3.0	0.0	0.0	0.0

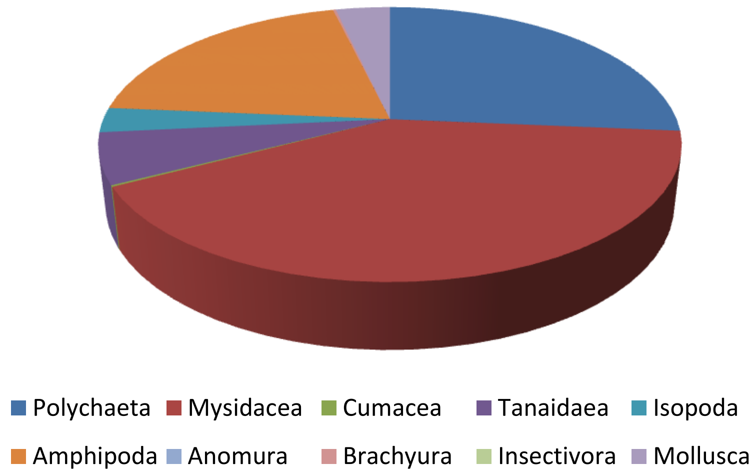

Figure D.4 Pie diagram of the most abundant macrozoobenthic taxa in the Goukou Estuary. Values represent their total abundance (see Table D.7) at all sites in the estuary and expressed as percentage contribution of each group

APPENDIX E: FISH SPECIALIST REPORT

Prepared by J du Plessis, SANParks, Wilderness and S Lamberth, Department of Agriculture, Forestry and fisheries, Cape Town

E.1 AVAILABLE DATA

Fish data requirements for Intermediate level assessment (DWAF, 2008), as well as availability of data for this study, are presented below:

Data required	Availability	Reference
Conduct fish surveys using gear appropriate to the habitat of a particular estuary, but with seine nets and gill nets as primary gear. One survey in summer/spring and 1 survey in winter/autumn to sample the spectrum of species in the system recording the abiotic state of the estuary at the time. For temporarily open/closed estuaries one survey needs to be conducted in a stable closed phase and one in a stable open phase.	Historical data Twice annual in spring/summer and autumn/winter since 2002-2014 Dec 2013	Harrison (1999); Carter and Brownlie (1990) DAFF (unpublished data) This study

Beach-seine and gillnet sampling has been undertaken for the period 2002-2014 by DAFF and CapeNature as part of an existing monitoring protocol. The sampling occurred on a twice-annual basis including the December 2013 field-survey. Other available data comprises that of previous studies done by Carter and Brownlie (1990) and Harrison (1999). *Japie* Kamminga, Bosbokduin, Stilbaai, provided access to his photographic fish records. In addition, CapeNature has been doing opportunistic baseline data collection in the Goukou Estuary since 2002 up to the present day.

E.2 METHODS

The fish assemblage of the Goukou Estuary has been sampled using seine and gillnets since 2002 until the present. For the first three years sampling was quarterly and thereafter twice annually in spring-summer and autumn-winter respectively. The seine-net used was 30 m long, 2 m deep with a stretched mesh of 12 mm in and 5 m either side of the cod end and 20 mm in the wings. Gillnets used were seven 30 m long by 2 m deep panels with mesh sizes of 44, 48, 52, 54, 75, 100 and 145 mm stretched-mesh. Physico-chemical variables temperature, salinity, oxygen, turbidity, pH and habitat characteristics sediment, type, vegetation, burrows etc. were recorded at each of the nine sampling sites. Fish densities were analysed in relation to these variables.

E.3 FISH ASSEMBLAGE

A total of 78 species from 40 families have been recorded in the Goukou Estuary (**Table E.1**). The species are classified according to the five major categories of estuarine-dependence as suggested by Whitfield 1994. Overall, the Goukou fish assemblage reflects the high degree of endemism amongst fish in estuaries and the sea along the cool and warm temperate coasts of South Africa. Based on their distributional ranges given by Smith and Heemstra (1986), 31 (40%) of the fish recorded in the Goukou are southern African endemics. Twelve of these are South African endemics. The occurrence of the checked-goby *Redigobius dewaali* in the Goukou Estuary is a new distribution record and had not been documented in any of the previous Goukou (or Breede, Duiwenhoks and Knysna) surveys prior to 2000. Consequently it may be one of numerous examples of southwards range expansion of warm temperate and subtropical species that have occurred over the last four decades.

All the fish recorded in the Goukou were grouped according to the five major categories of estuarine-dependence as suggested by Whitfield 1994 (**Table E.2**). Category Ia estuarine breeders are represented by five species estuarine round-herring *Gilchristella aestuaria*, Cape halfbeak *Hyporhamphus capensis*, kappie blenny *Omobranchus woodi*, checked goby *Redigobius dewaali* and possibly the Knysna seahorse *Hippocampus capensis*. These species spends their entire life-cycles in estuaries and represented 57.1% of the total catch sample. *Gilchristella aestuaria* was overwhelmingly the most abundant in this category with 57% of the total sample and the remainder of the species in Category Ia contributing 0.1%.

Table E.1 A list of all species recorded in the Goukou River Estuary and tributaries during (a) this study (2003-2006), (b) Carter and Brownlie (1990), (c) J. Kaminga photos, observation, collection (2002-2014), (d) J. Du Plessis opportunistic baseline data collection.

Family name	Species name	Common name	Dependence category	Recorded by
OSTEICHTHYES				
Anabantidae	*Sandelia capensis*	Cape kurper	IV	b
Anguillidae	*Anguilla mossambica*	Longfin eel	Va	b
	Anguilla bengalensis	African mottled eel	Va	b
	Anguilla marmorata	Madagascar mottled eel	Va	b
Ariidae	*Galeichthyes feliceps*	Barbel	IIb	a,b
Atherinidae	*Atherina breviceps*	Cape silverside	Ib	a,b
Blenniidae	*Omobranchus banditus*	Bandit blenny	III	a,b
	Omobranchus woodi	Kappie blenny	Ia	a,b
Carangidae	*Caranx papuensis*	Brassy kingfish	III	a,b
	Caranx sem	Blacktip kingfish	III	a,b
	Gnathanodon speciosus	Golden kingfish	III	a,b
	Lichia amia	Leervis	IIa	a,b
Centrarchidae	*Lepomis macrochirus*	Bluegill sunfish	IV	a
	Micropterus dolomieu	Smallmouth bass	IV	a,b
Chaetodontidae	*Chaetodon auriga*	Threadfin butterflyfish	III	c
	Chaetodon marleyi	Doublesash butterflyfish	III	c
	Heniochus acuminatus	Coachman	III	c

Family name	Species name	Common name	Dependence category	Recorded by
Clinidae	*Clinus superciliosus*	Super klipvis	Ib	a,b
Clupeidae	*Gilchristella aestuaria*	Estuarine round herring	Ia	a,b
Coryphaenidae	*Coryphaena hippurus*	Dorado	III	a
Cyprinidae	*Cyprinus carpio*	Carp	IV	a,b
	Pseudobarbus burchelli	Burchell's redfin	IV	b
Elopidae	*Elops machnata*	Ladyfish	IIa	b
Fistulariidae	*Aulostomus chinensis*	Trumpetfish	III	C
Galaxiidae	*Galaxias zebratus*	Cape galaxias	IV	b
Gobiidae	*Caffrogobius gilchristii*	Prison goby	Ib	a,b
	Caffrogobius natalensis	Baldy	Ib	a
	Caffrogobius nudiceps	Barehead goby	Ib	a
	Psammogobius knysnaensis	Knysna sandgoby	Ib	a,b
	Redigobius dewaali	Checked goby	Ia	a
	Pomadasys olivaceum	Piggy	III	a,b
Hemiramphidae	*Hemiramphus far*	Spotted halfbeak	IIc	a
	Hyporhamphus capensis	Cape halfbeak	Ia	a
Kuhliidae	*Kuhlia mugil*	Barred flagtail	III	c
Labridae	*Coris caudimacula*	Spot-tail coris	III	c
Monodactylidae	*Monodactylus argenteus*	Natal moony	IIb	a
	Monodactylus falciformis	Cape moony	IIa	a,b
Mugilidae	*Liza dumerilii*	Groovy mullet	IIb	a,b
	Liza macrolepis	Largescale mullet	IIa	a,b
	Liza richardsonii	Harder	IIc	a,b
	Liza tricuspidens	Striped mullet	IIb	a,b
	Mugil cephalus	Flathead mullet	IIa	a,b
	Myxus capensis	Freshwater mullet	Vb	a,b
Ostraciidae	*Ostracion cubicus*	Boxy	III	a
Platycephalidae	*Platycephalus indicus*	Bartail flathead	IIc	d
Pomacentridae	*Abudefduf sordidus*	Spot damsel	III	c
	Abudefduf vaigiensis	Sergeant major	III	c
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc	a,b
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	IIa	a.b
	Umbrina robinsonii	Baardman / belman	III	d
Scorpaenidae	*Pterois miles*	Devil firefish	III	c
Soleidae	*Heteromycterus capensis*	Cape sole	IIb	a,b
	Solea temminckii	Blackhand sole	IIb	a,b
Sparidae	*Diplodus cervinus*	Wildeperd	III	a
	Diplodus sargus	Dassie	IIc	a,b

Family name	Species name	Common name	Dependence category	Recorded by
	Lithognathus lithognathus	White steenbras	IIa	a,b
	Lithognathus mormyrus	Sand steenbras	III	a
	Rhabdosargus globiceps	White stumpnose	IIc	a,b
	Rhabdosargus holubi	Cape Stumpnose	IIa	a
	Sarpa salpa	Strepie	IIc	a,b
	Sparodon durbanensis	White musselcracker	III	a
	Spondyliosoma emarginatum	Steentjie	III	a
Syngnathidae	*Hippocampus capensis**	Knysna seahorse	Ia	To confirmed
	Hippocampus histrix	Thorny seahorse	III	d
	Syngnathus temminckii	Longsnout pipefish	Ib	a,b
Synodontidae	*Trachinocephalus myops*	Painted lizardfish	III	a
Teraponidae	*Terapon jarbua*	Thornfish	IIc	a
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III	a,b
	Arothron immaculatus	Blackedged blaasop	IIc	a
	Chelonodon laticeps	Bluespotted blaasop	III	a
Triglidae	*Chelidonichthys capensis*	Cape gurnard	III	a
Zanclidae	*Zanclus cornutus*	Moorish idol	III	c
CHONDRICHTHYES				
Dasyatidae	*Dasyatis chrysonota*	Blue stingray	III	a
	Gymnura natalensis	Butterfly ray	III	a
Myliobatidae	*Myliobatis aquila*	Bullray	III	a
	Pteromylaeus bovinus	Duckbill ray	III	a
Odontaspididae	*Carcharias taurus*	Ragged-tooth shark	III	a
Rhinobatidae	*Rhinobatos annulatus*	Lesser guitarfish	III	a

Seven category Ib species, Cape silverside *Atherina breviceps*, prison goby *Caffrogobius gilchristi*, barehead goby *Caffrogobius nudiceps*, sandgoby *Psammogobius knysnaensis* and longsnout pipefish *Syngnathus temminckii* have marine and estuarine breeding populations. This category comprised of 11.8% of the total sample size. The Gobiidae family (four species) was the most abundant group in this category with a 9.16% contribution.

Obligate estuarine-dependent species (category IIa) were represented by leervis *Lichia amia*, spotted grunter *Pomadasys commersonii*, cape moony *Monodactylus falciformis*, dusky kob *Argyrosomus japonicus* and white steenbras *Lithognathus lithognathus* and comprised a total of 11.1% of the total sample size. These species have to spend at least their first year of life in estuaries. Freshwater mullet *Myxus capensis* and flathead mullet *Mugil cephalus* fall into category IIa as well but venture far into freshwater and may therefore also be categorised as facultative catadromous (Vb) species.

Partially estuarine-dependent category IIb species whose juveniles are usually more abundant in estuaries were represented by barbel *Galeichthyes feliceps*, groovy mullet *Liza dumerili,* striped mullet *Liza tricuspidens*, Cape sole *Heteromycterus capensis* and blackhand sole *Solea temminckii*. Category IIc species whose juveniles tend to be more abundant in the surf-zone, were represented by southern mullet *Liza richardsonii*, elf *Pomatomus saltatrix* and blacktail *Diplodus sargus*. This was reflected in the total sample size with category IIb comprising 16.1% and II2 3.3% of the total sample size. Of these, *L. richardsonii* is the most versatile and opportunistic, able to take advantage of prime conditions in the estuarine and marine environment. This species was then also encountered throughout the entire length of the system with a total of 13% contribution to the total sample size as the second most abundant species.

Table E.2 The five major categories of fishes that utilize South African estuaries (adapted from Whitfield 1994)

Categories	Description of categories	Number of species
I	Estuarine species that breed in southern African estuaries: Ia. Resident species breed only in estuaries. Ib. Resident species that also have marine or freshwater breeding populations.	 5 7
II	Euryhaline marine species that usually breed at sea with the juveniles showing varying degrees of dependence on southern African estuaries: IIa. Juveniles dependent on estuaries as nursery areas. IIb. Juveniles occur mainly in estuaries but are also found at sea. IIc. Juveniles occur in estuaries but are usually more abundant at sea.	9 6 9
III	Marine species that occur in estuaries in small numbers but are not dependent	31
IV	Euryhaline freshwater species, whose penetration into estuaries is determined by salinity tolerance. Includes some species that may breed in both freshwater and estuarine systems: IVa. Indigenous IVb. Translocated from within southern Africa IVc. Alien	3 1 2
V	Catadromous species that use estuaries as transit routes between the marine and freshwater environments: Va. Obligate catadromous species that require a freshwater phase in their development Vb. Facultative catadromous species that do not require a freshwater phase in their development	*1(3)* *2*

Thirty-one estuarine-independent marine species, e.g. spot damsel *Abudefduf sordidus* wildeperd *Diplodus cervinus*, blaasop *Amblyrhynchotes honckenii* and trumpet-fish *Aulostomus chinensis* have been recorded in the Goukou. The proportion of marine species (40%) is high compared to other permanently open systems and may be partly due to the greater marine influence in the present day. Their abundance in the estuary at present is, however low with only 0.3% of the total sample size.

Freshwater fish (category IV) are represented by the indigenous and regionally endemic Cape kurper *Sandelia capensis*, Eastern Cape redfin *Pseudobarbus afer* and cape galaxias *Galaxias* *zebratus* as well as the introduced or translocated smallmouth bass *Micropterus dolomieu*, Mozambique tilapia *Oreochromis mossambicus* and banded tilapia *Tilapia sparrmanii*. Longfin eel *Anguilla mossambica* is the only catadromous species reported from the system but the occurrence of at least two other Anguillid species should not be discounted as they occur in other catchments in the region.

Species diversity in the Goukou Estuary is similar to the Gouritz and Duiwenhoks systems in that the cumulative species curve (seine catches) flattened out after 35-40 species (**Figure E.1**). Since then, most new additions have been marine vagrant species.

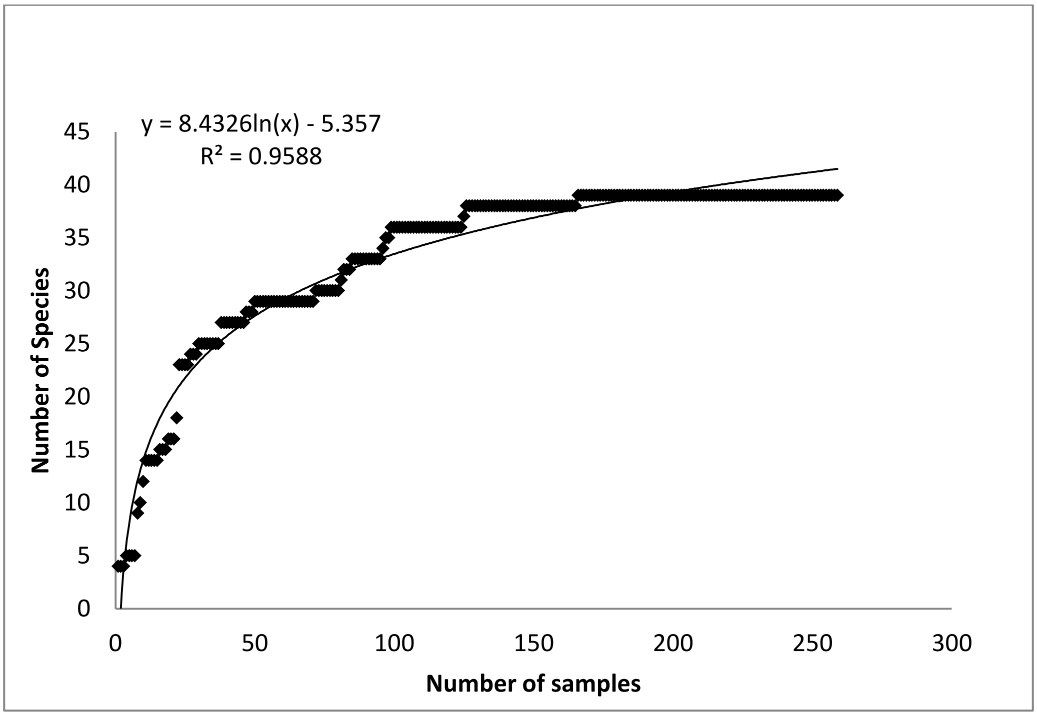

Figure E.1 Cumulative species curve for the fish assemblage of the Goukou Estuary

E.3 SPATIAL AND TEMPORAL DISTRIBUTION OF THE FISH ASSEMBLAGE

Fish distribution within the Goukou Estuary is largely a reflection of the estuary-dependence category to which they belong (**Table E.3**). Typically, most (53%) Ia resident breeders are in the REI zone whereas Ib marine and estuarine breeders, IIa obligate dependents and IIb partial dependents are evenly distributed in the salinity < 30 zones. Most of the IIc marine opportunists and III marine vagrants were in the salinity > 30 range. All category IV freshwater and V catadromous fish were in the salinity 0-10 REI zone.

Table E.3 Percentage distribution of the Goukou Estuary fish assemblages according to salinity (colour indicte dominate categories)

	Dependence category	S‰	>30	20-30	10-20	<10
Ia	Resident breeders		14	4	29	53
Ib	Marine & estuarine breeders		17	29	25	30
IIa	Obligate dependents		17	28	29	25
IIb	Partial dependents		29	26	21	24
IIc	Marine opportunists		45	20	7	28
III	Marine vagrants		49	24	27	
IV	Freshwater					100
V	Catadromous					100

L. richardsonii occurred in 65% and *R. holubi, Caffrogobius* spp., *P. knysnaensis, L. dumerili* and *S. turbynei* in 30 – 40 % of hauls (Table 5). A further seven species e.g. *L. amia, S. temminckii* and *L. lithognathus* occurred in 10 – 20 % of hauls. *G. aestuaria* only occurred in 13 % of hauls but in large shoals so that numerically it contributed 57 % to the total catch. Another 14 species e.g. *Myxus capensis, Hyporhamphus capensis* and *Pomatomus saltatrix* occurred in 2 – 10 % of hauls and the remainder were either depleted, naturally rare or marine vagrants.

Species diversity remained more or less constant at 27 – 32 fish throughout the year (**Table E.4**). Overall catches were highest in summer and autumn at 205 and 480 fish/haul, respectively. The autumn catches were still high even taking into account that these were inflated by large shoals of *G. aestuaria* - at 312 fish/haul (**Table E.4**). Twenty species experienced relatively higher densities in summer and autumn but only 10 in winter and spring.

Table E.4 Seasonality (number per haul), total catch, % catch and % occurrence of all fish caught in 260 seine and gillnet hauls during the period 2002 – 2014. Fish arranged in descending order of occurrence (colour indicate dominant seasons)

Species	Spring	Summer	Autumn	Winter	Total catch	% catch	% occurrence
Liza richardsonii	17.52	30.77	54.59	31.94	9262	13.70	65.25
Rhabdosargus holubi	7.80	25.90	36.93	4.41	5557	8.22	37.07
Caffrogobius spp.	20.00	8.94	31.53	9.98	4861	7.19	36.68
Psammogobius knysnaensis	3.63	5.01	4.07	8.88	1332	1.97	35.14
Liza dumerili	2.59	5.39	3.11	1.82	875	1.29	34.36
Solea turbynei	2.05	1.54	1.58	1.02	405	0.60	30.50

Species	Spring	Summer	Autumn	Winter	Total catch	% catch	% occurrence
Lichia amia	0.25	0.46	0.24	0.10	72	0.11	16.22
Syngnathus temminckii	2.02	2.25	0.51	0.49	339	0.50	16.22
Heteromycteris capensis	1.84	0.92	5.28	3.45	775	1.15	14.29
Gilchristella aestuaria	115.32	86.42	312.53	1.86	38625	57.13	13.51
Lithognathus lithognathus	0.61	0.70	0.34	0.06	115	0.17	13.51
Monodactylus falciformis	1.05	4.25	8.23	0.57	1072	1.59	12.36
Rhabdosargus globiceps	1.82	3.79	3.92	0.22	707	1.05	12.36
Amblyrhynchotes honckenii	0.09	0.30	0.13	0.12	43	0.06	8.88
Galeichthys feliceps	0.02	1.54	0.64	0.02	164	0.24	8.49
Myxus capensis	0.16	1.76	2.40	1.73	418	0.62	8.49
Atherina breviceps	0.50	14.45	2.25	0.06	1244	1.84	6.95
Diplodus capensis	0.88	6.58	8.71	0.02	1240	1.83	6.56
Mugil cephalus	0.00	0.28	1.22	0.02	122	0.18	6.18
Liza tricuspidens	0.13	0.30	0.02	0.04	32	0.05	4.25
Pomatomus saltatrix	0.02	0.08	0.14	0.02	20	0.03	3.86
Lithognathus mormyrus		0.07	0.12	1.67	97	0.14	2.70
Clinus superciliosus	0.25	0.10	0.06	0.18	35	0.05	2.32
Hyporhamphus capensis	0.02	0.01	0.58		50	0.07	2.32
Sarpa salpa	1.86	2.06	0.01		251	0.37	2.32
Diplodus hottentotus		0.06	0.01		5	0.01	1.54
Pomadasys olivaceum			0.47	0.02	40	0.06	1.54
Spondyliosoma emarginatum		0.56	0.05	0.06	47	0.07	1.54
Arothron nigropuntatus			0.05		4	0.01	1.16
Hemiramphus far	0.61	0.01			35	0.05	1.16
Argyrosomus japonicus				0.02	1	<0.01	0.39
Gnathanodon speciosus	0.02				1	<0.01	0.39
Lactoria diaphana			0.01		1	<0.01	0.39
Monodactylus argenteus	0.02				1	<0.01	0.39
Omobranchus woodii			0.01		1	<0.01	0.39
Pomadasys commersonnii				0.18	9	0.01	0.39
Redigobius dewaali			0.01		1	<0.01	0.39
Terapon jarbua	0.02				1	<0.01	0.39
Number of species	**27**	**28**	**32**	**27**			
Total	**181**	**205**	**480**	**69**	**67860**		

E.4 CONNECTIVITY

A collaborative telemetry study has been undertaken by the South African Institute for Aquatic Biodiversity (SAIAB) and DAFF from February 2013 to December 2014 (**Figure E.2**). During that study, 15 spotted grunter *Pomadasys commersonnii,* and 15 leervis, *Lichia amia* were caught and tagged with acoustic transmitters to observe their movements in the Goukou Estuary. Several related studies are also being done in the region, including the Breede Estuary. Fish movements are recorded by a network of receivers installed in the Goukou. When fish move out of the system individual fish will be detected by acoustic receiver arrays installed at other locations. The acoustic transmitters have contact details printed on them so caught and slaughtered fish may also be reported.

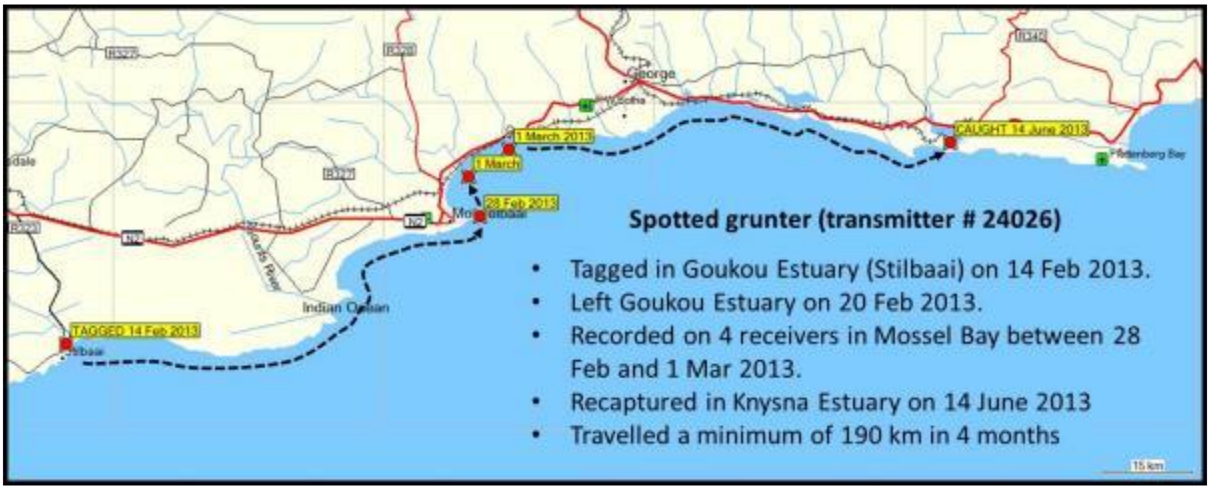

Figure E.2 Movement of an acoustically tagged spotted grunter from the Goukou Estuary (Source P. Cowley SAIAB)

During the mentioned study several fish have moved out of the Goukou and have been recorded in the Knysna and Breede estuaries.

- A Spotted Grunter, *Pomadasys commersonnii* left the Goukou Estuary 6 days after it was initially caught approximately 2 km from the estuary mouth on 20 February 2013.The same fish was caught again in the Knysna Estuary by a recreational angler on 15 June 2013.
- Two Leervis and a spotted Grunter also left the Goukou Estuary during a high flow (cut-off low) period and entered the Breede Estuary during the same high flow period where all the fish remained in 2014.

The remainder of the individual fish that were caught remained in the Goukou Estuary. Broadly, initial data suggest that there is a high degree of residency in the Goukou and other estuaries and that regional movement and connectivity between systems occur during floods and high flow. An indication of fishing pressure in the Goukou Estuary is presented in **Figure E.3**. Most important is not the specific areas targeted, rather the total amount of recreational fishers over the 9 month period is noteworthy.

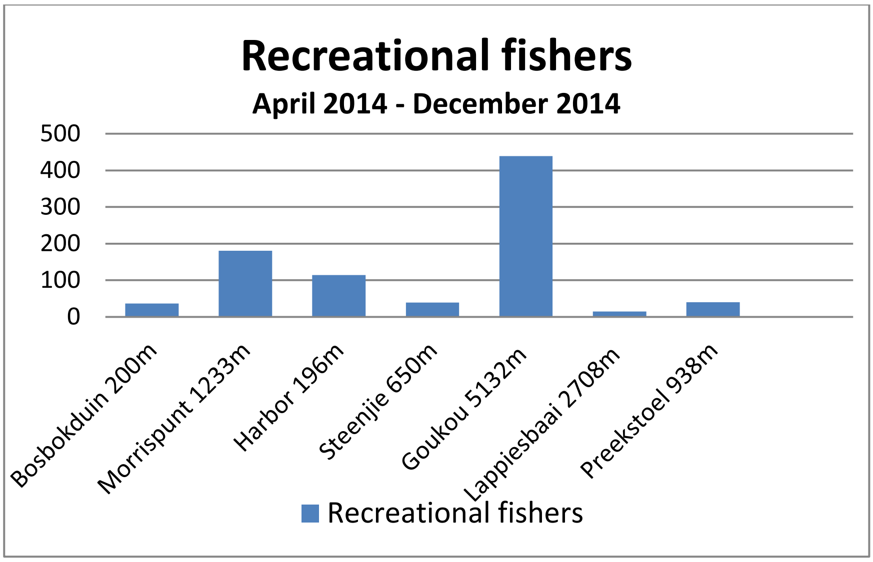

Figure E.3 Recreational fishing pressure in the Stilbaai Marine Protected Area

E.5 FISHING PRESSURE

Significantly the entire Goukou Estuary lies within the MPA. This is the first estuary that is included in a MPA in the Western Cape. The increased conservation status of the estuary helps provide urgent protection for the marine resources through high levels of compliance management. The zoning structure of the MPA consists of Controlled Zones where fishing and bait collecting is allowed as well as Restricted Zones where no extractive usage of marine organisms is permitted. The zoning structure in the Goukou Estuary consists of a Controlled Zone from the mouth to a point 4.2 km upstream. Fishing is allowed in this zone although the western intertidal area of the Controlled Zone is protected from bait collecting. The main motivation for the partial closure of the Controlled Zone for bait collecting was allocate a higher level of protection to habitat and macro invertebrates. The remainder of the estuary is a Restricted Zone with no fishing or bait collection allowed. This constitutes an approximate area of 187ha (75%) of total protection for marine organisms in the estuary.

Recreational fishing pressure in the Controlled Zone is intensive compared to the rest of the MPA. **Figure E.4** shows recreational fishing pressure for the whole of the Stilbaai MPA for the period April 2014 to December 2014. Spatially this results in 1 fisher utilising every 11 m of the estuary during this time period compared to 18 m per fisher for the remainder of the Controlled zones of the MPA. The main targeted species in the Goukou Estuary are *Argyrosomus japonicus*, *Lithognathus lithognathus Lichia amia* and *Pomadasys commersonnii*. All four of these are obliged to spend at least their first year of life in estuaries. The accessibility of the Goukou Estuary and high catchability of juveniles and sub-adults in the estuary makes these species extremely vulnerable to overexploitation. Nationally, the stocks of *A. japonicus* and *L. lithognathus* are overexploited and in a collapsed state.

Compliance management since the proclamation of the Stilbaai MPA has ensured high levels of compliance by the recreational fishing component and illegal gill netting has also been reduced considerably. **Figure E.4** shows levels of compliance from 2008 to 2013 encountered by law enforcement officials from DAFF and CapeNature. The law enforcement effort has remained constant during this time with an average of 300 patrols per year combined.

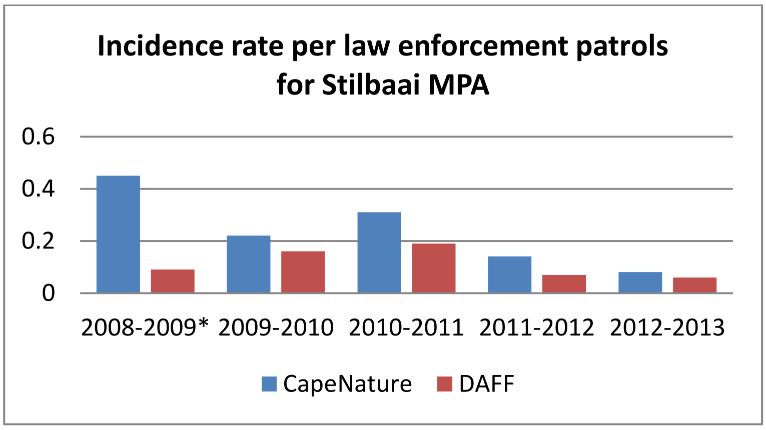

Figure E.4 Compliance level indicators for the Stilbaai MPA including the Goukou Estuary

APPENDIX F: BIRD SPECIALIST REPORT

Prepared by J Turpie
Anchor Environmental Consultants, Cape Town

F.1 AVAILABLE DATA

Bird data requirements for Intermediate level assessment (DWAF, 2008), as well as availability of data for this study, are presented below:

Data required	Availability	Reference
Undertake full bird counts of all water-associated birds along entire estuary. One summer month count when the tide in the estuary is at its lowest. In the case of temporarily open/closed estuaries this must be conducted when the mouth is open.	Several counts of avifauna populations have been conducted. Dec 2013	CWAC data This study

F.2 TAXONOMIC COMPOSITION

Taking only non-passerine waterbirds into account and excluding vagrant species, a total of eight orders are represented on the estuary, with Charadriiformes making up 42% of the waterbird species recorded on the estuary (**Table F.1**). The Ciconiiformes are the next most specious order (nine species) and the other groups are relatively evenly represented. A total of 14 species are long-distance seasonal migrants.

Table F.1 Numbers of species of different groups that have been recorded on the estuary (non-passerine waterbirds, excluding vagrants)

Order	Common names	Total	Migratory
Podicipediformes	Grebes	1	
Pelecaniformes	Cormorants and darters	4	
Ciconiiformes	Herons, egrets, ibis, spoonbills	6	
Anseriformes	Ducks	6	
Falconiformes	Birds of prey	1	
Gruiformes	Rails, crakes, coots and moorhens	2	
Charadriiformes	Waders	22	11
	Gulls	2	
	Tern	4	2
Alcediniformes	Kingfishers	4	

F.3 SPECIES RICHNESS AND ABUNDANCE

A total of 52 non-passerine waterbird species have been recorded on the Goukou Estuary. Across all CWAC[2] counts from 2000 to 2013, a total of 45 species were recorded in summer and 46 in winter. During the January 1981 survey (Underhill and Cooper, 1984), 20 species were recorded. The average number of waterbird species recorded per count between 2000 and 2013 was 26 in summer and 22 in winter. During the Anchor 2013 survey 21 species were recorded. One species recorded in January 1981 (Ruddy Turnstone) has not been recorded since. The Goukou Estuary supports an average of 254 birds in summer and 181 birds in winter. Mean and maximum numbers of birds recorded in the 2000-2013 CWAC counts are summarised in **Table F.2**, together with the Underhill and Cooper 1984 count and the Anchor 2013 count.

Table F.2 Numbers of species that have been recorded on the estuary from Underhill and Cooper 1984, 2000-2013 CWAC data and Anchor 2013 (Non-passerine waterbirds, excluding vagrants)

	13 Jan 81	CWAC summer (2000-2013)		CWAC winter (2000-2013)		03 Dec 13
		Average	Max	Average	Max	
Little Grebe	0	0	13	6	13	0
Whitebreasted Cormorant	2	2	6	8	25	2
Cape Cormorant	0	2	5	3	8	0
Reed Cormorant	24	13	44	14	29	12
African Darter	0	0	9	4	9	0
Grey Heron	0	3	9	4	7	6
Purple Heron	0	0	0	0	1	0
Black-crowned night Heron	0	0	0	0	0	1
Little Egret	8	6	11	6	9	2
African Sacred Ibis	0	14	31	19	47	0
African Spoonbill	0	0	0	0	2	0
Egyptian Goose	0	4	21	3	11	17
Cape Shoveler	0	0	0	0	2	0
African Black Duck	0	0	2	1	2	0
Yellow-billed Duck	27	4	15	25	46	15
Red-billed Teal	0	0	0	0	1	0
Cape Teal	0	1	6	2	7	2
African Fish-Eagle	0	0	1	0	2	0
Common Moorhen	0	0	0	0	1	0
Red-knobbed Coot	67	0	1	0	0	0
African Black Oystercatcher	0	2	7	2	7	0
Ruddy Turnstone	1	0	0	0	0	0
Common Ringed Plover	17	2	6	0	1	7
White-fronted Plover	26	7	12	7	13	1
Kittlitz's Plover	0	0	0	1	5	0
Three-banded Plover	3	1	8	2	8	0

[2] CWAC data were obtained from the Animal Demography Unit, University of Cape Town

	13 Jan 81	CWAC summer (2000-2013)		CWAC winter (2000-2013)		03 Dec 13
		Average	Max	Average	Max	
Greater Sand Plover	0	0	2	0	0	0
Grey Plover	53	21	43	3	10	21
Blacksmith Lapwing	1	17	28	4	7	5
Curlew Sandpiper	150	7	46	1	4	0
Little Stint	0	1	7	0	3	0
Sanderling	0	2	13	0	0	0
Common Sandpiper	11	6	26	1	4	3
Marsh Sandpiper	0	2	11	2	11	0
Common Greenshank	22	14	34	3	7	37
Bar-tailed Godwit	0	0	0	0	0	4
Eurasian Curlew	2	1	7	0	0	0
Common Whimbrel	27	16	31	2	6	22
Pied Avocet	0	0	2	0	0	0
Black-winged Stilt	0	1	3	1	2	1
Water Thick-knee	0	1	4	0	0	5
Kelp Gull	164	75	194	43	79	24
Grey-headed Gull	0	0	0	0	2	0
Caspian Tern	2	0	2	1	2	0
Common Tern	0	10	46	1	7	0
Sandwich Tern	25	0	2	0	0	0
Swift Tern	0	11	70	5	29	47
Pied Kingfisher	7	4	8	3	5	7
Giant Kingfisher	0	0	0	1	4	0
Half-collared Kingfisher	0	0	1	0	2	0
Malachite Kingfisher	0	0	2	1	2	0
Total	**639**	**254**	**383**	**181**	**220**	**246**

There were no apparent trends for any of the species recorded during the CWAC counts, apart from Egyptian Goose, which appeared to have increased over time. Overall it does appear that total summer bird numbers have remained similar throughout the period 2000-2013 (**Figure F.1**). However, the maximum number of birds recorded during the CWAC summer counts (383 birds) is considerably lower than the number recorded in summer 1981 (639 birds).

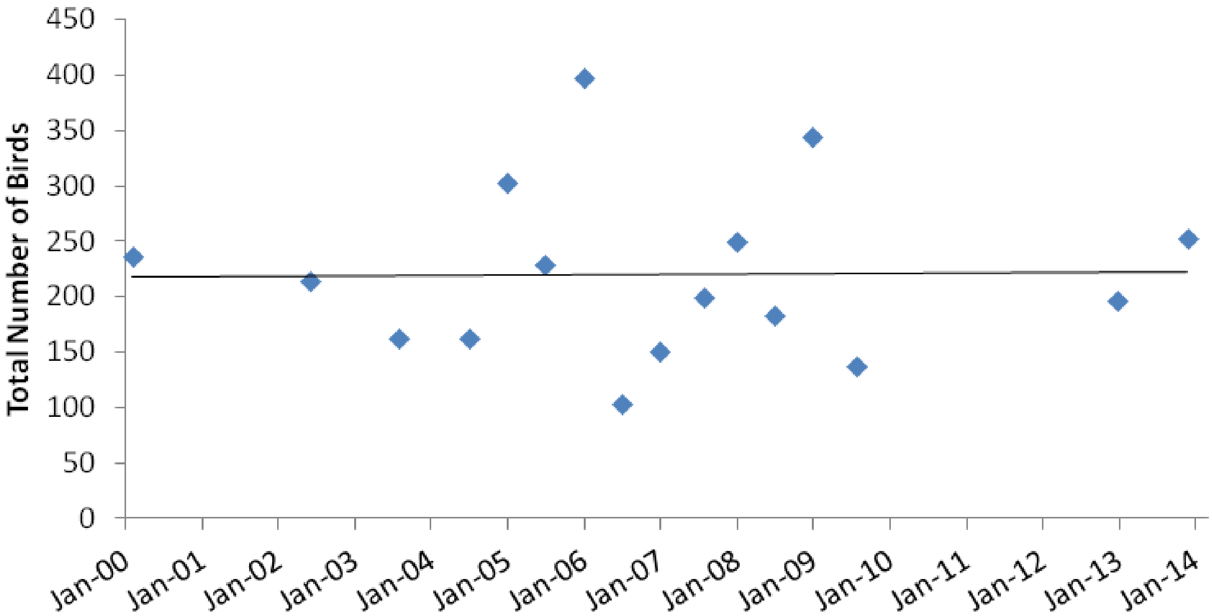

Figure F.1 Total number of birds counted at Goukou Estuary during summer counts of 2000-2013 (Source: CWAC data)

The CWAC data allow a comparison of summer and winter bird composition. In summer, the avifauna of the Goukou Estuary is dominated by waders (42%), and gulls and terns (32%) (**Figure F.2**). Many of the wader species present at this time are Palaearctic migrants. The most numerous waders during summer were the migratory Grey Plover (9%), Common Greenshank (7%) and Common Whimbrel (7%) as well as the resident Blacksmith Lapwing (6%). Curlew Sandpiper were recorded in reasonable numbers in 1981 (150 birds), but have only occurred in sizeable numbers in one year since then (46 birds in 2005). Kelp Gull was the most numerous species within the piscivorous gulls and terns group and alone comprised 25% of all birds. Tern numbers were higher during summer than winter, when the migratory Common Tern was more numerous. Historically the Caspian Tern was also recorded in Goukou Estuary but has not been recorded in counts since 2000.

In winter, the avifauna is much more evenly spread across different groups of birds and is mainly comprised of resident species. The most common species in winter are Kelp Gull (17%), Yellow-billed Duck (13%), African Sacred Ibis (10%) and Reed Cormorant (8%). The numbers of both cormorants and waterfowl are higher in winter than summer, mainly due to higher numbers of White-breasted Cormorant and Yellow-billed Duck.

Community composition was fairly similar in the 1981 count, the 2000-2013 CWAC summer counts and the December 2013 count (**Figures F.2** and **F.3**). The most notable difference was the higher total number of birds, and the higher number of herbivorous waterfowl (mainly Red-knobbed Coot) in the 1981 survey.

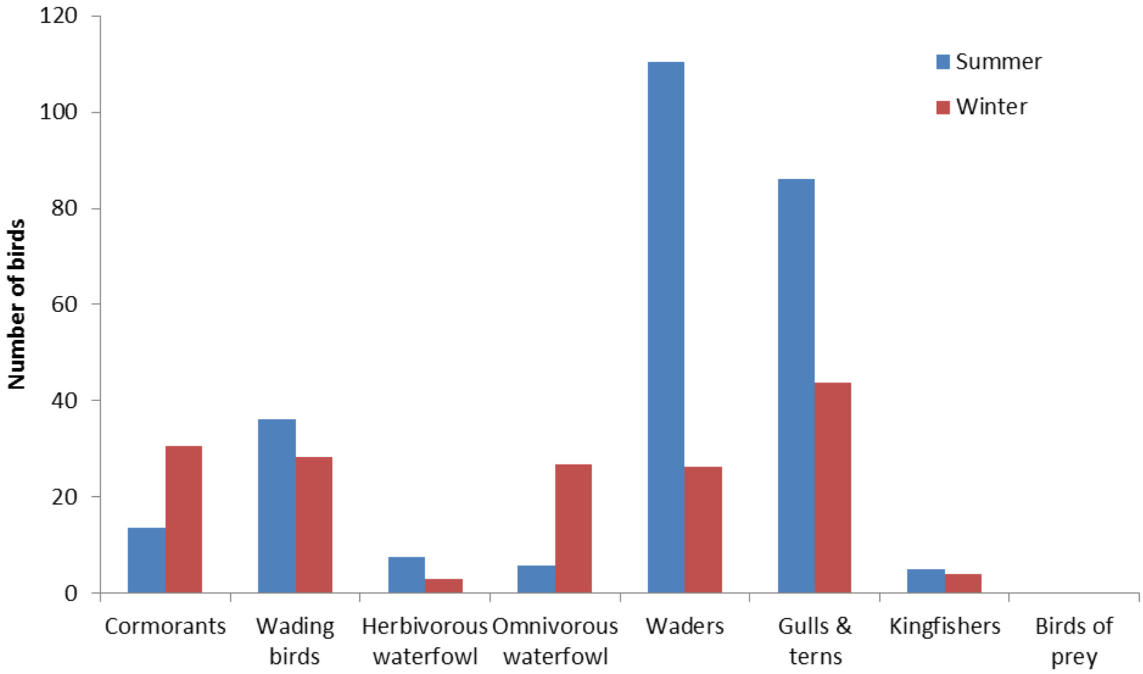

Figure F.2 **Average counts of different groups of birds in summer and winter (2000-2013 CWAC data)**

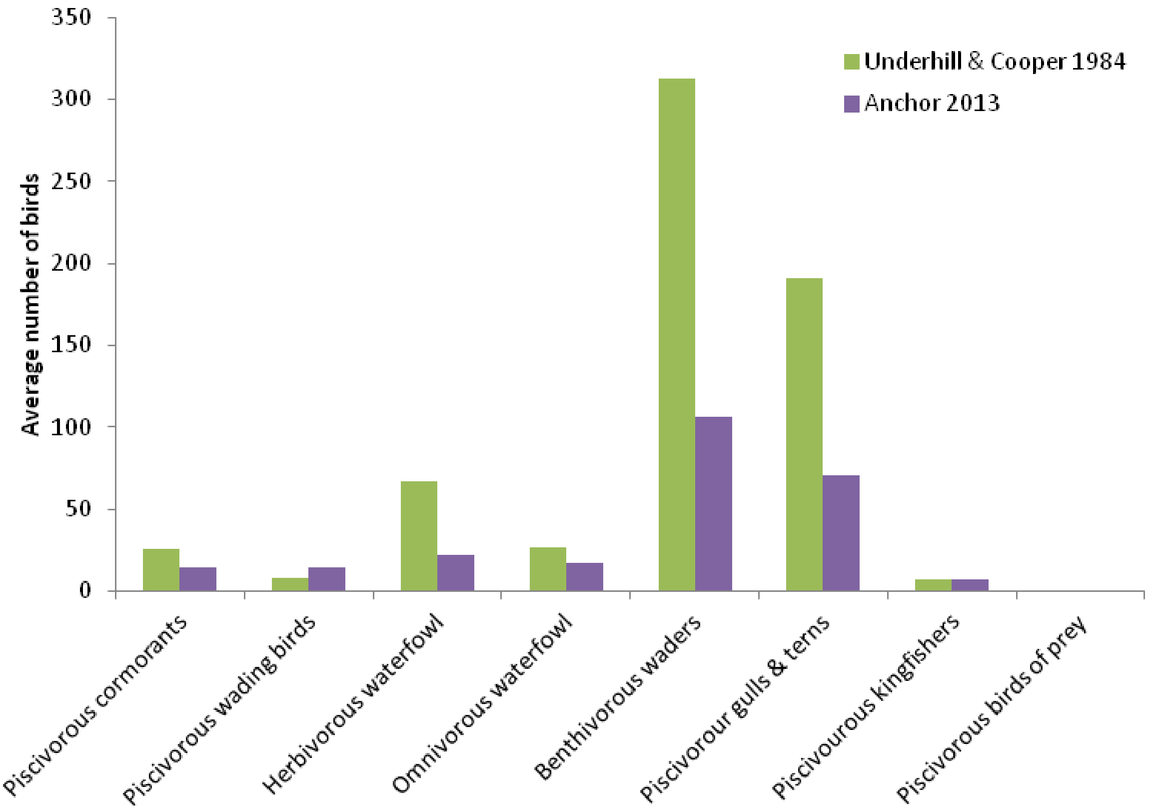

Figure F.3 **Counts of different groups of birds in Underhill and Cooper 1984 and Anchor 2013 summer surveys**

F.4 DIETARY GILDS

The avifauna is dominated by piscivores in both seasons (**Figure F.4**), although the contribution of benthivores almost equals that of piscivores in summer. In winter the proportion of omnivores becomes more predominant.

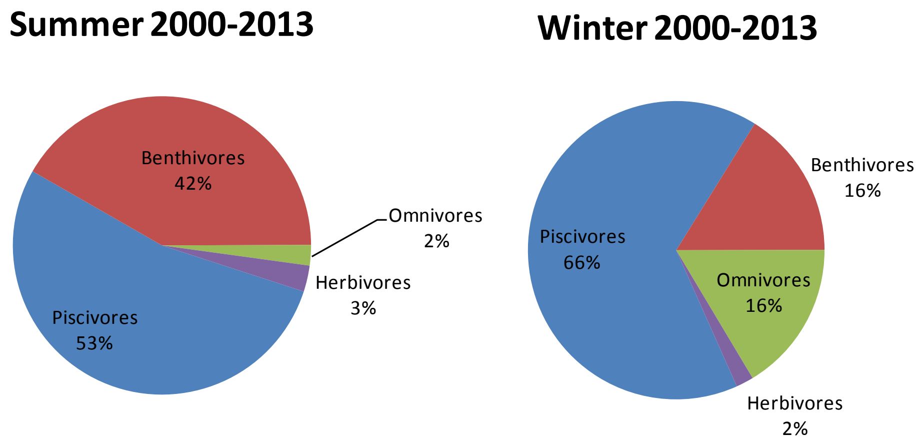

Figure F.4 Percentage composition of different dietary guilds in summer and winter at Goukou Estuary using 2000-2013 CWAC data

The piscivorous birds include the gulls, which also eat invertebrates, the cormorants, terns, kingfishers, ospreys and fish eagles which concentrate on fish (although fish eagles do take other vertebrate prey), and the herons and egrets, which include a variety of vertebrates (e.g. frogs) in their diet. Piscivore numbers are lower in summer, consisting mainly of birds whose numbers tend to be stable year round (e.g. kingfishers, herons), but increase in winter due to increases in the numbers of cormorants and grebes. As is typical of marine or freshwater habitats, many of these are species that feed elsewhere during the breeding season, or coastal species that may be seeking more sheltered feeding areas during winter.

Benthivorous waders are opportunistic foragers whose diets reflect the macroinvertebrate fauna and are typically dominated by prawns (*Upogebia*), crabs (e.g. *Hymenosoma*), polychaetes (e.g. *Ceratonereis*) and amphipods.

The omnivorous species comprise most of the waterfowl, which consume small invertebrates as well as plant material. They are dominated by Yellow-billed Duck. The herbivore group includes moorhen and coot which feed predominantly on submerged macrophytes, as well as Egyptian Goose, which tends to do most of its feeding outside of the estuary. Many of the waterfowl also favour areas where there are reedbeds for shelter.

F.5 SPATIAL PATTERNS IN DISTRIBUTION AND HABITAT USE

The distribution of birds along the estuary (**Figure F.5**) was recorded during the December 2013 Anchor survey Detailed variation in community composition for the different sections sampled during the summer 2013 Anchor survey are presented in **Figure F.6** and summarised into the lower, middle and upper reaches in **Figure F.7.** For the latter, the lower reaches consisted of the first two sampling sections, the middle reaches the third and fourth sampling sections and the upper reaches the top three counting sections.

Figure F.5 Goukou Estuary (image from Google Earth)

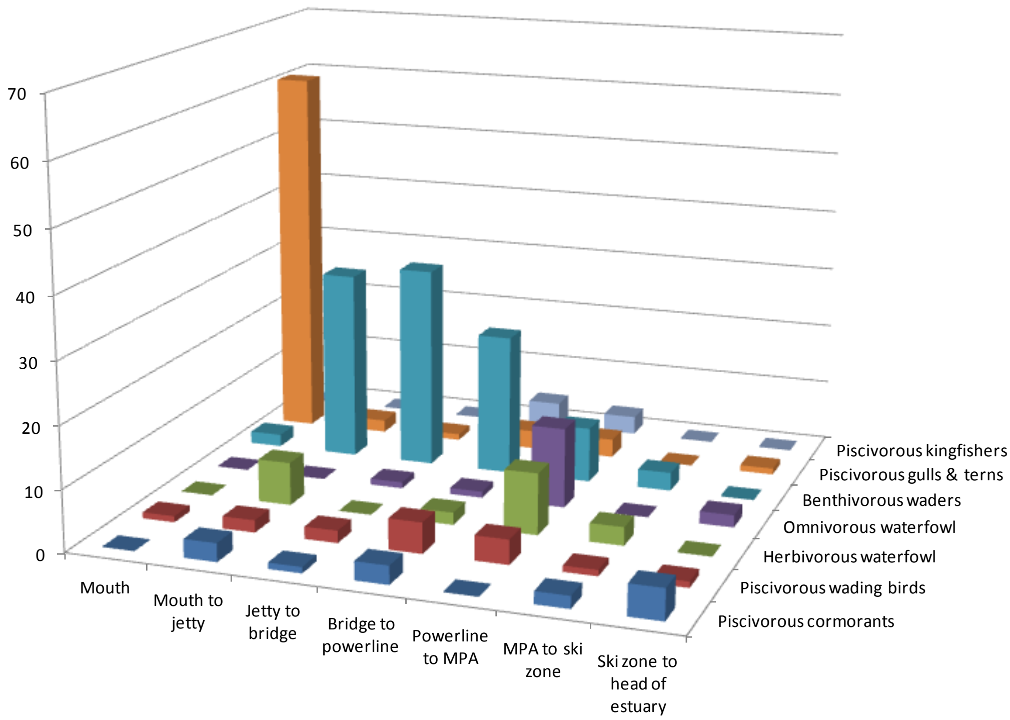

Figure F.6 Fine scale differences in community composition along different sampling sections of the estuary during the December 2013 Anchor survey

Gulls and terns tend to be concentrated in the mouth area, which they tend to use as a roosting area. While a few waders that usually associate with sandy habitats occur at the mouth, most of the waders are found on the intertidal mudflat and saltmarsh areas in the lower estuary between the mouth and the powerline. As one progresses up the estuary to encounter narrower intertidal areas, and grassy verges, the type of waders also tends to change.

Piscivorous wading birds are found throughout the estuary but are more common in the middle reaches, where fish also tend to be most abundant. The waterfowl tend to be found in the upper reaches of the estuary where there are more reedbeds and the estuary is dominated by the open channel.

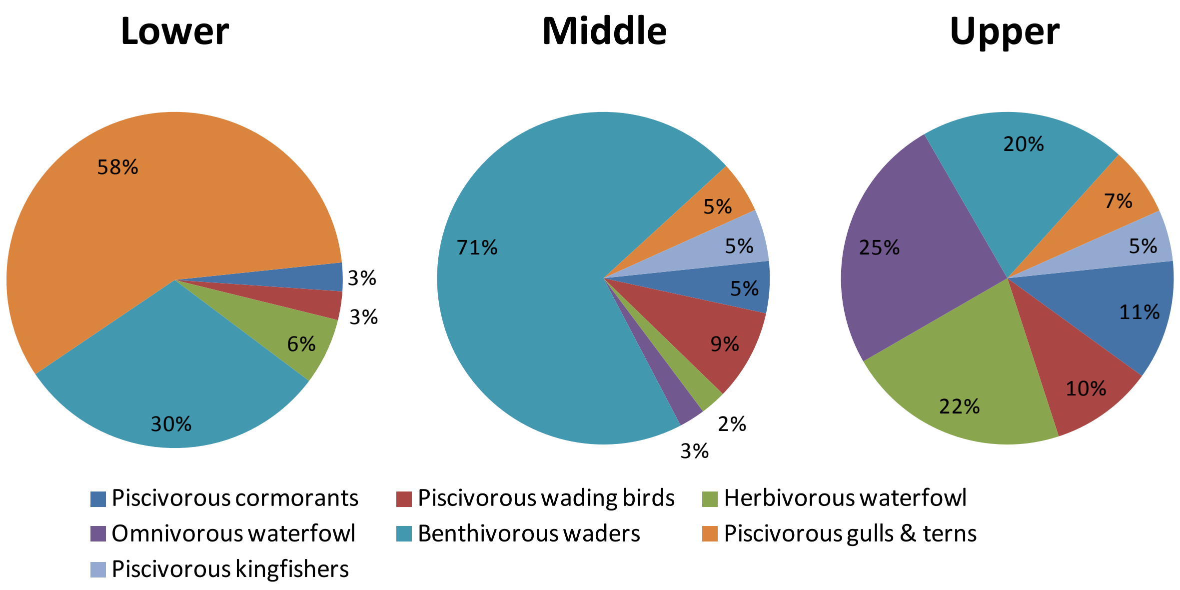

Figure F.7 Differences in community composition along the estuary during the December 2013 survey

APPENDIX G: COMMENTS AND RESPONSE REGISTER

Section	Report Statement	Comments	Addressed in Report?	Author Comment
Comments: Dr Andrew Gordon (DWS) dated 12 May 2015				
8.2	EcoSpecs	No EWRs and Ecospecs have been proposed for alternate Ecological Category scenarios	No	In terms of the Estuary methods (DWAF, 2008) and ToR for this preliminary Reserve study, EcoSpecs will only be provided for REC
8.2	EcoSpecs	Phrase “Resource Quality Objective” is used to describe what I think are actually Ecospecs	Yes	RQOs changed to EcoSpecs throughout report
8.3	Monitoring programme	Recommended monitoring programmes for the estuaries are beyond the current capabilities of the DWS/CMA. Is it possible to suggest a monitoring plan that is phased in over a number of years so that the managing agency has a chance to build capacity	Yes, mostly	Priority components in the monitoring programme has been identified. Also the monitoring was split between baseline surveys and long-term monitoring.
8.2	EcpSpecs: Fish	EcoSpecs for fish need to be more explicit	Yes	Uncertainly in EcoSpecs for fish was changed (see Section 8.2)
Comments: Dr Angus Paterson (external reviewer, SAIAB) dated May 2015				
Entire report	Entire report	Editorial corrections pointed out in his report	Yes	Editorial corrections were made through out report
9	References	Referencing in the report is not comprehensive. In some instances references in main report are listed in Appendices	Yes	References were check and consolidated (i.e. removed from individual Appendices) in the Reference section (see Section 9)
4 and 7	Colour coding of Abiotic States in Tables and Graphs	A colour legend should be included with each of the figures in these sections for the various abiotic state	Yes, mostly	To include a legend in each of the graphs and figures would result in major repetition. The colour legend is first described in Table 3.2.

Section	Report Statement	Comments	Addressed in Report?	Author Comment
				Therefore in the legend of each table and figure, the reader is referred to Table 3.2 (see Sections 4.1 and 7.1).
1.1	Introduction	The introduction to all the reports should include more detail on the rationale of the RDM analysis level applied to that system.	Yes, this was been included	This has been included (see Section 1.1, paragraph 2). The sections referred to in the Inception report provides the level of EWR studies for those estuaries not included in this study)
1.4	Assumptions and Limitations	The assumptions and limitations of each study must be clearly outlined and should be linked to the Data Availability Tables. Specifically any data requirement that is not met in the Data Availability Tables but is prescribed as being required in the 2008 Methods, must be discussed even if it is to indicate that an omission will have negligible bearing on the confidence or outcome of the Reserve.	Yes	The Assumptions and Limitation sections has been updated accordingly (see Section 1.4)
1.4	Use of study data	The reports must include a more comprehensive guideline on how the different reports should be used by DWS. These guidelines are available in the 2008 methods but should be included in each report and customised to that particular system.	Yes	The Assumptions and Limitation sections has been updated accordingly (see Section 1.4, last bullet)

Section	Report Statement	Comments	Addressed in Report?	Author Comment
2.2	Human activities affecting estuary	This section in all the reports is not comprehensively covered, yet in many systems these non-flow drivers are very important.	Yes, mostly	Where possible and information was readily available these tables were amended. Care was specifically taken to make sure that the important pressures that impact in a particular system were included (see Section 2.2)
5.3	Confidence	Low confidences – It is suggested that in Sections which end up having a low or Very Low confidence, the low confidence be explained in the narrative on that section and/or specifically discussed . If it is data that was limiting or inconclusive this then needs to be linked to the limitations and assumptions section as per comment 5.6 above.	Yes, mostly	Components with low data availability were highlighted in Section 5.3 on confidence. Section 1.2 also explains the different levels of confidence (including low and very low confidence
4 and 7	Water quality tables	The Water Quality tables used in the Reports e.g. Gouritz 4.12; 4.13 and 7.18 do not have a colour legend or colour explanation	No	Unlike for abiotic states the colour coding in the WQ tables do not have any explicit meaning other than to alert the reader to changes in concentration, mostly arbitrary.
8.3	Monitoring programme	The resource monitoring programmes should be divided into two discreet sections namely Baseline surveys and Long term compliance monitoring. In terms of long term monitoring a priority system should be included.	Yes	The monitoring was split into baseline survey and long-term programmes. Priorities were also defined (see Tables 8.2 and 8.3)

Section	Report Statement	Comments	Addressed in Report?	Author Comment
Appendices A-F	Data availability for all Specialist studies	The Specialist reports vary in the manner in which Available information and Data Requirements are reported on. It is important that the reports clearly outline: a) data required for the level of Reserve being undertaken and b) the availability of the prescribed data and if it will be collected in this study. Key missing data should be indicated in Limitations and Assumptions section of the Report.	Yes	Data availability tables were included in the first section of all the specialist reports (see Appendices A-F). Missing data was also indicated in Assumptions and Limitations (Section 1.4)
Appendices A-F	Station numbering	Stationing numbering should be distance from mouth as per methods	Yes, mostly	As far as possible distance from mouth was provided.
1.4	Assumption and limitations	The constraints and assumptions around the seeps in this system should be commented on in greater detail as they are important enough to be included in the methods but there is very little available information	Yes	Bullet on this matter added to Assumptions and limitation (see Section 1.4)
Table 4.8	Sediment dynamics	Check bullets and cross referencing within the Table and in particular Bullet 11	Yes	Checked and amended where required
Table 4.16	Microalgae	Why is table number goin backwards?	Yes	Changed
Table 4.23 and C2	Macrophytes	Tables slightly different	Yes	Table C2 corrected
Tables 4.27 and 4.22	Invertebrates	The link between Invertebrate response to different abiotic states and macrophytes needs to be checked to ensure specialists	Yes	Text in tables were adjusted to be consistent

Section	Report Statement	Comments	Addressed in Report?	Author Comment
		are in agreement with respect to changes in submerged macrophytes.		
Table 4.28 and 4.29	Invertebrates	Variability wrt to community composition needs to be checked to ensure they are aligned.	Yes	Text in tables were aligned
Tables 4.29 and 4.32	Fish	Check consistency between wrt to compatibility of changes to zooplankton and benthic invertebrate abundance.	Yes	Text were changed to be consistent
Table 5.2	Wastewater input	WWTW must be in full	Yes	Amended
Figure 6.1		Labelsare not visible	Partly	Figure was made larger to improve visibility
6.1	Importance rating	The estuary importance score for five estuaries…? What 5 estuaries?	Yes	Corrected, not 5 estuaries only Goukou Estuary
8.1	Recommendations	Restoring 50% of the flood plain habitat along the estuary. Is this a feasible recommendation?	Not addressed	This need to be confirmed by DWS in signing off templates
Table 8.1	EcoSpecs	Hydrodynamics – Loss of wet riparian zones ……? Incomplete sentence	Yes	Amended
9	References	Carter & Brownlie not in references – Check all references	Yes	Amended
Figure A2.1	Abiotic components	No zones on map	Yes	Reference to figure with zones add to legend
9	References	Tanner 1969 and Wentworth 1922 missing	Yes	Amended
Table 4.23 and C6	Macrophytes	Same title different values?	Yes	Table C6 amended
Table E1	Fish	Data gaps and editing	Yes	Amended
Table E3	Fish	% not indicated	Yes	Legend amended
Table E4	Fish	Shading and decimal place of pipefish	Yes	Legend amended and decimals removed

Section	Report Statement	Comments	Addressed in Report?	Author Comment
Figure E6	Fish	Figure and associated text needs to be more clearly explained	Yes	Text amended to reflect focus of figure
Comments: Barbara Weston (DWS) dated September 2015 as presented in Gouritz Report in track changes				
Entire report	Entire report	Editorial corrections made in track changes	Yes	Editorial corrections were made through out report, where also applicable to Duiwenhoks study
Entire report	Salinity	Add units for salinity	No	Salinity is unitless (IS units)