





WP 10543

RDM/WMA16/04/CON/0813, Volume 1

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

PROJECT TECHNICAL REPORT 8, VOLUME 1

ESTUARIES RDM REPORT – INTERMEDIATE ASSESSMENT, VOLUME 1

DUIWENHOKS ESTUARY

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Chief Directorate: Water Ecosystems

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Final report	September 2015

EXECUTIVE SUMMARY

GEOGRAPHICAL BOUNDARIES

The Duiwenhoks Estuary is a permanently open estuary located in the warm temperate region of the Western Cape between Riversdal and Heidelberg with a catchment area of 1340 km^2. The catchment receives rainfall throughout the year, with peaks in autumn and spring. The geographical boundaries of the estuary are defined as follows:

Downstream boundary:	*Estuary mouth 34°21'54.31"S 21° 0'0.51"E*
Upstream boundary:	*34°15'5.87"S 20°59'30.95"E*
Lateral boundaries:	*5 m contour above Mean Sea Level (MSL) along each bank*

PRESENT ECOLOGICAL STATUS

*The Estuarine Health Score for the Duiwenhoks Estuary is 72, thus a **Present Ecological Status (PES)** of **Category C:***

Variable	***Weight***	***Score***
Hydrology	*25*	*47*
Hydrodynamics and mouth condition	*25*	*95*
Water quality	*25*	*72*
Physical habitat alteration	*25*	*82*
Habitat health score		***74***
Microalgae	*20*	*73*
Macrophytes	*20*	*60*
Invertebrates	*20*	*70*
Fish	*20*	*70*
Birds	*20*	*78*

Biotic health score	***70***
ESTUARY HEALTH SCORE Mean (Habitat health, Biological health)	***72***
PRESENT ECOLOGICAL STATUS (PES)	***C***

ECOLOGICAL IMPORTANCE

*The Duiwenhoks Estuary is rated as a **'Highly Important'** system. The National Biodiversity Assessment 2011 (NBA 2011) (Van Niekerk and Turpie, 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 listed species under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).*

RECOMMENDED ECOLOGICAL CATEGORY

*As a highly important estuary, the Duiwenhoks Estuary should at least be managed in a Category B. Considering the various flow and non-flow related factors that currently contribute to a Present Ecological Status (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. The Recommended Ecological Category (REC) for the Duiwenhoks Estuary, therefore, was set as a **Category B.***

RECOMMENDED ECOLOGICAL FLOW SCENARIO

***Present inflow (plus the ecological water requirement to meet the recommended ecological category for the upstream river** (equivalent to a mean annual runoff [MAR] of 73.01 million m^3) was selected as the recommended ecological flow scenario for the Duiwenhoks Estuary:*

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	19.1	23.2	23.5	12.4	9.9	16.5	22.2	11.5	6.5	9.0	26.3	23.1
99	15.2	17.9	13.1	9.5	8.8	11.9	21.2	11.4	6.0	8.3	22.1	13.6
90	9.3	6.6	2.5	1.8	2.7	4.1	5.4	5.7	4.3	4.6	6.0	6.3
80	4.8	4.8	1.6	0.5	0.7	2.4	3.2	3.0	3.5	3.5	5.0	5.5
70	3.8	3.0	0.6	0.4	0.4	1.7	2.5	2.4	2.4	2.8	4.0	3.9
60	2.6	1.9	0.5	0.3	0.3	1.1	1.6	1.9	2.0	2.4	3.3	3.3
50	2.3	1.4	0.4	0.2	0.2	0.5	1.0	1.3	1.6	2.1	2.8	2.8
40	1.8	0.7	0.4	0.2	0.1	0.2	0.6	1.1	1.2	1.6	2.4	2.5
30	1.5	0.5	0.3	0.1	0.1	0.1	0.6	0.8	1.1	1.4	2.1	1.9
20	1.1	0.5	0.2	0.1	0.0	0.1	0.4	0.5	0.8	1.1	1.5	1.7
10	0.8	0.4	0.2	0.0	0.0	0.0	0.2	0.3	0.5	0.9	1.1	1.3
1	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.7	0.5
0.1	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.3

This flow scenario improves the ecological health of the estuary from a PES of Category C to a Category B/C (just below a Category B) by returning some base flows to the estuary, and in doing so, addresses the key flow-related factor contributing modification in ecological health in this estuary. Considering the significant contribution of other, non-flow related factors, as well as the reversibility of some of these impacts, this flow scenario was considered appropriate. However, in order to improve from a Category B/C (achieved by this scenario only), additional interventions in terms of non-flow related impacts will be essential to improve the ecological health of the estuary to *the REC (Category B). Therefore, as a minimum, the following non-flow related interventions must also be undertaken:*

- *Peat land upstream of the estuary is rehabilitated to improve the regulation of river inflow to the estuary so as to maintain the river-estuary-interface (REI) zone for longer periods;*
- *At least 10% of degraded estuarine habitat in the riparian zones is rehabilitated, including the removal of alien vegetation;*
- *Control/reduce fishing effort through improved compliance monitoring of fishing activities;*
- *Implement an alien fish control programme; and*
- *Institute a control programme to reduce the number of Egyptian geese in the surrounding habitat.*

*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 possible to define and characterise the five abiotic states for this system with medium confidence, mainly because long-term river inflow records were available, as well as long-term river water quality (collected in close proximity to the head of the estuary at gauging station [H8H001]). Also, 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 estuarine monitoring programme which significantly enhanced confidence in this assessment. The only exception was data on sediment dynamics (which is not a key requirement for Intermediate level assessment), as well as inorganic nutrient data in the estuary (although long-term data on river inflow quality could be used to estimate conditions for various abiotic states). In terms of the biotic components, medium confidence in the macrophyte component is largely attributed to recent extensive research conducted by the Nelson Mandela Metropolitan University (NMMU) on estuarine systems in the region. 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. Sufficient bird data were also available through the Coordinated Waterbird Counts (CWAC) programme. Although there was medium to low confidence in the microalgae and invertebrate components (mainly as a result of limited data on the Duiwenhoks system itself), the specialists drew on experience from their collective research on other, related estuarine systems, not warranting a drop in the overall confidence of this study. However, the recommended monitoring programme should focus on these components in order to improve confidence for future reviews.*

ECOLOGICAL SPECIFICATIONS

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

Component	***EcoSpecs***	***Thresholds of Potential Concern***
Hydrology	*Maintain flow regime as per recommended ecological flow*	*River inflow:* ▪ *< 0.1 m^3/s for more than one month a year* ▪ *< 1.0 m^3/s for more than three months a year*

Component	EcoSpecs	Thresholds of Potential Concern
Hydrodynamics	*Maintain connectivity with marine environment*	*Average tidal amplitude < 10% of present observed data from the water level recorder in the estuary near the mouth during low flows (summer)*
Sediments	▪ *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 (8 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 8 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 5 km upstream from mouth > 20 more than three months of the year*
	System variables (pH, dissolved oxygen and turbidity) not to cause exceedance of TPCs for biota (see below)	*River inflow:* ▪ *6.0 < pH > 7.5* ▪ *Dissovled 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*
	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*

Component	EcoSpecs	Thresholds of Potential Concern
	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 SA Water Quality Guidelines for coastal marine waters (DWAF, 1995)* ▪ *Concentrations in sediment exceed target values as per Western Indian Ocean (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/ mℓ*
Macrophytes	▪ *Maintain the distribution of macrophyte habitats, particularly the salt marsh, reeds and sedges.* ▪ *Maintain the integrity of the salt marsh.* ▪ *Maintain the reed and sedge stands in the middle and upper reaches of the estuary.* ▪ *Rehabilitate 10% of the floodplain habitat by removing any agricultural berms and invasive plants.* ▪ *Maintain the integrity of the riparian zone*	▪ *Greater than 20 % change in the area covered by salt marsh and reeds and sedges (2013 survey)* ▪ *Increase in bare areas in the salt marsh because of a decrease in moisture and increase in salinity. Hypersaline sediment caused by evaporation, infrequent flooding or rainfall on this area.* ▪ *Loss and die-back of reeds fringing the estuary 5-10 km upstream from the mouth; salinity should not be greater than 20 for three months.* ▪ *Drying of floodplain habitat. Invasive plants (e.g. black wattle, prickly pear, Tamarix) cover > 5% of total floodplain area.* ▪ *Unvegetated, cleared areas along the banks caused by human disturbance.*
Invertebrates	▪ *Maintain presence of sand prawn Callichirus kraussi on sand banks in lower estuary* ▪ *Maintain the presence of REI species in the upper estuary for specific invertebrate communities associated with REI (zooplankton and benthos)*	▪ *Sand prawn density should not deviate from average baseline levels (as determined in the 8 visits undertaken in the first 2 years) by more than 40 % in each season* ▪ *Dominant species in the REI zone (zooplankton and benthos) should not deviate from average baseline levels (as determined during the 8 visits undertaken in the first 2 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 Condition. Numerically, assemblage should comprise:* ▪ *Ia estuarine residents (50-80%)* ▪ *Ib marine and estuarine breeders (10-20%)* ▪ *IIa obligate estuarine-dependent (10-20%)* ▪ *IIb estuarine associated species (5-10%),* ▪ *IIc marine opportunists (20-80%)* ▪ *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 specifically 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 < 50%* ▪ *IV indigenous fish < 1%* ▪ *V catadromous species < 1%* *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 groups. Tern roosts should be seen at the estuary on a regular basis. Apart from gulls, terns and regionally increasing species such as the Egyptian Goose, the estuary should generally support more than 50 bird species.*	▪ *Numbers of birds other than gulls, terns and regionally increasing species fall below 50 for three consecutive counts* ▪ *Numbers of waterbird species drop below ten for three consecutive counts*

BASELINE AND LONG-TERM MONITORING PROGRAMMES

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

Component	***Action***	***Temporal scale (frequency and when)***	***Spatial scale (No. stations)***
Sediment dynamics	*Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detail in the mouth including the 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 organic content (and ideally origin, i.e. microscopic observations).	*Once-off*	*Entire estuary*
Water quality	*Collect samples for pesticides/herbicide and metal determinations in river inflow.*	*Once-off*	*Near head of estuary (gauging station H8H001)*
	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 (13 stations, coinciding with microalgae and invert sampling sites)*
	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, High Performance Liquid Chromatography or 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 (No. stations)*
Invertebrates	▪ *Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh)* ▪ *Collect grab samples (5 replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each sample 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.* ▪ *Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton)*	*Quarterly, preferably over two years*	*Minimum of 3 sites along length of entire estuary.* *For hole counts – three sites on sandy substrata near the mouth (western shore).*

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 (No. stations)*
Hydrodynamics	*Record water levels*	*Continuous*	*Near the mouth of the estuary*
	Measure freshwater inflow into the estuary.	*Continuous*	*Near head of estuary (gauging station H8H001)*
	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 the mouth including the 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 organic content (and ideally origin, i.e. microscopic observations).	*Every three years*	*Entire estuary*

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (No. stations)
Water quality	*Collect data on 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 (gauging station H8H001)*
	Collect samples for pesticides/herbicide and metal determinations in river inflow	*Every 3 – 6 years if baseline shows contamination*	*Near head of estuary (gauging station H8H001)*
	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 (above16 km from mouth)*
	Record longitudinal in situ salinity and temperature pH, DO, turbidity profiles	*Seasonally*	*Entire estuary (13 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 (13 stations, coinciding with microalgae and invert sampling sites)*
	Measure pesticides/herbicides and metal accumulation in sediments (for metals investigate establishment of distribution models – see Watling and Newman, 2007)	*Every 3 – 6 years, if results show contamination*	*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, High Performance Liquid Chromatography of 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*

Component	***Monitoring action***	***Temporal scale (frequency and when)***	***Spatial scale (No. 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 reaches (5-10 km). 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 the 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 (transect sites as shown in Appendix C of this report)*
Invertebrates	▪ *Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh)* ▪ *Collect grab samples (5 replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each sample 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.* ▪ *Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton)*	*Every two years mid-summer*	*Minimum of three sites along length of entire estuary.* *For hole counts – three sites on sandy substrata near the mouth (western shore).*

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (No. stations)
Fish	▪ *Record species and abundance of fish, based on seine net and gill net sampling. Sampling with a small beam trawl for channel fish should also be considered.* ▪ *Seine net specifications: 30 m x 2 m, 15 mm bar mesh seine with a 5 mm bar mesh with a 5 mm bar mesh 5 m either side and including the cod-end* ▪ *Gill nets specifications: Set of gill nets each panel 30 m long by 2 m deep with mesh sizes of 44 mm, 48 mm, 51 mm, 54 mm, 75 mm, 100 mm and 145 mm* ▪ *Trawl specification: 2 m wide by 3 m long, 10 mm bar nylon mesh in the main net body and a 5 mm bar in the cod-end*	*Twice annually Spring/Summer and autumn/winter*	*Entire estuary (10 stations)* *Spacing of station Stations ~ length/10*
Birds	*Undertake counts of all non-passerine water birds, identified to species level (see Appendix F of this report)*	*Annual winter and summer surveys*	*Entire estuary (about six sections, must be standardised)*

The recommended interventions, as well as the 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 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 a mechanisms through which to facilitate the implementation these interventions

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ACRONYMS

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
Conf	Confidence
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
EHI	Estuarine Health Index
EIS	Estuarine Importance Score
ERC	Ecological Reserve Category
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
NRF	National Research Foundation
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 cc
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 DWAF (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), 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) 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 Duiwenhoks 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, un-impacted 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 unmodified natural disturbance regimes. There should be no human induced risks to the abiotic and biotic maintenance of the resource. The supply capacity of the resource will not be used.
76 – 90	B	**Largely natural with few modifications.** A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged. Only a small risk of modifying the natural abiotic template and exceeding the resource base should not be allowed. Although the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a very limited number of localities may be slightly higher than expected under natural conditions, the resilience and adaptability of biota must not be compromised. The impact of acute disturbances must be totally mitigated by the presence of sufficient refuge areas.
61 – 75	C	**Moderately modified.** A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the wellbeing and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least be partly 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 field work 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 Duiwenhoks Estuary study team:

Specialist	Affiliation	Area of responsibility
Dr S Taljaard	CSIR, Stellenbosch	Project co-ordinator/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;
- Nompumelelo Thwala (NMMU/National Research Foundation) – invertebrate component; and
- Corné Erasmus (DAFF) – 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.
- Abiotic data available for this study were mostly sufficient for an Intermediate level assessment, mainly because long-term river inflow records were available, as well as long-term river water quality data (collected in close proximity to the head of the estuary at gauging station [H8H001]). Also, 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 estuarine monitoring programme. The exception was for sediment data (which is not a critical requirement for Intermediate level assessments), as well as inorganic nutrient data (but which could be derived from long-term data collected in river inflow).
- In terms of the biotic components, data were sufficient for Intermediate level assessment for the macrophyte component, largely attributed to recent extensive research conducted by the NMMU on estuarine systems in the region.
- Extensive data on the fish component collected by DAFF as part of their long-term monitoring programmes was also available meeting the Intermediate assessment level requirements
- Bird data were available from CWAC counts.
- Data on microalgae and invertebrates were not completely sufficient at the Intermediate level, but specialists drew on experience from their collective research on other, related estuarine systems, not warranting a drop in overall confidence.
- 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 present ecological status) of the estuary. It also summarises the overall confidence of the study and the degree to which non-flow factors have contributed to the degradation of the system.
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 AND LAND-USE

The Duiwenhoks catchment receives rainfall throughout the year, with peaks in autumn and spring. The Duiwenhoks River is 54 km long (from source to the estuary mouth) with a catchment area of 1340 km^2 (Carter and Brownlie, 1990).

The dominant land-use types in the catchment are (**Figure 2.1**):

- About 46% (green) cultivated, commercial dryland;
- About 29% (light brown) scrubland and low fynbos;
- About 23% (beige) thicket, bush clumps and high fynbos;
- About 1% planted grassland.

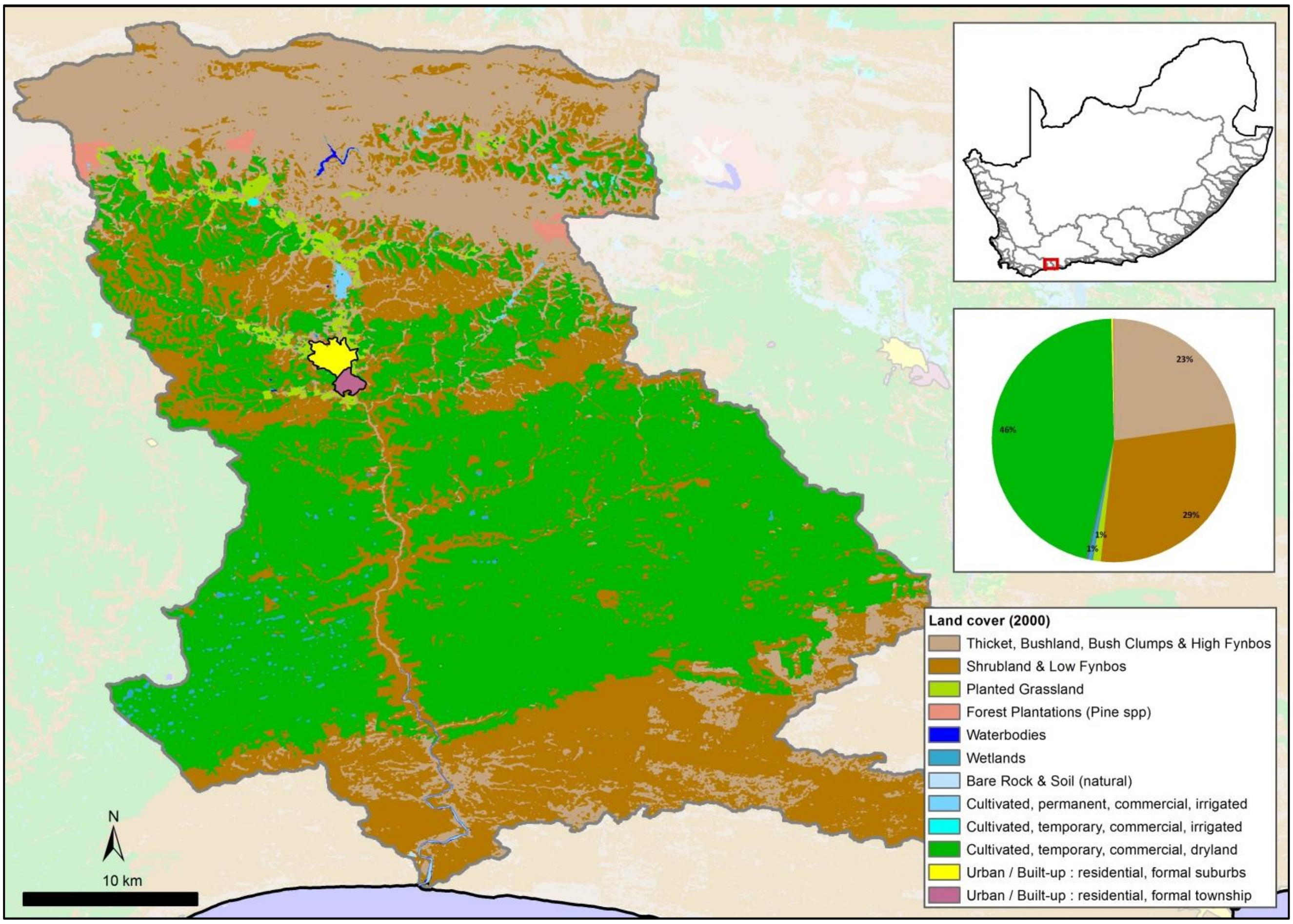


Figure 2.1 Catchment of the Duiwenhoks River, as well as dominant land-use distribution

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)	✓	Farm dams, run-of-river abstraction from Duiwenhoks Dam
Augmentation/Inter-basin transfer schemes		None
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	✓	Agricultural and pastoral run-off containing fertilisers, pesticides and herbicides. Significant agricultural activities in the catchment (nearly 50% cultivation) lead to increased land erosion and thus sediment yield to the estuary.
Municipal waste (including sewage disposal)/infrastructure problems	✓	Heidelberg wastewater treatment works (WWTW) (but upstream of water quality monitoring station [H8H001]
Bridge(s)		None in close proximity to estuary
Artificial breaching		None
Bank stabilisation and destabilisation	✓	A 10 m wide channel was blasted through the reefs on the seaward side of the mouth to allow for launching of fishing boats from the estuary. A short section of access road constructed along the eastern bank of the estuary in the lower reaches (Zone A).
Low-lying developments	✓	Limited agricultural cultivation within the estuary floodplain
Migration barrier in river	✓	The channel blasted through the reefs adjacent to the mouth will tend to keep the mouth opposite this channel open, thus reducing natural mouth location variations.
Recreational fishing	✓	Over fishing and bait collection can lead to a decline in the natural proliferation of the species
Commercial/Subsistence fishing (e.g. gillnet fishery)		No commercial fishing
Illegal fishing (Poaching)		Not known
Bait collection		Not known

Activity	Present	Description of impact
Grazing and trampling of salt marshes	✓	Limited, but result in loss and destruction of natural habitat
Recreational disturbance of waterbirds	✓	Limited, but extensive human activity along estuary can disturb birds

3 DELINEATION OF ESTUARY

3.1 GEOGRAPHICAL BOUNDARIES

The Duiwenhoks Estuary is a permanently open estuary located in the warm temperate region of the Western Cape between Riversdale and Heidelberg along the Cape south coast **(Figure 3.1)** (Carter and Brownlie, 1990). The geographical boundaries of the estuary are defined as follows:

Downstream boundary:	Estuary mouth 34°21'54.31"S 21° 0'0.51"E
Upstream boundary:	34°15'5.87"S 20°59'30.95"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

Figure 3.1 Geographical boundaries (Estuarine Functional Zone) of the Duiwenhoks Estuary

3.2 ZONING OF THE DUIWENHOKS ESTUARY

For the purposes of this study, the Duiwenhoks Estuary is sub-divided into four distinct zones, primarily based on bathymetry **(Figure 3.2).**

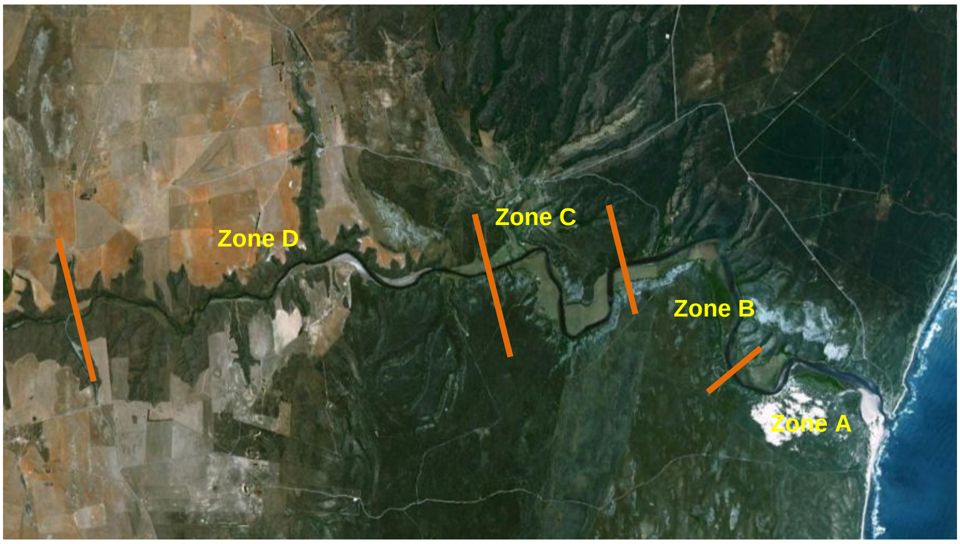


Figure 3.2 Zonation in the Duiwenhoks Estuary

Table 3.1**Table 3.1** lists key features of the various zones demarcated in the Duiwenhoks Estuary.

Table 3.1 Key features of the Duiwenhoks Estuary zonation

Parameter	Zone A	Zone B	Zone C	Zone D
Area (ha)	37.5	43.3	36.7	21.2
Depth (m)	-2.0 to -3.0	-3 to -7.0	-2 to -9.0	-1.0 to -5.0
Relative percentage	25	35	30	10

3.3 TYPICAL ABIOTIC STATES OF THE DUIWENHOKS ESTUARY

Based on current understanding, a number of characteristic 'abiotic states' were identified for the Duiwenhoks Estuary, associated with specific flow ranges, also taking into account the variability in characteristics such as tidal exchange, salinity distribution and water quality. The different abiotic states are listed in **Table 3.2**.

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

State	Flow range (m^3/s)	Description
State 1	< 0.1	Marine dominated, no REI
State 2	0.1 – 1	Full salinity gradient
State 3	1 – 3	Partial salinity gradient
State 4	3 –20	Limited salinity penetration
State 5	> 20	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, a number of techniques were used:

- Colour coding (indicated above) was used to visually highlight the occurrence of the various abiotic states between different scenarios.
- Summary tables of the occurrence of different flows at increments of 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 Duiwenhoks Estuary is provided in **Section 4**. For more detail on the underlying data and assumptions, refer to the Abiotic Specialist Report (**Appendix A**).

4 ECOLOGICAL BASELINE AND HEALTH ASSESSMENT

4.1 HYDROLOGY

4.1.1 Baseline description (including reference)

According to the hydrological data provided for this study, the present Mean Annual Runoff (MAR) into the Duiwenhoks Estuary is 72.91 million m^3. This is a decrease of 18% compared to the natural MAR of 89.29 million m^3. The flow distributions (expressed as mean monthly flows in m^3/s) for the Reference Condition and Present State, as derived from a 85-year simulated data set, are provided in **Tables 4.1** and **4.2** The full 85-year simulated monthly runoff data for the Reference Condition and Present State is provided in **Tables 4.3** and **4.4**. A graphic representation of the occurrence of the various abiotic states for the Reference Condition and Present State (refer to **Table 3.2**) is presented in **Figures 4.1** and **4.2.**

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

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	19.7	24.2	24.1	12.9	12.8	19.5	24.7	12.7	6.8	9.3	28.4	24.0
99	15.9	18.6	13.7	10.4	9.8	13.0	23.5	12.1	6.3	8.6	23.0	14.4
90	9.8	7.0	3.3	2.9	4.1	5.0	6.8	6.0	4.6	5.2	6.2	6.5
80	5.0	5.5	2.5	1.6	2.1	3.6	4.5	3.9	3.7	3.7	5.2	5.6
70	4.1	3.6	1.9	1.2	1.4	2.6	3.1	2.9	2.8	3.1	4.2	4.1
60	3.1	2.6	1.5	0.8	0.9	1.8	2.1	2.4	2.3	2.6	3.5	3.6
50	2.7	2.1	1.2	0.6	0.7	1.3	1.6	1.9	1.9	2.3	3.1	3.1
40	2.5	1.7	0.9	0.5	0.6	0.9	1.2	1.5	1.7	2.0	2.6	2.7
30	2.2	1.5	0.7	0.4	0.5	0.7	0.9	1.1	1.4	1.7	2.3	2.3
20	1.8	1.3	0.6	0.3	0.3	0.5	0.7	0.7	1.1	1.5	1.8	2.0
10	1.5	1.0	0.5	0.2	0.2	0.3	0.5	0.5	0.7	1.2	1.5	1.8
1	1.0	0.8	0.2	0.1	0.1	0.1	0.2	0.4	0.4	0.7	1.0	1.1
0.1	0.9	0.8	0.2	0.1	0.1	0.1	0.2	0.2	0.4	0.5	1.0	0.8

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

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	19.1	23.3	23.5	12.3	11.9	18.7	23.7	12.1	6.5	9.0	27.4	23.1
99	15.4	17.9	13.0	8.9	9.1	12.6	22.6	11.6	6.1	8.3	22.3	13.5
90	9.1	6.5	2.3	0.9	3.4	4.6	6.2	5.8	4.4	5.0	6.0	6.3
80	4.8	4.8	0.9	0.1	0.3	3.1	4.0	3.6	3.5	3.5	5.0	5.4
70	3.7	2.4	0.3	0.1	0.1	1.8	2.7	2.8	2.6	2.9	4.0	3.9
60	2.5	1.5	0.1	0.0	0.0	1.2	1.9	2.2	2.2	2.4	3.3	3.3
50	2.0	0.6	0.1	0.0	0.0	0.4	1.3	1.7	1.8	2.2	3.0	2.8
40	1.4	0.4	0.1	0.0	0.0	0.1	0.8	1.3	1.5	1.9	2.5	2.5
30	1.0	0.3	0.1	0.0	0.0	0.0	0.6	1.0	1.2	1.6	2.2	2.0
20	0.7	0.2	0.1	0.0	0.0	0.0	0.4	0.6	1.0	1.3	1.7	1.6
10	0.4	0.2	0.0	0.0	0.0	0.0	0.1	0.3	0.5	1.1	1.4	1.0
1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.7	0.3
0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.5	0.2

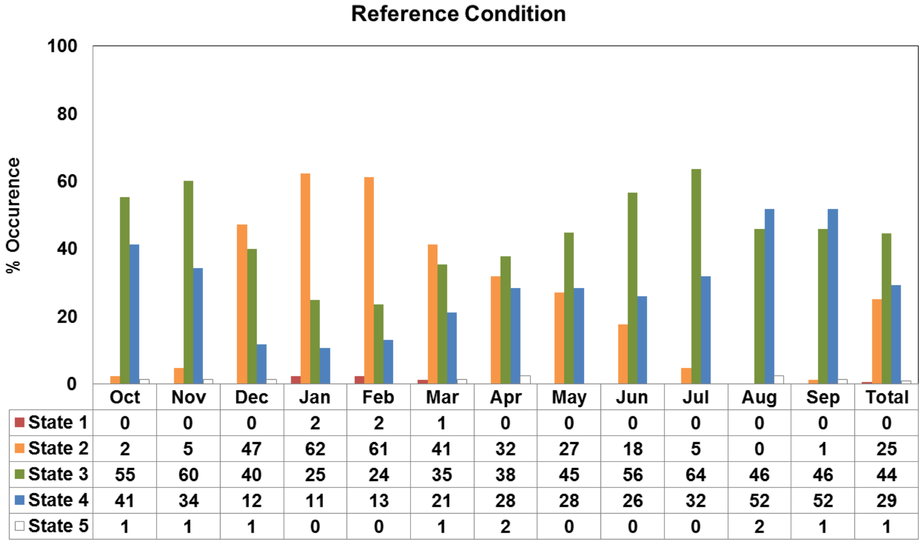
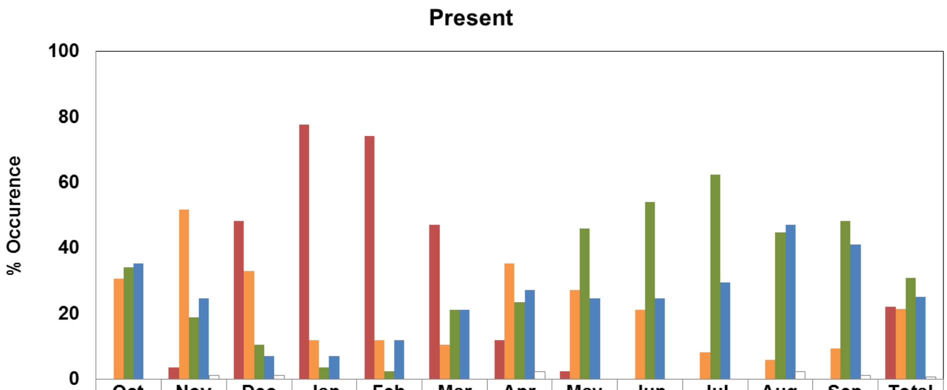


Figure 4.1 Occurrence of abiotic states under the Reference Condition (refer to Table 3.2 for colour coding of abiotic states)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	4	48	78	74	47	12	2	0	0	0	0	22
State 2	31	52	33	12	12	11	35	27	21	8	6	9	21
State 3	34	19	11	4	2	21	24	46	54	62	45	48	31
State 4	35	25	7	7	12	21	27	25	25	29	47	41	25
State 5	0	1	1	0	0	0	2	0	0	0	2	1	1

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

Table 4.3 Simulated monthly flows (in m^3/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	1.6	1.0	3.0	1.2	5.2	2.6	5.6	3.0	4.6	4.0	4.2	3.9
1921	2.1	0.9	1.3	4.7	2.1	4.3	2.2	1.1	1.3	2.2	2.2	1.7
1922	1.6	2.7	1.0	0.4	0.3	0.1	3.8	4.7	4.1	3.3	2.7	1.9
1923	2.3	2.8	1.0	0.3	0.5	0.4	0.4	0.5	1.1	1.2	4.8	3.1
1924	1.4	1.5	0.8	0.4	0.2	2.1	1.2	0.6	1.6	1.7	1.7	2.8
1925	2.7	1.8	0.7	0.4	0.3	0.5	1.0	0.8	0.9	2.1	2.6	2.6
1926	6.1	3.7	0.9	0.1	0.6	0.7	0.7	1.5	1.5	1.2	2.3	1.8
1927	1.0	1.4	0.7	0.3	0.2	5.5	2.4	0.7	0.9	1.0	1.7	2.9
1928	1.9	24.8	11.4	1.5	0.7	0.9	0.9	1.7	1.9	5.4	5.5	3.8
1929	2.4	1.0	0.9	0.5	13.1	5.8	1.5	2.7	2.4	1.9	2.3	2.2
1930	3.4	1.7	0.4	0.4	0.3	5.0	7.7	3.1	1.5	3.7	3.4	3.0
1931	6.5	2.9	7.9	3.0	2.8	1.5	0.5	0.5	1.0	1.5	1.6	25.1
1932	10.1	1.8	0.6	0.1	0.5	0.8	0.6	1.8	1.8	1.5	5.4	3.4
1933	1.2	5.4	2.0	2.0	2.1	4.2	1.8	0.5	0.4	2.8	3.4	2.7
1934	20.2	11.4	2.0	0.3	0.2	0.8	1.1	5.3	5.3	3.8	2.9	4.0
1935	2.8	3.3	1.5	0.4	0.6	0.4	0.2	1.6	1.2	1.8	1.8	3.4
1936	2.7	14.8	6.5	1.2	0.3	4.0	1.8	0.4	0.6	1.2	1.3	2.0
1937	1.3	1.3	2.5	1.4	0.4	1.8	2.1	1.3	1.2	1.7	1.8	2.1
1938	2.7	6.0	2.5	0.7	2.1	7.2	3.2	1.0	0.7	1.9	9.8	5.9
1939	2.5	1.5	0.5	0.7	9.2	4.0	2.2	1.4	1.3	1.3	1.1	1.7
1940	1.3	4.2	1.5	0.7	0.5	0.3	5.1	2.7	2.6	2.7	2.9	3.1
1941	4.4	2.5	1.0	1.4	0.7	0.9	1.0	1.6	1.7	1.6	1.6	1.8
1942	1.8	1.0	1.6	6.5	2.9	0.8	0.7	0.5	0.5	0.5	1.1	5.4
1943	3.0	6.4	2.6	0.4	0.1	1.9	1.2	3.2	2.8	2.8	3.5	5.9
1944	4.4	1.7	0.4	0.1	0.1	0.1	0.3	4.4	4.2	3.1	3.9	3.8
1945	5.9	2.7	0.5	0.2	0.3	8.3	3.4	0.6	0.6	1.1	1.5	1.5
1946	1.3	0.9	0.3	0.1	0.6	9.1	4.4	2.2	2.3	4.0	3.1	3.1
1947	2.6	2.1	0.8	1.6	0.8	2.9	4.0	1.8	1.2	1.4	1.3	1.8
1948	9.6	4.2	0.6	0.7	0.4	0.1	0.7	1.8	1.4	1.2	1.2	1.2
1949	0.9	8.8	3.1	0.3	0.1	0.1	0.9	1.0	0.8	1.6	2.2	2.2
1950	4.4	6.1	2.1	8.1	3.5	1.7	1.0	1.2	2.1	5.7	4.5	6.5
1951	3.6	1.1	0.2	0.7	0.7	0.3	0.6	0.6	0.7	1.0	2.1	8.6
1952	4.5	5.0	2.1	0.6	0.9	0.4	1.1	0.7	1.2	5.5	4.2	5.0
1953	5.3	3.7	1.1	0.2	0.1	0.8	4.4	8.0	4.7	3.4	10.9	6.4
1954	2.3	1.8	0.7	1.5	8.2	2.7	0.5	0.5	0.9	1.7	2.6	3.1
1955	2.3	1.5	0.5	0.3	0.3	2.0	1.4	6.0	3.7	2.6	3.0	2.8
1956	4.5	2.1	3.0	1.1	1.8	1.4	0.9	2.3	6.2	4.8	5.4	7.7
1957	4.7	1.7	0.4	0.1	0.1	3.0	2.1	12.8	6.9	2.7	5.3	3.8
1958	2.5	1.3	0.5	2.1	4.3	4.4	7.5	5.6	3.2	8.4	7.8	5.0
1959	7.3	3.2	0.6	0.6	0.5	1.8	1.5	2.1	2.8	2.9	2.6	2.7
1960	1.8	2.6	2.5	2.1	1.1	1.1	1.1	2.0	1.9	2.4	3.5	3.4
1961	3.9	2.1	0.5	0.6	1.4	2.8	2.5	1.5	1.5	1.6	21.9	9.7
1962	7.1	6.7	1.9	1.0	0.5	5.0	2.8	2.1	1.7	2.5	2.3	1.5
1963	1.9	1.5	2.6	1.9	1.1	2.1	1.2	0.7	4.5	3.0	3.9	6.4
1964	4.1	2.6	0.9	0.3	1.1	1.8	1.7	3.3	2.5	2.2	2.5	1.9
1965	10.1	8.4	2.9	1.4	0.5	0.6	0.9	3.8	2.7	1.8	7.5	6.5
1966	2.9	1.0	0.3	0.2	0.8	3.1	24.8	11.9	5.4	5.7	5.4	5.7
1967	3.1	2.4	0.8	0.1	0.1	0.6	1.1	2.4	5.4	3.4	5.5	4.2
1968	2.4	3.7	1.3	0.2	0.5	0.5	0.7	0.7	3.1	2.6	2.6	2.3
1969	1.5	0.8	0.2	0.5	1.4	0.6	0.2	0.2	0.5	0.9	3.5	2.3
1970	2.0	1.0	1.0	0.5	3.8	3.5	6.0	5.2	3.9	9.4	12.5	6.5
1971	2.7	3.9	1.5	0.4	1.9	1.7	2.2	2.5	2.3	2.5	5.2	5.6
1972	2.7	1.6	0.7	0.3	0.1	0.2	0.8	1.0	1.9	2.5	3.1	2.9
1973	1.8	1.4	1.2	2.6	4.7	4.3	1.6	6.1	3.6	1.8	5.1	4.2
1974	2.4	1.6	0.5	0.6	0.4	0.3	0.5	1.4	2.3	3.2	6.3	7.4
1975	3.7	2.6	1.2	0.5	2.1	2.7	2.2	2.6	6.2	5.6	4.3	3.6
1976	10.1	6.2	1.9	0.5	5.9	2.6	1.8	10.2	6.0	3.3	3.4	3.4
1977	2.7	3.3	1.6	0.5	0.2	0.3	1.6	1.1	1.8	2.3	3.3	3.0
1978	2.6	1.5	1.6	0.9	2.2	0.9	0.2	1.9	1.6	5.9	6.1	5.4
1979	4.1	1.8	1.3	1.2	0.7	0.3	0.6	0.5	1.6	1.5	1.8	2.4
1980	2.5	9.0	3.4	13.2	9.0	7.8	15.9	8.9	4.5	4.1	10.9	6.7
1981	2.6	1.3	2.5	1.0	0.7	1.3	23.3	8.6	2.7	3.8	4.2	8.2
1982	4.7	1.7	0.6	0.2	0.7	0.4	0.6	2.3	3.7	4.9	3.9	6.1
1983	3.8	3.5	1.4	0.4	0.6	1.8	1.1	0.7	0.8	1.7	1.6	1.1
1984	1.8	1.0	0.6	6.0	4.9	1.3	2.8	1.6	1.9	6.3	4.3	2.2
1985	10.0	6.5	3.0	0.9	0.6	0.6	0.7	0.5	0.5	0.8	29.0	12.3
1986	4.9	2.6	0.7	0.2	0.2	0.3	7.0	3.2	1.8	2.0	3.4	4.5
1987	2.5	0.9	0.9	0.4	0.2	1.0	4.6	2.4	2.2	2.4	3.0	2.7
1988	2.1	1.1	1.5	1.2	0.7	1.3	6.6	3.0	1.5	1.7	2.1	1.9
1989	10.4	6.8	1.5	0.2	0.8	0.6	8.4	4.4	4.4	3.4	2.4	2.0
1990	1.7	1.1	0.9	1.3	1.8	0.7	0.3	0.5	0.7	1.0	1.0	0.8
1991	15.1	5.8	1.0	0.6	0.9	1.0	0.8	0.9	2.6	3.7	3.4	2.8
1992	10.4	7.2	1.7	0.4	0.3	0.2	12.6	6.1	2.5	2.5	2.7	3.9
1993	2.4	1.1	3.8	1.6	1.3	1.5	1.7	1.4	1.6	2.1	5.5	4.1
1994	3.1	1.4	6.4	2.5	1.7	2.5	3.6	4.2	2.9	2.2	2.2	2.5
1995	1.8	9.5	11.0	3.3	0.5	1.2	0.7	0.4	0.4	1.3	1.2	1.4
1996	6.1	17.4	5.6	0.4	0.5	1.8	1.6	2.9	2.9	4.7	5.2	3.6
1997	1.9	1.2	0.5	0.6	0.7	5.1	4.9	3.0	2.2	2.2	2.3	1.9
1998	1.2	2.2	2.3	1.6	2.9	2.3	1.8	1.4	1.2	1.6	1.7	2.0
1999	3.0	1.4	0.5	3.2	1.6	11.6	4.6	2.4	1.9	1.4	1.3	1.3
2000	1.4	2.5	1.6	0.6	0.2	0.7	4.2	2.2	1.1	1.0	3.5	2.8
2001	1.7	2.0	0.8	0.8	0.8	0.3	0.7	1.5	1.7	2.2	3.7	4.1
2002	2.1	1.0	0.9	0.8	0.5	20.3	8.1	6.2	4.1	2.7	3.3	2.5
2003	3.7	1.7	0.4	0.7	1.3	0.8	4.2	2.4	1.7	2.3	2.1	2.0
2004	12.5	5.0	25.3	9.9	1.0	1.3	5.2	3.7	3.6	2.8	2.4	2.0

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	0.5	0.2	2.3	0.1	4.8	1.6	5.4	2.8	4.4	3.8	4.0	3.8
1921	0.7	0.2	0.1	4.3	0.1	4.1	2.1	1.0	1.2	2.1	2.1	1.2
1922	0.9	2.2	0.0	0.0	0.0	0.0	3.2	4.5	3.9	3.1	2.6	0.9
1923	2.1	2.1	0.1	0.0	0.0	0.0	0.0	0.3	0.8	1.1	4.7	2.5
1924	0.3	0.2	0.0	0.0	0.0	1.6	0.9	0.5	1.5	1.6	1.6	2.7
1925	2.4	0.2	0.0	0.0	0.0	0.0	0.6	0.5	0.8	1.9	2.5	2.5
1926	5.8	2.3	0.1	0.0	0.0	0.0	0.4	1.2	1.3	1.1	2.2	0.8
1927	0.2	0.3	0.0	0.0	0.0	4.9	1.7	0.6	0.9	0.9	1.7	2.8
1928	0.4	23.9	10.8	0.2	0.0	0.0	0.6	1.5	1.8	5.3	5.3	3.5
1929	1.3	0.2	0.1	0.0	12.2	5.3	1.3	2.6	2.3	1.8	2.2	2.1
1930	3.3	0.2	0.0	0.0	0.0	4.3	7.4	2.9	1.4	3.5	3.2	2.9
1931	6.2	0.8	7.6	0.4	1.5	0.1	0.0	0.3	1.0	1.4	1.5	24.2
1932	9.0	0.5	0.1	0.0	0.0	0.0	0.0	1.2	1.6	1.4	5.3	2.2
1933	0.4	5.1	0.2	0.7	0.1	4.0	0.8	0.2	0.3	2.7	3.3	2.5
1934	19.5	10.9	0.3	0.0	0.0	0.0	0.6	4.9	5.2	3.7	2.8	3.8
1935	2.0	2.9	0.1	0.0	0.0	0.0	0.0	1.1	1.1	1.6	1.7	3.3
1936	2.1	14.4	5.0	0.1	0.0	3.6	0.8	0.1	0.5	1.2	1.1	1.9
1937	0.2	0.1	1.5	0.0	0.0	1.5	1.9	1.1	1.1	1.6	1.7	1.9
1938	2.5	5.8	0.3	0.0	0.6	6.9	3.0	0.8	0.6	1.8	9.6	5.7
1939	1.2	0.3	0.0	0.0	8.5	3.1	2.0	1.3	1.2	1.2	0.5	1.6
1940	0.2	3.9	0.1	0.0	0.0	0.0	4.4	2.6	2.5	2.6	2.7	2.9
1941	4.2	0.6	0.1	0.0	0.0	0.0	0.6	1.5	1.6	1.4	1.4	1.7
1942	1.0	0.1	0.2	6.2	0.3	0.1	0.5	0.3	0.4	0.4	1.0	5.2
1943	1.4	6.1	0.4	0.0	0.0	1.4	0.9	3.1	2.6	2.7	3.3	5.7
1944	4.2	0.4	0.1	0.0	0.0	0.0	0.1	3.5	4.0	3.0	3.7	3.6
1945	5.8	0.5	0.1	0.0	0.0	7.3	2.5	0.2	0.5	1.1	1.4	1.0
1946	0.3	0.1	0.0	0.0	0.0	8.1	4.2	2.1	2.2	3.8	2.5	3.0
1947	2.1	0.9	0.0	0.1	0.0	2.6	3.8	1.7	1.1	1.3	0.9	1.7
1948	9.1	1.8	0.1	0.0	0.0	0.0	0.4	1.3	1.1	1.0	1.1	0.9
1949	0.1	8.3	0.6	0.0	0.0	0.0	0.5	0.6	0.5	1.5	2.1	2.0
1950	4.2	5.8	0.3	7.6	0.6	1.2	0.3	1.1	2.0	5.6	4.3	6.3
1951	1.8	0.3	0.0	0.0	0.0	0.0	0.3	0.3	0.4	0.9	2.0	8.4
1952	3.4	4.7	0.3	0.0	0.0	0.0	0.6	0.4	1.1	5.2	4.0	4.9
1953	5.1	2.8	0.1	0.0	0.0	0.0	3.6	7.6	4.5	3.3	10.5	5.6
1954	1.0	0.4	0.1	0.0	7.8	0.3	0.1	0.4	0.9	1.6	2.4	2.9
1955	1.4	0.2	0.1	0.0	0.0	1.3	1.2	5.7	3.5	2.4	2.9	2.5
1956	4.3	0.3	2.4	0.0	0.1	0.1	0.6	2.1	5.8	4.6	5.2	7.5
1957	4.1	0.5	0.1	0.0	0.0	2.2	1.9	12.1	6.5	2.4	5.0	2.9
1958	2.0	0.3	0.1	1.0	3.6	4.2	7.3	5.4	3.1	8.1	7.6	4.7
1959	7.1	0.9	0.1	0.0	0.0	1.1	1.3	1.9	2.6	2.8	2.4	2.5
1960	0.4	2.1	1.3	0.6	0.0	0.1	1.0	1.9	1.8	2.3	3.3	3.3
1961	3.7	0.3	0.1	0.0	0.0	2.2	2.3	1.3	1.4	1.5	21.2	8.1
1962	6.8	6.4	0.2	0.0	0.0	4.4	2.7	2.0	1.7	2.4	2.2	0.4
1963	1.7	0.5	1.8	0.3	0.0	1.8	0.8	0.6	4.3	2.9	3.8	6.2
1964	3.6	1.3	0.1	0.0	0.0	1.0	1.5	3.1	2.3	2.1	2.4	1.0
1965	9.9	8.2	0.9	0.1	0.0	0.0	0.5	3.7	2.6	1.7	7.3	6.3
1966	0.9	0.2	0.0	0.0	0.0	2.5	23.8	11.6	5.3	5.5	5.2	5.5
1967	1.5	1.4	0.1	0.0	0.0	0.0	0.7	2.1	5.2	3.2	5.4	4.0
1968	1.2	3.4	0.1	0.0	0.0	0.0	0.4	0.4	2.9	2.4	2.5	2.0
1969	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	3.1	1.2
1970	1.8	0.1	0.0	0.0	3.1	3.2	5.7	5.1	3.8	9.1	11.8	5.4
1971	1.5	3.7	0.1	0.0	0.3	0.8	2.0	2.3	2.2	2.4	5.0	5.5
1972	0.8	0.2	0.0	0.0	0.0	0.0	0.5	0.6	1.8	2.3	3.0	2.7
1973	0.4	0.1	0.1	1.8	4.3	4.1	0.6	6.0	3.5	1.6	5.0	4.1
1974	1.1	0.3	0.1	0.0	0.0	0.0	0.2	0.9	2.2	3.0	6.1	7.2
1975	1.8	1.6	0.1	0.0	0.5	2.5	2.1	2.5	6.0	5.4	4.1	3.5
1976	9.8	5.5	0.3	0.1	5.4	1.3	1.7	10.0	5.8	3.2	3.3	3.3
1977	2.0	2.8	0.1	0.0	0.0	0.0	1.1	1.0	1.6	2.0	3.2	2.8
1978	2.3	0.2	0.1	0.0	0.5	0.1	0.0	1.7	1.5	5.7	5.9	5.2
1979	3.8	0.4	0.1	0.1	0.0	0.0	0.3	0.3	1.5	1.3	1.6	2.2
1980	2.3	8.7	0.9	12.7	8.4	7.7	15.4	8.7	4.4	4.0	10.7	6.3
1981	1.1	0.4	1.7	0.0	0.0	0.4	22.4	7.8	2.6	3.7	4.1	8.0
1982	4.0	0.4	0.1	0.0	0.0	0.0	0.3	1.7	3.4	4.7	3.7	5.9
1983	2.8	3.0	0.1	0.0	0.0	1.4	0.8	0.6	0.7	1.5	1.3	0.3
1984	1.6	0.1	0.1	5.5	3.8	0.1	2.6	1.5	1.8	6.1	4.1	1.1
1985	9.7	6.1	1.8	0.1	0.0	0.0	0.4	0.3	0.4	0.7	28.0	11.5
1986	4.7	0.6	0.1	0.0	0.0	0.0	6.1	3.0	1.7	1.8	3.3	4.3
1987	0.7	0.2	0.0	0.0	0.0	0.0	4.2	2.2	2.1	2.3	2.9	2.5
1988	1.2	0.2	0.1	0.1	0.0	0.4	6.3	2.8	1.4	1.6	2.0	1.2
1989	10.0	6.5	0.2	0.0	0.0	0.0	7.6	4.2	4.2	3.1	2.3	1.6
1990	0.8	0.1	0.1	0.0	0.1	0.1	0.0	0.3	0.5	0.9	0.7	0.1
1991	14.6	2.4	0.1	0.0	0.0	0.0	0.5	0.8	2.4	3.5	3.2	2.6
1992	10.1	6.6	0.4	0.1	0.0	0.0	11.8	5.9	2.4	2.4	2.6	3.7
1993	0.8	0.2	3.6	0.1	0.0	0.7	1.6	1.3	1.5	1.9	5.3	3.9
1994	2.9	0.3	6.2	0.3	0.1	2.4	3.5	4.1	2.7	2.1	2.1	2.3
1995	0.5	9.1	10.6	0.6	0.0	0.5	0.1	0.2	0.3	1.2	0.9	1.3
1996	5.9	16.8	2.3	0.1	0.0	1.4	1.5	2.8	2.8	4.5	5.0	2.9
1997	0.7	0.3	0.1	0.0	0.0	4.7	4.7	2.9	2.1	2.1	2.2	1.3
1998	0.4	1.6	1.2	0.1	1.8	1.8	1.7	1.3	1.2	1.5	1.6	1.9
1999	2.9	0.2	0.0	2.9	0.1	11.3	3.9	2.4	1.8	1.3	1.2	0.8
2000	0.7	1.9	0.2	0.0	0.0	0.0	4.0	2.0	1.0	0.9	3.4	2.7
2001	0.5	1.1	0.1	0.0	0.0	0.0	0.6	1.4	1.6	2.0	3.6	3.9
2002	0.6	0.2	0.1	0.0	0.0	19.4	7.8	6.0	4.0	2.6	3.2	1.7
2003	3.5	0.3	0.1	0.0	0.1	0.1	4.0	2.2	1.6	2.2	2.0	1.8
2004	12.0	1.5	24.7	8.2	0.2	0.8	5.0	3.6	3.4	2.5	2.3	1.4

4.1.2 Hydrological health

Under the Reference Condition, river inflow did not decrease below 0.2 m^3/s (< 1% of the time). As a result the REI zone always occurred in the upper reaches of the estuary. Under the Present State flows of less than 0.2 m^3/s occur for about 20% of the time (**Table 4.5**).

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

Percentile	Monthly flow (m^3/s)		% Remaining
	Natural	Present	
30%	1.2	0.3	26.2
20%	0.8	0.1	9.5
10%	0.5	0.0	4.9
% Similarity in low flows			**13.5**

No large dams are present in the Duiwenhoks catchment. The largest dam, the Duiwenhoks Dam, has a capacity of about 6 million m^3, thus about 7% of natural MAR. Therefore any changes in the flood regime are mostly related to smaller farm dams, land-use change and associated catchment permeability. No flood analysis was done for this study, but an evaluation of the highest simulated monthly flow data shows that flood events occur relatively untransformed from Reference Condition to Present State, i.e. between 2 and 7% change from Reference.

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

Date	Monthly volume (x10^6 m^3/month)		% Remaining
	Natural	Present	
Aug-86	77.8	75.0	96
Dec-04	67.7	66.2	98
Sep-32	65.0	62.6	96
Nov-28	64.4	61.9	96
Apr-67	64.3	61.8	96
Apr-82	60.3	58.0	96
Aug-62	58.6	56.9	97
Mar-03	54.3	52.0	96
Oct-34	54.0	52.2	97
Nov-96	45.1	43.5	96
Apr-81	41.2	40.0	97
Oct-91	40.4	39.1	97
Nov-36	38.3	37.3	97
Jan-81	35.3	34.0	96

Date	Monthly volume ($x10^6$ m^3/month)		% Remaining
	Natural	Present	
May-58	34.3	32.4	94
Oct-04	33.5	32.2	96
Aug-71	33.5	31.6	94
Apr-93	32.7	30.5	93
May-67	32.0	30.9	97
% Similarity in floods			**96**

4.1.3 Hydrological health

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

Table 4.7 Present hydrological health scores

Variable	Summary of change	Weight	Score	Conf*
a. % Similarity in period of low flows	Significant increase in the low flow period and reduction in flow rate.	60	14	H
b. % Similarity in mean annual frequency of floods	The simulated monthly flow data indicate that under Reference Condition floods were about 4-7% higher than at present, depending on the size class.	40	96	M
Hydrology score: weighted mean (a,b)			**47**	**M**

* Conf = Confidence

4.2 PHYSICAL HABITAT

4.2.1 Baseline description

No large dams; the Duiwenhoks Dam has a capacity of about 6 million m^3, thus about 7% of natural MAR. Farm dams, run-of-river abstraction and Duiwenhoks Dam reduce MAR by 18%. Evaluation of the 95%ile, 99%ile and 99.9%ile shows that flood events occur relatively untransformed from Reference Condition to Present State, i.e. between 5 and 7% change from Reference. The ten largest floods over the preceding 85 years have reduced floods by an average of about 4%. Thus slightly reduced mobility and flushing of sediments in estuary, and increased penetration of marine sediments.

4.2.2 Physical habitat health

Table 4.8 provides the present physical habitat health scores of the Duiwenhoks 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 effects

Variable		Summary of change	Weight	Score	Conf
a	% similarity in supratidal area	1. No large dams; the Duiwenhoks Dam has a capacity of about 6 million m^3, thus about 7% of natural MAR. Farm dams, run-of-river abstraction and Duiwenhoks Dam reduce MAR by 18%. Evaluation of the 95 %ile, 99 %ile and 99.9 %ile show that flood events occur relatively untransformed from Reference Condition to Present State, i.e. between 5 and 7% change from Reference. The 10 largest floods over the preceding 85 years have reduced floods by an average of about 4%. Thus slightly reduced mobility and flushing of sediments in estuary, and increased penetration of marine sediments 2. The dams will preferentially trap a larger proportion of the coarser sediments, but have low sediment trapping efficiency and capacity 3. Significant agricultural activities in the catchment (nearly 50% of cultivation) lead to increased land erosion and thus sediment yield to the estuary 4. Short section of access road constructed along the eastern bank of the estuary in the lower reaches (Zone A). Limited agricultural cultivation within the floodplain 5. Limited grazing and trampling of salt marshes	25	82	L
b	% similarity in area of intertidal sand- and mudflats	1. Points 1 to 3 of above 2. A 10 m wide channel was blasted through the reefs on the seaward side of the mouth to allow for launching of fishing boats from the estuary. This channel is likely to slightly reduce the asymmetry of the tidal flow regime in the estuary by slightly increasing the velocity of the ebb-tide outflow, thus affecting sediment transport 3. The channel blasted through the reefs adjacent to the mouth will tend to keep the mouth opposite this channel open, thus reducing natural mouth location variations	25	82	L
c	% similarity in area of subtidal/ submerged sand and mud substrates	Same as for intertidal area	25	82	L

Variable		Summary of change	Weight	Score	Conf
d	% similarity in bathymetry/ estuary water volume	1. Volume probably very similar to reference, but slightly more marine water with associated marine sediments ingressing 2. Also slightly higher sediment load in the water column due to ~50% catchment cultivation	25	95	L
Physical habitat score: min (a to d)				**82**	**L**
% of impact due to non-flow factors				60	
Adjusted score				93	L

4.3 HYDRODYNAMICS

4.3.1 Baseline description

A summary of the hydrodynamic characteristics in the Duiwenhoks 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	State 2	State 3	State 4	State 5
Flow range (m^3/s)	< 0.1	0.1-0.5	0.5-3.0	3.0-20.0	> 20.0
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	2.0-0.5	2.0-0.5	2.0-0.5	2.0-0.5	2.0-0.5
Dominant circulation process	Tide	Tide	Tide	River and tide	River
Salinity structure	Well mixed	Well mixed	Stratification	Stratification	Stratification, Zone A

4.3.2 Hydrodynamic health

Table 4.10 provides the present hydrodynamic and mouth condition health scores for the Duiwenhoks Estuary.

Table 4.10 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	Conf
a.	% similarity in abiotic states and mouth condition	It is a permanently open estuary – no change	50	100	H
b.	% similarity in the water column stratification	No resolution			
c	% similarity in water retention time	No data			
d.	% similarity in water level (using tidal amplitude and symmetry	The tidal amplitude in the lower reaches has increased by 0.5 m due to mouth manipulations. As a result of the stabilisation of the mouth position, the estuary inlet will not meander over the berm and cause reduction in tidal amplitude and increase tidal symmetry on the low tide	50	90	L
Hydrodynamic score: weighted mean (a to d)				**95**	**M**
% of impact due to non-flow factors				10	
Adjusted score				96	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 is presented in **Table 4.11**. This summary was derived from available information on the estuary as presented in the Water Quality Data Summary Report (**Appendix A**).

Salinity characteristics in the system are largely influenced by river inflow ranges. While other characteristics in other water quality parameters are also influenced by changes in river inflow (based on the differences in some water quality characteristics of river water and seawater), shifts in water quality from the Reference Condition to the Present State were largely as a result of increased agricultural activities in the catchment, as well as along the banks of the estuary (e.g. Vermaaklikheid). In particular, these activities affected inorganic nutrient characteristics and turbidity characteristics in the estuary, especially under states representing higher river inflow ranges.

A summary of the average water quality condition in each of the zones, under Reference and Present State is presented in **Table 4.12**.

Table 4.11 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	State 2	State 3	State 4	State 5
Salinity	Reference: 35, 25, 20, 10 Present/Future: 35, 30, 25, 20	Reference: 30, 20, 10, 5 Present/Future: 35, 25, 15, 10	Reference: 25, 15, 5, 0 Present/Future: 30, 20, 10, 5	Reference: 15, 5, 0, 0 Present/Future: 20, 10, 5, 0	Reference: 5, 0, 0, 0 Present/Future: 5, 0, 0, 0
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 (usually lower in fresher waters compared with more saline waters				
DO (mgl/ℓ)	6, 6, 4, 4	6, 6, 6, 6	6, 6, 6, 6	6, 6, 6, 6	6, 6, 6, 6
Turbidity (NTU)	Reference: 10, 10, 10, 10 Present/Future: 10, 10, 30, 20	Reference: 10, 10, 10, 10 Present/Future: 10, 10, 30, 20	Reference: 10, 10, 10, 10 Present/Future: 10, 10, 30, 20	Reference: 10, 10, 10, 10 Present/Future: 10, 10, 30, 20	Reference: 30, 30, 30, 30 Present/Future: 80, 80, 80, 80
Dissolved inorganic nitrogen (DIN) (µg/ℓ)	Reference: 50, 50, 50, 50 Present/Future: 50, 50, 100, 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	State 2	State 3	State 4	State 5
Dissolved inorganic phosphate (DIP) (µg/ℓ)	Reference: 10, 10, 10, 10 Present/Future: 10, 10, 20, 20	Reference: 10, 10, 10, 10 Present/Future: 10, 10, 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, 500, 700, 800	100, 500, 700, 900	200, 700, 900, 1000	500, 800, 1000, 1500	1000, 1500, 1500, 1500

Table 4.12 Summary of average changes in water quality parameters from Reference Condition to Present State within each of the zones in the Duiwenhoks Estuary (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 mouth manipulations and the loss of the peat wetlands in the catchments that would have moderated baseflows	A	25	29
		B	15	22
		C	6	16
		D	2	9
DIN (µg/ℓ)	⇧ due to agricultural activity in the catchment and along the banks (Vermaaklikheid opposite Zone C)	A	50	64
		B	50	90
		C	50	179
		D	50	179
DIP (µg/ℓ)	⇧ due to agricultural activity in the catchment and along the banks (Vermaaklikheid opposite Zone C)	A	10	13
		B	10	16
		C	10	18
		D	10	20
Turbidity (NTU)	⇧ due to agricultural activity in the catchment and along the banks (Vermaaklikheid opposite Zone C)	A	10	10
		B	10	10
		C	10	30
		D	10	20
DO (mg/ℓ)	No marked changes	A	6	6
		B	6	6
		C	6	6
		D	6	6
Toxic substances	⇧ due to agricultural activities in catchment potentially introducing herbicides and pesticides	80% similar to Reference		

4.4.2 Water quality health

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

- Define **zones** along the length of the estuary **(Z)** (i.e. Zones A, B, C and D)
- **Volume fraction** of each zone **(V)** (i.e. 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) = [({∑% occurrence of states in C_1}*C_1)+ ({∑% occurrence of states in C_2}*C_2)+({∑% occurrence of states in C_n}*C_n)] divided by 100
- Calculate similarity between Average Conc's Reference and Present/Future Scenario for each Zone using the Czekanowski's similarity index: ∑(min(ref,pres) (∑ref + ∑pres)/2)

For the present day health scores, a weighted average of the similarity scores of changes in the different zones as presented in **Table 4.13**.

Table 4.13 Present water quality 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	Weight	Score	Conf
1	**Similarity in salinity**	⇧ due to increase in low flow states and loss of a more constricted mouth under States 1 to 3, but the estuary was always a marine dominated system	40	73	M
2	**General water quality in estuary**				
a	DIN/DIP concentrations	⇧ due to agricultural activity in the catchment and along the banks (Vermaaklikheid opposite Zone C)		71	M
b	Turbidity	⇧ due to agricultural activity in the catchment and along the banks (Vermaaklikheid opposite Zone C)		81	M
c	Dissolved oxygen	No marked change		99	M
d	Toxic substances	⇧ agricultural inputs		80	L
General water quality in estuary (min (a to d)			60	71	M
Water quality health score weighted mean (1,2)				**72**	**M**
% of impact non-flow related				60	
Adjusted score				89	M

4.5 MICROALGAE

4.5.1 Overview

4.5.1.1 Main grouping and baseline description

The biomass of phytoplankton in the Duiwenhoks Estuary has consistently been lower than 3.0 µg/ℓ (very low), which is typical of oligotrophic aquatic ecosystems and similar to the biomass expected for the Reference Condition. Carter and Brownlie (1990) reported winter (flow ~3.0 m^3/s) and summer (flow > 10 m^3/s) chlorophyll *a* measurements that ranged from 0.1 to 1.6 µg/ℓ, all measurements by Harrison (unpublished data) in winter 1994 were below detectable limits, and measurements by Lemley (2015; flow >10 m^3/s) were below detectable limits at all sites (excluding 5.5 m depth at site 3 where 2.96 µg/ℓ was measured).

Contradictory to biomass, Lemley (2015) measured vertically averaged phytoplankton cell densities exceeding 20 000 cells/ml at 8.5 km (40 575 cells/ml), 11.8 km (44 930 cells/ml) and 16.2 km (32 797 cells/ml). This is typical of eutrophic aquatic ecosystems and suggests that the cells were heterotrophic and did not contain significant amounts of photosynthetic pigments. The phytoplankton were dominated (> 98%) by the chlorophyte *Sphaerocystis* sp. The two sites nearest to the mouth (0.2 and 3.8 km) contained very few phytoplankton cells (< 200 cells ml-1) and were dominated (72% and 62% respectively) by flagellates.

Benthic chlorophyll *a* ranged from 0 to 17.0 mg/m^2. The chlorophyll *a* values associated with the middle reaches (3.8, 8.5 and 11.8 km) were significantly higher ($F = 22.42$; $P < 0.001$; df = 4) than those observed near the mouth (0.2 km) and head of the estuary (16.2 km). Additionally, the intertidal zone of the estuary had higher chlorophyll *a* ($F = 7.46$; $P < 0.05$; df = 1) than the subtidal zone. Median intertidal benthic chlorophyll *a* for the entire estuary was 11.7 mg/m^2, which is regarded as medium when compared to other permanently open estuaries (Snow, 2008).

The Shannon Diversity Index and Evenness scores for the benthic diatoms in the Duiwenhoks Estuary were 2.26 and 0.74 respectively (Lemley, 2015). These values are relatively high when compared to other estuaries within the Gouritz WMA; ranges of 1.5 – 3.1 (diversity) and 0.55 – 0.84 (evenness).

4.5.1.2 Description of factors influencing microalgae

Table 4.14 summarises the key responses of estuarine microalgae to changes in abiotic and other biotic components, while **Table 4.15** translates these into expected responses within each of the abiotic states (see **Table 3.2**).

Table 4.14 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 and P)	↑	↑	↓	↑	-
Herbicides	↓	↓	↓	↓	↓
Tidal flushing	↓	↓	↓	↓	↓
Turbidity	↓	↓	↓	↓	↓
Dissolved oxygen	-	-	-	-	↑

VARIABLE	GROUPING			
	Diatoms (Epipelic)	Diatoms (Episammic)	Cyanobacteria	Euglenophytes
Fines (silt and clay)	↑	↓	↑	↑
Organic loading	-	-	↑	↑
Nutrients (N and P)	↑	↑	↑	↑

Table 4.15 Summary of microalgal biotic responses to different abiotic states

Abiotic state	Response
State 1: Marine dominated, no REI	Marine dominated, negligible nutrient and suspended solid input, decrease in phytoplankton and intertidal microalgal biomass and increase in subtidal benthic microalgal biomass. Strong tidal flushing will limit microalgal biomass in the lower reaches (phytoplankton and benthic microalgae).
State 2: Full salinity gradient	Low river flow and well mixed. Slightly elevated phytoplankton biomass in upper reaches, and elevated benthic microalgae (subtidal and intertidal) in middle reaches responding to nutrients in the water column and settling of floccules (nutrients, fine sediments and organic materials). Tidal flushing will limit microalgal biomass in the lower reaches (phytoplankton and benthic microalgae).
State 3: Partial salinity gradient	Medium river flow introducing nutrients to middle and upper estuary with stratification. This is likely to support an elevated phytoplankton biomass with dinoflagellates, and elevated benthic microalgae in middle reaches. Herbicides and suspended solids may limit primary production.
State 4: Limited salinity penetration	Medium/High river flow introducing nutrients to middle and upper estuary with stratification. Residence time is low and very little suspended material likely to settle from the water column limiting microalgal growth (medium-low phytoplankton and low benthic microalgal median biomass – December 2013). Herbicides and suspended solids may limit primary production further.
State 5: Freshwater dominated	High river flow introducing nutrients to entire estuary. Residence time is too low to support microalgal growth (low phytoplankton and benthic microalgal median biomass throughout). Herbicides and suspended solids may limit primary production further.

4.5.1.3 Reference Condition

Expected changes in microalgae from the Reference Condition to the Present State is summarised in **Table 4.16**.

Table 4.16 Summary of relative changes in microalgae from Reference Condition to Present State

Key drivers	Change
Slightly higher flow – particularly States 2 and 3	Slightly higher phytoplankton and subtidal microalgal biomass
Suspended solids – lower loads from agriculture	Slightly higher phytoplankton and subtidal microalgal biomass
Nutrients - oligotrophic	Microalgal growth limited by N and P (P in particular)

4.5.2 Microalgae health

The microalgae health scores for the Present State are presented in **Table 4.17**.

Table 4.17 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	Conf
Phytoplankton			
a. Species richness	Elevated presence of dinoflagellates, cyanobacteria and chlorophytes in response to lower river flow and elevated nutrients; more even spread of phytoplankton groups (118% change of evenness).	100	M
b. Abundance	Suspended solids cause 15% ↓. P causes 68% ↑; overall 127% ↑	73	M
c. Community composition	Slight changes in phytoplankton groups with flow and nutrients but no overall loss/gain of groups; fewer diatoms at head of estuary at high flows, more cyanobacteria at low flows, and more dinoflagellates when estuary is stratified.	82	M
Benthic microalgae			
a. Species richness	The present species richness score of benthic diatoms (Dec 2013) was 2.26 and evenness 0.74. Any changes would be related to sensitivity to nutrients and shift to finer sediments (episammics to epipelics). Mouth sandier and middle reaches (B and C) finer sediments; overall 5% finer. Assume slight change related to loss of sensitive species (5%) and some episammic species in middle reaches (10%).	85	L

Variable	Summary of change	Score	Conf
b. Abundance	Suspended solid causes 15% ↓. P causes 68% ↑; overall 127% ↑	73	M
c. Community composition	Reference Condition would have had slightly lower nutrients (oligotrophic) and finer sediments (muddier) supporting fewer cyanobacteria species, and more episammic species than epipelics. However, the estuary still has sandy and muddy areas so it is unlikely to have lost any species. Assume slight (5%) change related to loss of nutrient-sensitive species.	95	L
Microalgae health score: min (a to c)		**73**	**M**
% of impact non-flow related (nutrients, suspended solids, sediments and canalised mouth)		80	M
Adjusted score		95	M

4.6 MACROPHYTES

4.6.1 Overview

4.6.1.1 Main groupings and baseline description

The Duiwenhoks Estuary has intact salt marshes occurring along some steep gradients with distinct zonation. Species composition showed a direct relationship with changes in elevation and depth to groundwater (**Table 4.18**). Along both Transect 1 and 2 three zones could be identified based on the elevation and dominant species within the lower, upper and supratidal zones. Distribution of lower intertidal salt marsh species (e.g. *C. coronopifolia*) was limited to areas in which the depth to groundwater was low (< 14 cm), while supratidal species such as *S. pillansii* occurred in areas where the depth to groundwater was higher (> 30 cm). Although the submerged macrophyte *Zostera capensis* has been reported previously it was not found in December 2013 probably because of recent flooding as well as the high tide at the time of sampling. Reeds and sedges occurred in the upper reaches of the estuary. Thick stands started in Zone C approximately 10 km upstream from the mouth. Alien invasive plants such as *Opuntia ficus-indica, Tamarix ramosissima, Acacia* spp. and *Eucalyptus* occurred sporadically along the banks.

Table 4.18 Summary of estuarine habitat area in the Duiwenhoks Estuary

Estuary habitat	Defining features, typical dominant species	Area (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	40
Sand and mud banks	Intertidal zone consists of sand/mud banks. This area provides habitat for microphytobenthos.	29
Macroalgae	The estuary was sampled after a flood in December 2013 and thus no macroalgae were observed.	-

Estuary habitat	Defining features, typical dominant species	Area (ha)
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 e.g. *Zostera capensis* which has been reported in the Duiwenhoks Estuary.	-
Salt marsh	Salt marsh extends from the lower to upper reaches of the estuary and had distinct zones along the elevation gradient. Dominant species occurring from the lower intertidal to upper intertidal were *Spartina maritima, Triglochin bulbosa, Cotula coronopifolia Sarcocornial tegetaria* and *Bassia diffusa*. The dominant supratidal species was *Sarcocornia pillansii*.	26
Reeds and sedges	The following species have been recorded, and belong to the families Cyperaceae, Juncaceae and Poaceae:, *Schoenoplectus scirpoides, Juncus kraussii* and *Phragmites australis.*	3
Floodplain	This is a mostly grassy area which occurs within the 5 m contour line. It also includes dune vegetation at the mouth and riparian vegetation along the middle and upper reaches of the estuary.	6
Riparian vegetation		27
Dune vegetation		21
Total area		**152**

A summary of changes in area covered by different habitats in the Duiwenhoks Estuary in 2014 compared with 1942 is presented in **Table 4.19**.

Table 4.19 Comparison of estuarine habitat area between 1942 and 2004

Habitat	Area (ha) in 1942	Area (ha) in 2009	% Change
Floodplain agriculture	34	6	-84.5
Riparian vegetation (degraded)		27	100
Dune vegetation	36	21	-42.7
Intertidal and supratidal salt marsh	22	26	15.5
Submerged macrophytes	-	-	-
Reeds and sedges	-	-	-
Mud and sandbanks	16	29	44.8
Open water surface area	41	40	-2.4
Total functional estuarine area	149	149	

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 (see **Table 3.2**).

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

Variable	Response
Mouth condition	Open mouth conditions create intertidal habitat. There are large areas of salt marsh on both banks of the estuary.
Retention times of water masses	This is a permanently open estuary with strong tidal flows and little retention of water. Macroalgal blooms are not expected.
Flow velocities (e.g. tidal velocities or river inflow velocities)	High flow velocity would remove macroalgae and also prevent the extensive growth of submerged macrophytes. Often macroalgal growth in the upper reaches during low flow. *Zostera capensis* is usually found throughout shallow areas from 0.5 -7 km from the mouth.
Total volume and/or estimated volume of different salinity ranges	Water volume would influence available habitat for macoalgae; however they are not considered extensive in the Duiwenhoks Estuary.
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. Hypersaline sediments caused by evaporation and infrequent flooding will result in dry bare patches in the supratidal areas. High groundwater level and freshwater flooding maintains suitable moisture conditions for plant growth in the marsh.
Salinity	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. Zone C and D have become more saline.
Turbidity	Increases sediment solids within the water column results in a reduction in the photic zone and will limit submerged macrophyte establishment and distribution. There has been an increase in sediment input from agricultural activities in the catchment.
Dissolved oxygen	The estuary is well oxygenated, except for deep waters in the upper estuary where there is leaf decay and lower oxygen levels.
Nutrients	Increased nutrient inputs would increase macrophyte growth particularly in areas of freshwater seepage (i.e. reeds and sedges). Inappropriate agricultural practises (excess fertilisers and ploughing) may exacerbate nutrient input into the system particularly through agricultural return flow.
Sediment characteristics (including sedimentation)	There has been some marine sedimentation which would encourage salt marsh and seagrass (*Zostera capensis*) growth.
Other biotic components	Grazing and trampling has occurred in certain sections of the salt marsh.

Table 4.21 Summary of macrophyte responses to different abiotic states

Abiotic state	Response
State 1: Marine dominated	Favourable conditions for salt marsh growth.
State 2: Full salinity gradient	
State 3: Partial salinity gradient	
State 4: Limited salinity penetration	This condition would favour the growth of reeds and sedges
State 5: Freshwater dominated	High flow conditions would remove macroalgae and submerged macrophytes.

4.6.1.3 Reference Condition

Past aerial photographs indicate changes that have occurred in the lower reaches of the Duiwenhoks Estuary over time (i.e. 1942, 1976, 1979 and 1981). There has been an expansion of vegetation on the large dunefields on the western shore of the estuary. However the large sandbank on the western shore in the lower reaches of the system has hardly changed. The mouth of this estuary remains permanently open due to the rocky outcrop on the eastern shore as observed in the aerial photographs. Overall, the area of sand and mudbanks, salt marsh and riparian vegetation increased from 1942 to 2009. Salt marsh would increase in cover in response to marine sedimentation and an increase in sediment stability. Riparian vegetation in the middle and upper reaches replaced what was previously agricultural lands. This now consists of riparian thicket vegetation and dune fynbos. The present degraded floodplain was agricultural lands.

Previous surveys of the Duiwenhoks Estuary report the presence of *Zostera capensis* in the lower reaches of the estuary on the sand and tidal flats. In 2013 no *Z. capensis* was visible possibly due to flooding prior to sampling. The increase in salt marsh along the lower and middle reaches of the Duiwenhoks Estuary could be related to reduced freshwater inflow and more stable sediment conditions which would allow the plants to grow and expand. Reed and sedge habitats could not be identified in past and present images. However a decrease in reeds and sedges in response to an increase in salinity in Zone C and D is expected. Some of the loss would be compensated for by the increase in growth in response to increased nutrient input in areas where salinity was favourable. Long-term changes in salt marsh would occur in response to an increase in salinity. If there is reduced flooding and freshwater input over consequent years, it could lead to a decrease in the depth to groundwater and hence cause a threat to the growth and survival of supratidal species such as *S. pilllansii*. An increase in salinity and change in the salinity gradient in the estuary would lead to a loss of biodiversity. Salt marsh species that prefer brackish conditions such as *Cotula coronopifolia* would be lost. Other impacts on salt marshes include grazing and trampling by cattle and sheep.

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

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

Key drivers	Change
⇩ river flow	⇧ Macrophytes due to ⇧ sediment stability
⇧ nutrients	⇧ Reed and sedge growth in upper reaches
⇧ salinity	⇩ Reed and sedge growth in upper reaches and salt marsh productivity
⇧ sedimentation	⇧ Marine sediment ⇧ salt marsh in lower reaches
Agriculture	⇩ Floodplain habitat
TOTAL CHANGE	⇧ 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 condition (**Table 4.21**). 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, which is now abandoned land and in a degraded state, removed 34 ha of estuarine habitat; there is currently 6 ha of agriculture within the 5 m contour line. Salt marsh has increased in cover from 22 to 26 ha and reeds and sedges have decreased in cover from 5.5 ha to 3 ha. Invasives would not have been present in the Reference Condition but now cover approximately 2 ha. In total macrophytes covered 61.5 ha but now cover 37 ha with a 59% similarity compared to Reference Conditions. Approximately 10% of the changes are due to flow related impacts and 30% due to non-flow related impacts.

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) (**Table 4.23**).

Table 4.23 Area covered by macrophyte habitats and calculation of the similarity in community composition for the Duiwenhoks Estuary

Macrophyte habitat	Reference area cover (ha)	Present area cover (ha)	Minimum
Salt marsh	22	26	22
Reeds and sedges	5.5	3	3
Invasive plants	0	2	0
Floodplain	34	6	6
% similarity	**Sum min / (sum ref + present) /2**	**31/([61.5+37)/2] = 63%**	

The macrophyte health scores for the Present State are presented in **Table 4.24**.

Table 4.24 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	Conf
a. Species richness	Invasive species potentially displaced some species. Species have been lost because of the less dynamic environment and disturbance of the floodplain.	85	M
b. Abundance	There has been a small increase in salt marsh from 22 to 26 ha, There has been a loss of 34 ha of floodplain habitat due to agriculture and disturbance. There has been a decrease in reeds and sedges due to increase in salinity in Zone C and D.	60	H
c. Community composition	Invasive species have altered the community composition. Floodplain habitat has been degraded.	63	M
Macrophyte health score: min (a to c)		**60**	**H/M**
% of impact non-flow related		30	
Adjusted score		72	H/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 intertidal macrozoobenthos) are identified for the purposes of reserve determination studies in estuaries. Of the four groups, the least information is available on zooplankton in the Duiwenhoks Estuary. With respect to the other three groups, only limited non-quantitative information is documented.

With respect to the zooplankton, broad conclusions can be drawn from Grindley's 1969 survey (published in Carter and Brownlie,1990), together with information gathered during the field survey conducted in December 2013 by the team. The copepod *Pseudodiaptomus hessei* was the only specific species on Grindley's list of 12 taxa; a species present in most estuaries around South Africa. Most of the remaining taxa were broadly identified e.g. lamellibranch and polychaete larvae. Zooplanktonic taxa present in the hyperbenthic samples collected in December 2013 also suggested that zooplankton is probably not well represented in the estuary, in terms of species richness, abundance and biomass. Support for this conclusion is further provided by the very low biomass estimate given by Grindley (10 mg DW/m^{-3} and described as 'low' by the author), as well as the oligotrophic nature of the estuary (refer to **Appendix B** of this report).

Although current thinking suggests that zooplankton is generally not well represented in the estuary, the potential influence of the flood shortly before the December 2013 survey cannot be discounted. At the time of the field trip (December 2013), all estuarine invertebrate populations would have been in a state of recovery following the flood. Although some recovery of populations had occurred, they were probably still on a trajectory of change and had not attained full recovery status. This is further supported by the salinity distribution along the estuary at the time of the survey (Salinity < 5 along most of the estuary).

Seventeen hyperbenthic taxa were recorded in the estuary during the December 2013 survey. Although typical estuarine species were present, population abundance levels were 1-2 orders of magnitude lower compared to many other temperate tidal estuaries. Only three of the 17 species exceeded 10 ind.m^{-3} (the mysid shrimp *Gastrosaccus brevifissura*, the amphipod *Grandidierella lignorum* and carid larvae). Of these three species, *Grandidierella lignorum* was the most abundant at 30 ind.m^{-3}. Carid larvae were probably those representing *Palaemon capensis*, as ovigerous adults were recorded in benthic samples. The presence of carids in samples suggests that this group attains significant biomass in the estuary as preferred habitat is associated with reeds and sedges. *Palaemon capensis* would provide an important food source for higher trophic levels.

The benthic community in the Duiwenhoks Estuary was represented by 12 species and must be considered low by comparison to other temperate estuaries. Abundance of individual species (ind.m^{-2}) was also low and may partly reflect a response to the oligohaline conditions recorded at most stations in the estuary at the time of sampling (populations in a state of recovery). Species present were typical of estuaries along the south coast, with the community dominated by two species of amphipods (*Corophium triaenonyx* and *Grandidierella lignorum*), Amphipods represented about 50% of the total number of individuals sampled in the benthos. The polychaete worm *Ceratonereis keiskama* was the only other relatively common species.

Along the narrow intertidal zone, very high densities of *Upogebia africana* were present along the banks of the middle estuary.

4.7.1.2 Description of factors influencing invertebrates

Table 4.25 summarises response of invertebrates to specific abiotic drivers in the estuary.

Table 4.25 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.
Turbidity	Increasing turbidity reduces predation pressure from visual-hunters. Other species such as the mysid *Rhopalophthalmus terranatalis* prefer deeper waters for the same reason.
Salinity	A full salinity gradient will increase species richness and enable zonation patterns to develop within the zooplankton community.
Floods	Floods will flush populations from the estuary – recovery in some cases will be relatively slow.
Tidal currents	Strong tidal currents flush populations from the estuary, particularly near the mouth.

Variable	Response of the zooplankton and hyperbenthos
REI Zone	The development of the REI zone will increase biomass, particularly among the euryhaline copepods.
Phytoplankton biomass	An increase in phytoplankton biomass would lead to an increase in density of invertebrate populations – food.
Variable	**Benthic response (subtidal and intertidal)**
Mouth state	Some species such as the mudprawn *Upogebia africana* require a marine phase of development – the population could become extinct in the estuary should the mouth close for extended periods.
Salinity	A full salinity gradient will increase species richness and enable zonation patterns to develop within the benthic community.
Floods	Some populations, particularly in unconsolidated sediments will be flushed from the estuary.
Estuary becomes shallower	Likely increase in the intertidal area leading to new habitat becoming available to intertidal organisms.
Organic content of the sediment	High organic content of the sediment favours species associated with the surface layers.
Changes in sediment characteristics	Benthic species distribution will change in accordance with the shift of habitat preference.
Development of subtidal macrophyte beds	Biomass and species composition of benthic populations particularly will increase significantly, both in response to new habitat becoming available and the production of detritus as food.

The abiotic state of the estuary impacts invertebrates in different ways and is summarised in **Table 4.26**.

Table 4.26 Summary of invertebrate responses to different abiotic states

Abiotic state	Response
State 1: Marine dominated	Because of increasing salinity along the estuary and loss of the REI, biomass of zooplankton will decrease, particularly in the upper estuary. Community composition will also change, with species favouring higher salinity values extending up-estuary. Oligohaline species will also disappear. Because of the development of submerged macrophytes under higher salinity conditions, the benthic community will change in composition as the habitat changes. Benthic species that favour submerged plants as a colonizing medium will begin to dominate the community and biomass will increase (e.g. isopods and bivalve molluscs). By contrast, benthic species favouring unvegetated sediments will decrease (e.g. amphipods). These 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 the benthic habitat iinfluenced by low salinity conditions. Other species are likely to begin dominating the estuarine benthic community, the change impacting higher trophic levels.
State 2: Full salinity gradient	A full salinity gradient will maximise for species richness and biomass – the latter also supported by an increase in primary production.
States 3-5 (State 3: Partial salinity gradient; State 4: Limited salinity penetration; State 5: Freshwater dominated)	As salinity penetration decreases progressively from States 3 to 5, there will be a concomitant decrease in species richness and biomass. Populations will shift downstream in accordance with salinity tolerance levels. Stenohaline species will mostly disappear from the estuary as salinity values decrease. 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.

4.7.1.3 Reference Condition

Expected changes between the Reference Condition and Present State with reference to the invertebrate community are shown in **Table 4.27**.

Table 4.27 Summary of relative changes in invertebrates from Reference Condition to Present State

Key drivers	Change
Increased marine dominance upstream	Eighteen percent reduction in MAR has resulted in marine dominance increasing up-estuary, particularly in summer. Under the Reference condition, the REI was nearly always present and this allowed for a REI zooplankton community to become permanently established. The salinity gradient under Reference therefore allowed for zonation of communities, as well as higher species richness and biomass associated with the REI (includes response to increased phytoplankton biomass). Increasing marine dominance has also lead 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. By contrast, the intertidal area inhabited by the mudprawn *Upogebia africana* has increased, leading to higher biomass of this species. Low salinity estuarine zones favoured by the benthic amphipods *Corophium triaenonyx* and *Grandidierella lignorum* has 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.

4.7.2 Invertebrate health

The invertebrate health scores for the Present State are presented in **Table 4.28**.

Table 4.28 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	Conf
Zooplankton			
a. Species richness	Species richness has not changed, based on a time frame of 1 year	100	H
b. Abundance	Abundance has decreased, particularly during summer when the REI zone disappears. Although relative, high abundance is linked to the euryhaline community that decreases with the absence of a REI zone	80	M
c. Community composition	There has been a shift towards less variability in community composition within the annual cycle. Under the Present State, the REI disappears and species more tolerant of high salinity conditions colonise the estuary for longer periods.	75	M
Hyperbenthos			
a. Species richness	Species richness has not changed, based on a time frame of 1 year.	100	H

Variable	Summary of change	Score	Conf
b. Abundance	Abundance has decreased, particularly during summer when the REI zone disappears. Key species in the hyperbenthos are predatory and a reduction in food availability (copepods) will lead to a reduction in abundance levels.	80	M
c. Community composition	There has been a shift towards less variability in community composition within the annual cycle. Under the Present State, the REI disappears and species more tolerant of high salinity conditions colonise the estuary for longer periods.	75	M
Benthos			
a. Species richness	Species richness has not changed, based on a time frame of 1 year.	100	H
b. Abundance	Subtidal abundance has decreased, particularly during summer when the REI zone disappears. Key species in the low salinity zone are the amphipods that favour low salinity conditions. Intertidal invertebrates have increased in abundance as exposed intertidal banks extend upstream. This is in response to shrinking margins of the reeds and sedges in an upstream direction.	70	M
c. Community composition	There has been a shift towards reduced variability within zooplantonic and hyperbenthic populations, but increased variability in benthic communities. As salinity zones shift intra-annually, benthic populations change in any given area.	70	M
Invertebrate score: min (a to c)		**70**	**M**
% of impact non-flow related		1%	
Adjusted score		70	M

4.8 FISH

4.8.1 Overview

4.8.1.1 Main grouping and baseline description

Forty-seven species of fish from 26 families have been recorded in the Duiwenhoks Estuary which is less than in the much larger Breede Estuary but comparable to that of the adjacent Goukou and Gouritz estuaries of equivalent size. Over a ten-year sampling period (twice annually 2003-2014), 37 species were caught in the Duiwenhoks compared to 60, 38 and 37 in the Breede, Goukou and Gouritz respectively. Similarly, Harrison (1999) sampled all four systems once off yielding 16-17 species in each of the Duiwenhoks, Goukou and Gouritz Estuaries and only marginally more (22) in the Breede system.

Four estuarine residents that breed only in estuaries e.g. estuarine round herring *Gilchristella aestuaria* and the checked goby *Redigobius dewaali* occur in the Duiwenhoks whereas those that breed in estuaries and the sea e.g. Cape silverside *Atherina breviceps* and Knysna sandgoby *Psammogobius knysnaensis* are represented by seven species. Obligate estuary-dependent fish such as dusky kob *Argyrosomus japonicus* and spotted grunter *Pomadasys commersonnii* comprise seven species whereas there are nine opportunistic partially estuary-dependent fish such as the harder *Liza richardsonii* and Cape sole *Heteromycterus capensis*. Marine vagrants such as silver kob *Argyrosomus inodorus* and sand steenbras *Lithognathus mormyrus* comprise six species. Of the seven freshwater fish in the estuary only three, Burchell's redfin *Pseudobarbus burchelli*, Cape galaxias *Galaxias zebratus* and Cape kurper *Sandelia capensis* are Cape endemics and have not been introduced whereas the others e.g. *Oreochromis mossambicus* are alien or translocated to the system. Catadromous fish are represented by three Anguillid eels whereas freshwater mullet *Myxus capensis* may be regarded as a facultative catadromous species. Altogether, including estuarine residents and catadromous fish, 15 (32%) of the Duiwenhoks fish assemblage are completely dependent on estuaries to complete their life-cycle, 16 (34%) are partially estuary-dependent and the remainder evenly split between estuary-independent marine and freshwater species.

Numerically*, G. aestuaria* (38%), *L. richardsonii* (21%) and *Caffrogobius* spp. (15%) dominate the Duiwenhoks fish assemblage providing 74% of sampling catches. *Myxus capensis* (7%), blackhand sole *Solea turbynei* (4%), groovy mullet *Liza dumerili* (4%), *P. knysnaensis* (3%) and Cape stumpnose *Rhabdosargus holubi* (2%) are also important. The remaining species all contributed < 1% to the sampling catch. However, these species e.g. dusky kob *Argyrosomus japonicus*, spotted grunter *Pomadasys commersonnii* and leervis *Lichia amia* are large and species of natural lower abundance. *G. aestuaria*, Caffrogobius spp., *S. bleekeri* and *P. knysnaensis* occurred in over 50% and *L. richardsonii* and *R. holubi* in 35% of sample hauls. The larger species e.g. *A. japonicus* and *L. lithognathus* occurred in 2-15% of hauls. Superficially, the occurrence of these larger and exploited species reflected their overexploited status.

Along-stream distribution was largely a reflection of salinity preferences and the estuary-dependence category to which the fish belonged. Most (90%) of the facultative catadromous *Myxus capensis* occurred in the < 10 salinity REI zone whereas most (66%) of the opportunistic marine *L. richardsonii* occurred in the salinity > 30 mouth region. Most individuals (60-100%) of species that have a preference for the < 10 salinity REI zone e.g. *G.aestuaria* and moony *Monodactylus falciformis* were in Zone D, even when salinities were high throughout the system. Numerically overall, 48% of the fish assemblage was in the REI zone compared to 26% in both the middle (salinity 10-30) and lower (salinity > 30) reaches respectively. This all suggests an estuary with a greater freshwater influence historically compared to the marine dominated system of the present day. Species richness was highest (20 species) in both the lower (salinity > 30, Zone A) and upper (salinity < 10, Zone D) reaches and lowest (15 species) in both the middle reaches (salinity 10-30, Zones B and C). On the whole, fish in Zones B and C were ubiquitous in the estuary but augmented by marine vagrants and freshwater species in the lower and upper reaches respectively.

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 4.29**, while a summary of fish responses to various abiotic states is presented in **Table 4.30**.

Table 4.29 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	Duiwenhoks permanently open. Ia species confined to middle to upper reaches, Ib mostly in the lower 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 refuge for both adult and juvenile fish.				Freshwater species can get washed into the estuary by strong river currents.
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 is driven by flood events.				High flow velocities may flush some individuals downstream into the estuary

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
Salinities	Resident and estuary associated marine species are very tolerant of salinities in the range 1-35.				Tend to stay as close to 35 as possible. Stressed less than 20 PSU.	Highly variable and most prefer salinity < 10 PSU.
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.
Dissolved oxygen	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.				Little tolerance to low oxygen levels/hypoxia.	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.*
Subtidal, intertidal and supratidal habitat	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.					
Other abiotic components (temperature)	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 are more in temporarily open/closed than permanently open estuaries.					
Sediment characteristics (including sedimentation)	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.					

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
Phytoplankton biomass	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 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.					
Benthic micro-algae biomass	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.					
Zooplankton biomass	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.					
Aquatic macrophyte cover	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.					
Benthic invertebrate biomass	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).					

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 4.30 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. One advantage is that the turbid 10-30 salinity area expands increasing available habitat for juvenile *A. japonicus, P. commersonnii* and other important exploited species. Although in low numbers, more marine species will occur in the lower and middle reaches of the estuary. 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.

Abiotic state	Response
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.
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 4.31 summarised the key drivers and changes in fish assemblages from Reference Condition to Present State.

Table 4.31 Summary of relative changes in fish assemblages from Reference Condition to Present State

Key drivers	Change
⇧⇩Floods	Flood peaks sharper, more intense as not attenuated due to loss of wetlands upstream. Floods still occur during peak recruitment periods in Autumn and Spring but intensity may flush some new recruits out of the system. Slightly shorter duration of high flow events may shorten recruitment window.
⇧Salinities	Salinity has increased upstream due to lower flows. The estuary was always a more marine dominated system but the species composition of the fish assemblage (e.g. *Myxus capensis*) suggests that the REI zone was persistent throughout much of the estuary for extended periods. So, REI species are now confined to the headwaters much of the time whereas estuary dependent marine species e.g. *L. lithognathus* are abundant throughout the estuary. Surprisingly, most of the opportunistic *Liza richardsonii* population are still in the lower reaches though this may be related to the availability of benthic diatoms there. Higher salinity translates into shallower burrows and increased prey availability for invertebrate feeders.
⇧Sediment Δ 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	An increase in turbidity from upstream fine sediment has been offset by reduced flow and the intrusion of more clear marine water into the lower and middle reaches. 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 decline as a result of decrease in zooplankton biomass.
⇩Benthic invertebrate biomass	A decrease in invertebrate biomass should disadvantage 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 4.32.**

Table 4.32 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	Conf
a. Species richness	Four alien / translocated freshwater species in the estuary. Range expansion of checked goby *Redigobius dewaali* into the southwestern Cape including the Duiwenhoks Estuary. The latter may be climate-change related.	89	M
b. Abundance	An increase in abundance (~30%) and diversity of small bodied species and juvenile fish but a drastic (nationwide) decline (60%-95 %) in abundance of large exploited species.	70	M
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.	70	M
Fish health score: min (a to c)		**70**	**M**
% of impact non-flow related		60	
Adjusted score		88	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 4.33 Major bird groups found in the Duiwenhoks 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 and ibises. 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.

Bird groups	Defining features, typical/dominant species
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 Egyptian Geese which 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, Hottentot 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.
Piscivorous 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 Osprey.

4.9.1.2 Description of factors influencing birds

Avifaunal communities in estuaries are likely to be affected primarily by the availability 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 Condition and future scenarios have to be made on the basis of expert understanding of the relationships between elements of estuarine bird communities and their main drivers (**Table 4.34**).

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 (**Table 3.34**). 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.

Table 4.34 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various bird groupings

Factor	Cormorants and wading piscivores	Kingfishers and fish-eagle	Waterfowl	Waders, gulls and terns
Mouth condition	Indirectly, through influence on water level and fish		Indirectly, through influence on macrophytes	Mouth closures has negative effect on preferred sandbanks in lower estuary
Salinities			Certain species of waterfowl prefer lower salinities	
Turbidity	Negatively affects visibility for foraging	Negatively affects visibility for foraging		
Intertidal area				Waders rely mostly on intertidal areas for feeding.
Sediment characteristics (including sedimentation)				Most waders prefer med to fine sand; a few prefer coarse sand
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			

A summary of responses to various abiotic states is summarised in **Table 4.35**.

Table 4.35 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, in conjunction with any evidence from existing data. Key flow-related changes and their expected effect are summarised in **Table 4.36**.

Table 4.36 Summary of relative changes in birds from Reference Condition to Present state

Key drivers	Change
⇧Salinities	Salinity has increased upstream due to lower flows. This will have reduced suitable habitat for waterfowl.
⇧Sediment Δ characteristics	Increased marine sediments may have led to reduced wader numbers near the mouth, and increased fine sediments could also have reduced suitability of some intertidal areas for foraging. Also reduced intertidal habitat in lower estuary.
⇧⇩Turbidity	Reduced turbidity in the mouth area and increased turbidity in the upper areas of the estuary. While reduced visibility can be a disadvantage for perching and aerial piscivores, the changes are unlikely to have been large enough to have a significant effect.
⇩Salt marsh	Reduced area of saltmarsh in lower estuary and mouth region will have led to reduction in productivity and numbers of larger wader species
⇩Emergent veg/reed marsh	Decreased habitat and food source for skulking rallids and waterfowl. Relates to the increased salinity.
⇧Benthic invertebrate biomass	Increase in intertidal area inhabited by the mudprawn *Upogebia africana* would have led to more favourable conditions for waders.

Key drivers	Change
⇧Fish biomass	Increase in biomass of smaller fish species and juvenile fish will have favoured piscivorous bird species.

Scrutiny of the detailed bird count data suggests a general decline in bird numbers from the 1980s and especially from 2000 to 2013, apart from a few species, such as Grey Heron, Egyptian Goose and Pied Kingfisher.

Egyptian Goose, which would not have occurred on the system in its Reference Condition, has become more common. This is due to a general increase in the population as a result of agricultural expansion. Numbers of other waterfowl have been consistently low, but Yellowbilled Duck has been absent in many of the more recent counts. The low numbers of other waterfowl may be indicative of the low levels of submerged and emergent macrophytes and absence of backwaters in this system, with decreases in numbers possibly a result of increased salinity of the system. It is likely that waterfowl numbers have decreased since the Reference Condition due to increased salinity and the reduction in reeds and submerged macrophytes.

While no White-breasted and Cape Cormorant and few Reed Cormorants were recorded in 1979-1981, they were relatively common in the early 2000s, then declined thereafter. Darters and Little Egret, generally present in small numbers in the 1980s and early 2000s, have become increasingly uncommon in the last few years. Since fish numbers are expected to have decline, these changes may have been driven by other factors. Numbers of White-breasted Cormorants have been generally stable in this part of the coast, suggesting factors other than general population trends may be at play. The decline in cormorant and darter numbers, if indeed real, could be due to disturbance or changes in habitat.

In contrast to the cormorants, African Fish Eagle was not recorded on the system until the mid-2000s, and has been regular since then. There appear to be increases in numbers of Pied Kingfisher. Giant Kingfisher, not recorded before 2004, has been recorded more often in recent years. Increases in the numbers of perching piscivores suggest better conditions, at least in the upper reaches. These findings are consistent with the suggestion that abundance of small fish species has increased.

Of the gulls and terns, Kelp Gull numbers appear to have declined, in spite of general increases in population. The numbers of Common, Sandwich and Swift terns have been erratic and asynchronous, suggesting that large roosts of the different species are not consistently present on the estuary, but occur sporadically. The choice of roost site would be determined by conditions at the estuary as well as at other localities in the region, and there is nothing to suggest a consistent change in habitat conditions at the Duiwenhoks Estuary. Nevertheless, it is estimated that the numbers of gulls and tern using the estuary would have decreased, since the changed mouth dynamics have made the system much less suitable for roosting.

Of the beach waders, numbers of Whitefronted Plover appear to have declined over time, while Oystercatcher numbers have remained low and sporadic. The former would indicate a decrease in availability or increase in disturbance of the dune habitats in the mouth area. Grey Plover, which favours expansive muddy (but not silty) sediments rich in the larger benthic macrofaunal species, appears to have declined over time, which does not support the estimated increases in their suitable habitat provided above. Common Whimbrel, which favour similar habitats but also make use of saltmarsh, were as numerous in 2013 as in the earliest count, and have been variable in between. Common Sandpiper and Greenshank, usually found along narrow stony or muddy shoreline and other marginal habitats, were both rare or absent in the early counts, and have become fairly regular in small numbers. These trends suggest a reduction in larger intertidal areas and increased extent of marginal intertidal area, possibly as a result of both marine sediment intrusion and the retraction of reed marsh habitat upstream. This is consistent with the predictions that the intertidal area extends further upstream and that benthic invertebrate biomass has increased. Overall, however, it is likely that wader numbers will have decreased due to reductions in their regional and global populations, as well as to some degree due to human disturbance. The improvements in intertidal habitats could have offset this to some degree.

4.9.2 Bird health

The bird health scores for the Present State are presented in **Table 4.37.**

Table 4.37 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	Conf
1. Species richness	No appreciable change in average instantaneous species richness amongst original community	95	M
2. Abundance	Overall abundance appears to have declined. Waterfowl numbers still low but change in composition; Numbers of cormorants and gulls have declined; Some of the waders have declined, a few have become more regular.	78	M
3. Community composition	Overall diversity has generally been fairly even, no groups present in large numbers; no major changes in community composition	80	M
Bird health score: min (a to c)		**78**	**M**
% of impact non-flow related		40	
Adjusted score		87	M

Non-flow related impacts include broader population changes (increases in Egyptian Goose, and general declines in numbers of waders), and human disturbance on the estuary, which may be part of the reason for declines in Whitefronted Plover and bird numbers in general.

5 PRESENT ECOLOGICAL STATUS

5.1 OVERALL ESTUARINE HEALTH INDEX SCORE

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

The Estuarine Health Score for the Duiwenhoks Estuary is 72, thus a **PES** of **Category C.**

Table 5.1 PES of the Duiwenhoks Estuary

Variable	Weight	Score
Hydrology	25	47
Hydrodynamics and mouth condition	25	95
Water quality	25	72
Physical habitat alteration	25	82
Habitat health score		**74**
Microalgae	20	73
Macrophytes	20	60
Invertebrates	20	70
Fish	20	70
Birds	20	78
Biotic health score		**70**
ESTUARY HEALTH SCORE Mean (Habitat health, Biological health)		**72**
PRESENT ECOLOGICAL STATUS (PES)		**C**
OVERALL CONFIDENCE		**Medium**

5.2 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.

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

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

Component	% of modification in health (non-flow related factors)	Key non-flow related factors
Hydrology	N/A	
Hydrodynamics and mouth condition	10	Destruction of peat lands upstream of estuary altering delivery pattern of river flow
Water quality	60	Nutrient input mainly from agricultural activities
Physical habitat alteration	60	Bank developments
Microalgae	80	Nutrient input mainly from agricultural activities
Macrophytes	30	Degradation of estuarine habitat development Alien vegetation in riparian zone Nutrient input mainly from agricultural activities
Invertebrates	1	Limited bait collection pressures
Fish	60	Fishing pressures Introduction of alien species
Birds	40	Human disturbance Egyptian geese which is an aggressive local species that has increased in abundance due to agricultural activities in the area and is now out competing other waterfowl and herbivorous species

Specialists estimated that by removing all non-flow related factors (**Table 5.2**) the PES of the Duiwenhoks Estuary (Category C) can be improved to a Category B. This demonstrates that the modification in river inflow patterns only partly contributed to the present ecological health status in the Duiwenhoks Estuary mainly associated with significant reduction in low flows (i.e. base flows).

5.3 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 possible to define and characterise the five abiotic states for this system with medium confidence, mainly because long-term river inflow records was available, as well as long-tern river water quality (collected in close proximity to the head of the estuary gauging station [H8H001]). Also, the DAFF in conjunction with the CSIR collected salinity, as well as other water quality parameters (i.e. temperature, pH, dissolved oxygen and turbidity) collected as part of a long-term estuarine monitoring programme which significantly enhanced confidence in this assessment. The only exception was data on sediment dynamics (which is not a key requirement for Intermediate level assessment), as well as inorganic nutrient data in the estuary (although long-term data on river inflow quality could be used to estimate conditions for various abiotic state). In terms of the biotic components, medium confidence in the macrophyte component is largely attributed to extensive, recent research conducted by the NMMU on estuarine systems in the region. 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. Sufficient bird data were also available through the CWAC programme. Although there was medium to low confidence in the microalgae and invertebrate components (mainly as a result of limited data on the Duiwenhoks system itself), the specialists drew on experience from their collective research on other, related estuarine systems, not warranting a drop in the overall confidence of this study. However, the recommended monitoring programme should focus on these components in order to improve confidence for future reviews.

6 THE RECOMMENDED ECOLOGICAL CATEGORY

6.1 ECOLOGICAL IMPORTANCE

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. 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 and the importance rating are presented in **Tables 6.2** and **6.3**, respectively.

Table 6.1 Estimation of the functional importance score of the Duiwenhoks Estuary

Functionality	Score
a. Estuary: Input of detritus and nutrients generated in estuary	40
b. Nursery function for marine-living fish and crustaceans	80
c. Movement corridor for river invertebrates and fish breeding in sea	100
d. Roosting area for marine or coastal birds	20
e. Catchment detritus, nutrients and sediments to sea	60
f. Coastal connectivity (way point) for fish	60
Functional importance score - Max (a to f)	**100**

Table 6.2 Estuarine Importance scores (EIS) for the Duiwenhoks Estuary

Criterion	Weight	Score
Estuary Size	15	100
Zonal Rarity Type	10	20
Habitat Diversity	25	90
Biodiversity Importance	25	77
Functional Importance	25	100
Weighted Estuary Importance Score		**84**

The functional importance of the Duiwenhoks Estuary was high as it is an important fish nursery (with a number of Red data and exploited fish species occurring in high numbers in the system. The estuary is also a very important conduit for eels which are CITES listed species. Referring to the estuarine importance rating system (DWAF, 2008), the importance score of the Duiwenhoks Estuary – a score of 84 - translates into an importance rating of **'Highly Important'** (**Table 6.3**).

Table 6.3 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 REC (**Table 6.4**), the Duiwenhoks Estuary should at least be managed in a **Category B**. The motivation being that the estuary is highly important, requiring a minimum REC of a B. Further, the NBA 2011 identified the estuary as an important nursery area for exploited fish stocks (Van Niekerk and Turpie, 2012).

Table 6.4 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 Best Attainable State (BAS)*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area (based on complementarity)		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category
Important	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D category

* BAS = Best Attainable State

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, if the current impacts are managed. The REC for the Duiwenhoks Estuary, therefore, was set as a **Category B.**

7 CONSEQUENCES OF ALTERNATIVE SCENARIOS

7.1 DESCRIPTION OF SCENARIOS

The future scenarios for the Duiwenhoks Estuary system are summarised in **Table 7.1**.

Table 7.1 Summary of flow scenarios

Scenario	Description	Mar (million m^3)	Percentage remaining
Reference	Natural MAR. H80F excluded since it discharges directly to sea Natural	89.29	100
Present	2004-development MAR	72.91	82
1	Return 50% of natural base flows (Present WRYM - reduce afforestation & water use)	85.43	96
2	Present with low flow category D EWR included	73.01	82
3	Present scenario plus1.5 million m^3 dummy dam upstream of estuary abstracting 9.5 million m^3/a	63.63	71
4	Worst case dam development	49.93	56

The occurrences of the flow distributions (mean monthly flows in m^3/s) under the future scenarios of the Duiwenhoks Estuary, derived from an 85-year simulated data set are provided in **Tables 7.2 to 7.5**. 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 distribution (in m^3/s) for Scenario 1 (refer to Table 3.2 for colour coding of abiotic states)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	19.8	24.2	24.1	12.8	12.6	19.4	24.6	12.7	6.8	9.3	28.4	24.0
99	15.9	18.6	13.5	10.3	9.7	12.9	23.4	12.1	6.3	8.6	23.1	14.3
90	9.8	6.9	3.0	2.6	3.8	4.9	6.6	6.0	4.5	5.2	6.2	6.5
80	4.9	5.3	2.3	1.3	1.9	3.4	4.4	3.8	3.6	3.7	5.2	5.6
70	4.0	3.5	1.6	1.0	1.2	2.4	3.0	2.9	2.7	3.1	4.2	4.1
60	3.0	2.4	1.3	0.6	0.7	1.7	2.0	2.3	2.3	2.6	3.4	3.5
50	2.5	2.0	1.0	0.4	0.5	1.2	1.5	1.8	1.8	2.2	3.1	3.0
40	2.3	1.5	0.7	0.3	0.3	0.8	1.0	1.4	1.6	2.0	2.6	2.7
30	2.0	1.3	0.5	0.2	0.2	0.6	0.8	1.1	1.3	1.6	2.2	2.2
20	1.6	1.1	0.3	0.1	0.1	0.3	0.6	0.6	1.0	1.4	1.7	1.9
10	1.3	0.8	0.3	0.0	0.0	0.1	0.4	0.5	0.7	1.1	1.5	1.7
5	1.1	0.7	0.1	0.0	0.0	0.0	0.2	0.4	0.5	1.0	1.2	1.4
1	0.8	0.6	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.7	1.0	1.0
0.1	0.7	0.5	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.5	0.9	0.7

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

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	19.1	23.2	23.5	12.4	9.9	16.5	22.2	11.5	6.5	9.0	26.3	23.1
99	15.2	17.9	13.1	9.5	8.8	11.9	21.2	11.4	6.0	8.3	22.1	13.6
90	9.3	6.6	2.5	1.8	2.7	4.1	5.4	5.7	4.3	4.6	6.0	6.3
80	4.8	4.8	1.6	0.5	0.7	2.4	3.2	3.0	3.5	3.5	5.0	5.5
70	3.8	3.0	0.6	0.4	0.4	1.7	2.5	2.4	2.4	2.8	4.0	3.9
60	2.6	1.9	0.5	0.3	0.3	1.1	1.6	1.9	2.0	2.4	3.3	3.3
50	2.3	1.4	0.4	0.2	0.2	0.5	1.0	1.3	1.6	2.1	2.8	2.8
40	1.8	0.7	0.4	0.2	0.1	0.2	0.6	1.1	1.2	1.6	2.4	2.5
30	1.5	0.5	0.3	0.1	0.1	0.1	0.6	0.8	1.1	1.4	2.1	1.9
20	1.1	0.5	0.2	0.1	0.0	0.1	0.4	0.5	0.8	1.1	1.5	1.7
10	0.8	0.4	0.2	0.0	0.0	0.0	0.2	0.3	0.5	0.9	1.1	1.3
1	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.7	0.5
0.1	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.3

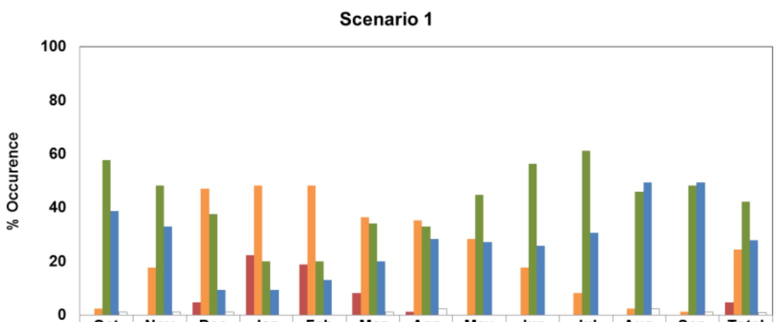
Table 7.4 Summary of the monthly flow distribution (in m^3/s) for Scenario 3 (refer to Table 3.2 for colour coding of abiotic states)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	18.8	23.0	23.2	12.1	9.7	16.4	22.1	11.2	6.2	8.7	26.2	22.8
99	15.1	17.6	12.8	9.2	8.5	11.9	21.3	11.1	5.8	8.0	21.9	13.3
90	8.9	6.3	2.2	1.3	2.7	3.8	5.2	5.4	4.1	4.3	5.7	6.0
80	4.5	4.5	1.3	0.0	0.2	2.1	3.1	2.7	3.2	3.2	4.7	5.2
70	3.5	2.6	0.2	0.0	0.0	1.1	1.8	2.0	2.2	2.5	3.6	3.6
60	2.3	1.6	0.0	0.0	0.0	0.4	1.4	1.7	1.8	2.1	3.0	3.0
50	1.9	1.1	0.0	0.0	0.0	0.1	0.7	1.0	1.3	1.8	2.5	2.5
40	1.5	0.4	0.0	0.0	0.0	0.0	0.3	0.6	1.1	1.3	2.1	2.2
30	1.2	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.2	1.8	1.7
20	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	1.3	1.3
10	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	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	0.4	0.3
0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1

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

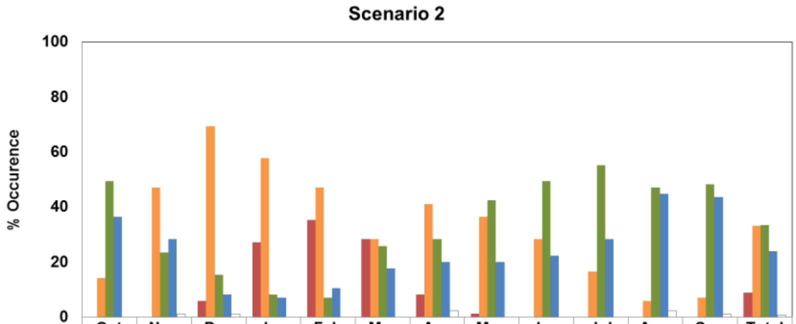
%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	17.9	22.3	22.5	10.4	5.7	14.8	21.4	11.0	6.0	8.5	24.7	22.1
99	12.8	16.9	12.0	7.5	5.5	10.0	19.7	10.9	5.6	7.8	21.5	12.6
90	8.2	5.4	1.3	0.0	0.0	2.6	4.5	5.2	3.8	4.1	5.5	5.3
80	3.8	3.3	0.2	0.0	0.0	0.8	2.3	2.4	2.8	3.0	4.5	4.4
70	2.8	1.9	0.0	0.0	0.0	0.0	1.2	1.6	1.9	2.3	3.4	2.9
60	1.6	0.9	0.0	0.0	0.0	0.0	0.5	0.9	1.4	1.9	2.8	2.3
50	1.2	0.2	0.0	0.0	0.0	0.0	0.0	0.4	1.0	1.6	2.2	1.8
40	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.1	1.9	1.5
30	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.5	1.0
20	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.6
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

A graphic representation of the occurrence of the various abiotic states for the Future scenarios is presented below in **Figures 7.1** to **7.4**.



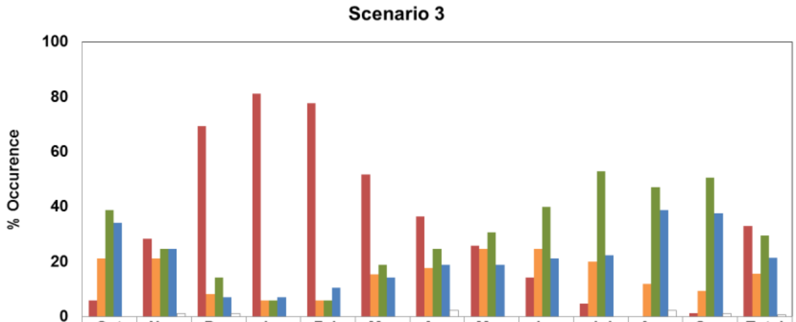
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	5	22	19	8	1	0	0	0	0	0	5
State 2	2	18	47	48	48	36	35	28	18	8	2	1	24
State 3	58	48	38	20	20	34	33	45	56	61	46	48	42
State 4	39	33	9	9	13	20	28	27	26	31	49	49	28
State 5	1	1	1	0	0	1	2	0	0	0	2	1	1

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



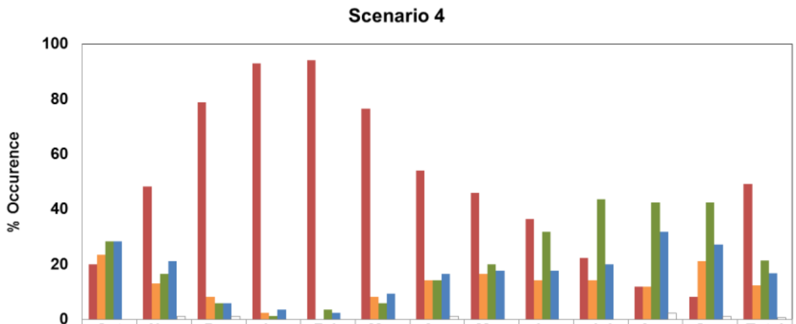
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	0	0	6	27	35	28	8	1	0	0	0	0	9
State 2	14	47	69	58	47	28	41	36	28	16	6	7	33
State 3	49	24	15	8	7	26	28	42	49	55	47	48	33
State 4	36	28	8	7	11	18	20	20	22	28	45	44	24
State 5	0	1	1	0	0	0	2	0	0	0	2	1	1

Figure 7.2 Occurrence of 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	6	28	69	81	78	52	36	26	14	5	0	1	33
State 2	21	21	8	6	6	15	18	25	25	20	12	9	15
State 3	39	25	14	6	6	19	25	31	40	53	47	51	30
State 4	34	25	7	7	11	14	19	19	21	22	39	38	21
State 5	0	1	1	0	0	0	2	0	0	0	2	1	1

Figure 7.3 Occurrence of 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	20	48	79	93	94	76	54	46	36	22	12	8	49
State 2	24	13	8	2	0	8	14	16	14	14	12	21	12
State 3	28	16	6	1	4	6	14	20	32	44	42	42	21
State 4	28	21	6	4	2	9	16	18	18	20	32	27	17
State 5	0	1	1	0	0	0	1	0	0	0	2	1	1

Figure 7.4 Occurrence of 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	1.4	0.8	2.8	1.0	5.0	2.5	5.6	2.9	4.5	3.9	4.1	3.9
1921	2.0	0.6	1.1	4.5	1.8	4.2	2.2	1.1	1.2	2.1	2.2	1.7
1922	1.4	2.5	0.8	0.2	0.1	0.0	3.7	4.6	4.0	3.2	2.7	1.8
1923	2.2	2.7	0.7	0.1	0.3	0.2	0.3	0.4	1.0	1.1	4.8	3.0
1924	1.3	1.3	0.6	0.2	0.0	2.0	1.1	0.5	1.5	1.6	1.6	2.8
1925	2.6	1.6	0.5	0.2	0.1	0.4	0.9	0.7	0.8	2.0	2.6	2.6
1926	6.1	3.5	0.6	0.0	0.3	0.6	0.6	1.4	1.4	1.1	2.2	1.7
1927	0.8	1.3	0.6	0.1	0.0	5.3	2.3	0.6	0.9	1.0	1.7	2.9
1928	1.7	24.9	11.3	1.2	0.5	0.7	0.8	1.6	1.8	5.4	5.5	3.7
1929	2.2	0.8	0.7	0.3	12.9	5.7	1.4	2.7	2.4	1.9	2.3	2.1
1930	3.4	1.5	0.2	0.3	0.1	4.8	7.6	3.1	1.4	3.7	3.3	3.0
1931	6.4	2.7	7.8	2.8	2.6	1.3	0.4	0.4	1.0	1.5	1.5	25.1
1932	10.0	1.6	0.4	0.0	0.2	0.7	0.5	1.7	1.7	1.4	5.4	3.3
1933	1.0	5.3	1.7	1.8	1.9	4.0	1.7	0.4	0.3	2.8	3.4	2.6
1934	20.2	11.2	1.7	0.1	0.0	0.6	1.0	5.1	5.3	3.8	2.9	3.9
1935	2.6	3.1	1.3	0.2	0.4	0.3	0.1	1.6	1.1	1.7	1.7	3.4
1936	2.5	14.8	6.3	1.0	0.1	3.8	1.6	0.3	0.5	1.2	1.2	2.0
1937	1.1	1.1	2.3	1.2	0.2	1.7	2.0	1.2	1.2	1.6	1.7	2.0
1938	2.6	6.0	2.3	0.5	2.0	7.0	3.1	0.9	0.6	1.9	9.9	5.9
1939	2.3	1.3	0.3	0.5	9.0	3.8	2.1	1.4	1.2	1.3	1.0	1.7
1940	1.1	4.0	1.3	0.5	0.3	0.1	5.0	2.7	2.6	2.7	2.8	3.1
1941	4.4	2.3	0.7	1.3	0.5	0.8	0.9	1.5	1.7	1.5	1.5	1.7
1942	1.6	0.8	1.5	6.3	2.7	0.7	0.6	0.4	0.4	0.4	1.0	5.4
1943	2.8	6.3	2.3	0.1	0.0	1.7	1.0	3.2	2.7	2.8	3.4	5.9
1944	4.3	1.5	0.1	0.0	0.0	0.0	0.1	4.0	4.2	3.1	3.9	3.7
1945	5.9	2.4	0.3	0.0	0.0	8.0	3.3	0.5	0.6	1.1	1.5	1.4
1946	1.1	0.7	0.1	0.0	0.3	8.9	4.4	2.2	2.2	4.0	3.0	3.1
1947	2.5	2.0	0.5	1.4	0.5	2.8	3.8	1.7	1.2	1.4	1.2	1.8
1948	9.5	4.0	0.4	0.6	0.2	0.0	0.6	1.8	1.3	1.1	1.1	1.1
1949	0.7	8.7	2.7	0.0	0.0	0.0	0.6	1.0	0.7	1.5	2.1	2.1
1950	4.3	6.0	1.8	8.0	3.2	1.5	0.9	1.1	2.1	5.7	4.5	6.5
1951	3.3	0.8	0.1	0.4	0.5	0.2	0.5	0.5	0.7	1.0	2.0	8.6
1952	4.3	4.9	1.9	0.4	0.7	0.2	1.0	0.6	1.1	5.4	4.2	5.0
1953	5.2	3.6	0.8	0.0	0.0	0.4	4.2	7.9	4.6	3.4	10.9	6.3
1954	2.1	1.6	0.4	1.3	8.0	2.5	0.4	0.5	0.9	1.7	2.5	3.0
1955	2.2	1.3	0.3	0.0	0.0	1.9	1.3	5.9	3.7	2.6	3.0	2.7
1956	4.4	1.8	2.8	0.9	1.6	1.2	0.8	2.2	6.1	4.8	5.4	7.7
1957	4.6	1.4	0.1	0.0	0.0	2.6	1.9	12.8	6.8	2.7	5.3	3.7
1958	2.4	1.1	0.3	1.9	4.0	4.2	7.5	5.6	3.2	8.4	7.8	4.9
1959	7.3	2.9	0.3	0.4	0.2	1.6	1.4	2.0	2.7	2.9	2.5	2.6
1960	1.6	2.5	2.3	1.9	0.8	1.0	1.0	1.9	1.8	2.4	3.4	3.4
1961	3.8	1.8	0.3	0.4	1.2	2.6	2.4	1.4	1.5	1.6	21.9	9.5
1962	7.0	6.6	1.6	0.8	0.2	4.8	2.7	2.0	1.7	2.5	2.3	1.4
1963	1.8	1.2	2.4	1.6	0.9	2.0	1.1	0.7	4.5	3.0	3.9	6.4
1964	4.0	2.4	0.6	0.1	0.9	1.6	1.6	3.2	2.4	2.1	2.4	1.8
1965	10.1	8.3	2.6	1.1	0.2	0.5	0.8	3.7	2.7	1.8	7.5	6.5
1966	2.6	0.7	0.0	0.0	0.6	3.0	24.7	11.9	5.4	5.7	5.3	5.6
1967	2.9	2.2	0.6	0.0	0.0	0.3	0.8	2.4	5.3	3.4	5.5	4.2
1968	2.2	3.5	1.0	0.0	0.2	0.3	0.6	0.6	3.0	2.5	2.6	2.2
1969	1.3	0.5	0.0	0.2	1.2	0.3	0.0	0.1	0.5	0.8	3.4	2.2
1970	1.8	0.8	0.8	0.3	3.6	3.3	5.9	5.2	3.9	9.4	12.5	6.4
1971	2.5	3.7	1.2	0.1	1.7	1.5	2.1	2.4	2.3	2.5	5.1	5.6
1972	2.4	1.4	0.4	0.0	0.0	0.0	0.7	0.9	1.9	2.4	3.1	2.8
1973	1.6	1.1	1.0	2.5	4.5	4.2	1.5	6.1	3.6	1.7	5.1	4.2
1974	2.2	1.4	0.2	0.4	0.1	0.1	0.4	1.3	2.3	3.1	6.3	7.4
1975	3.5	2.4	1.0	0.3	1.9	2.6	2.1	2.5	6.2	5.6	4.2	3.6
1976	10.0	6.0	1.6	0.2	5.7	2.4	1.8	10.2	6.0	3.3	3.4	3.4
1977	2.5	3.1	1.3	0.2	0.0	0.1	1.5	1.1	1.7	2.2	3.3	3.0
1978	2.5	1.3	1.4	0.6	2.0	0.7	0.1	1.8	1.5	5.9	6.1	5.4
1979	3.9	1.6	1.1	1.0	0.5	0.2	0.5	0.4	1.5	1.4	1.7	2.3
1980	2.4	8.9	3.2	13.1	8.9	7.8	15.9	8.9	4.5	4.1	10.9	6.6
1981	2.4	1.0	2.3	0.7	0.5	1.2	23.2	8.5	2.7	3.7	4.2	8.2
1982	4.6	1.4	0.4	0.0	0.4	0.2	0.5	2.2	3.6	4.9	3.9	6.1
1983	3.6	3.3	1.1	0.2	0.4	1.7	1.0	0.6	0.7	1.6	1.5	1.0
1984	1.6	0.8	0.3	5.8	4.7	1.1	2.7	1.6	1.9	6.3	4.3	2.1
1985	10.0	6.3	2.8	0.7	0.4	0.5	0.6	0.5	0.5	0.7	29.0	12.2
1986	4.8	2.4	0.4	0.0	0.0	0.1	6.7	3.1	1.8	1.9	3.4	4.4
1987	2.3	0.6	0.7	0.1	0.0	0.8	4.5	2.3	2.2	2.4	3.0	2.6
1988	1.9	0.9	1.3	1.0	0.4	1.2	6.4	2.9	1.5	1.6	2.1	1.7
1989	10.4	6.7	1.2	0.0	0.5	0.4	8.2	4.3	4.4	3.3	2.4	1.9
1990	1.5	0.8	0.7	1.1	1.6	0.6	0.2	0.4	0.6	1.0	0.9	0.7
1991	15.1	5.5	0.8	0.4	0.8	0.9	0.7	0.8	2.5	3.6	3.3	2.7
1992	10.3	7.0	1.4	0.1	0.1	0.1	12.5	6.0	2.4	2.4	2.7	3.9
1993	2.2	0.9	3.7	1.3	1.2	1.3	1.7	1.3	1.5	2.0	5.5	4.0
1994	3.0	1.2	6.3	2.3	1.5	2.4	3.6	4.1	2.8	2.2	2.2	2.4
1995	1.6	9.4	10.9	3.0	0.3	1.1	0.6	0.3	0.3	1.3	1.2	1.4
1996	6.1	17.4	5.3	0.2	0.4	1.7	1.5	2.8	2.9	4.7	5.2	3.5
1997	1.7	1.0	0.3	0.5	0.6	4.9	4.8	3.0	2.1	2.2	2.2	1.8
1998	1.0	2.1	2.2	1.5	2.7	2.2	1.7	1.3	1.2	1.6	1.6	2.0
1999	2.9	1.2	0.3	3.1	1.5	11.5	4.5	2.4	1.8	1.3	1.3	1.2
2000	1.3	2.4	1.4	0.4	0.1	0.6	4.1	2.1	1.0	0.9	3.5	2.8
2001	1.5	1.9	0.7	0.6	0.7	0.2	0.6	1.4	1.6	2.1	3.7	4.1
2002	1.9	0.9	0.7	0.6	0.3	20.1	8.0	6.2	4.1	2.7	3.3	2.4
2003	3.6	1.5	0.3	0.6	1.2	0.7	4.1	2.3	1.7	2.2	2.0	1.9
2004	12.5	4.8	25.3	9.7	0.8	1.2	5.1	3.7	3.6	2.7	2.4	1.9

Table 7.7 Simulated monthly flows (in m^3/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	0.8	0.4	2.1	0.4	4.1	2.0	5.3	2.8	4.4	3.8	4.0	3.8
1921	1.3	0.3	0.5	3.7	0.5	4.1	2.1	1.0	1.2	2.1	2.1	1.4
1922	1.2	2.4	0.4	0.1	0.0	0.0	2.3	3.5	3.9	3.1	2.6	1.4
1923	2.1	2.4	0.4	0.1	0.1	0.0	0.1	0.3	0.6	0.7	3.3	2.7
1924	0.7	0.8	0.3	0.1	0.0	1.3	0.6	0.3	1.0	1.0	1.5	2.7
1925	2.5	0.9	0.2	0.1	0.0	0.1	0.6	0.4	0.5	1.3	1.7	2.4
1926	5.8	2.9	0.3	0.0	0.1	0.1	0.4	0.9	0.9	0.7	1.4	1.2
1927	0.4	0.7	0.3	0.1	0.0	3.3	1.6	0.6	0.9	0.9	1.6	2.8
1928	1.1	23.8	10.9	0.5	0.2	0.2	0.5	1.0	1.2	5.3	5.3	3.6
1929	1.8	0.4	0.3	0.2	10.0	5.4	1.3	2.6	2.3	1.8	2.2	2.1
1930	3.3	0.6	0.1	0.1	0.0	3.0	6.8	2.9	1.4	3.5	3.2	2.9
1931	6.2	1.4	7.7	1.7	2.1	0.7	0.1	0.2	1.0	1.4	1.5	24.2
1932	9.3	0.7	0.2	0.0	0.1	0.2	0.1	1.1	1.1	0.9	4.6	2.8
1933	0.4	4.9	0.6	1.1	1.1	4.0	1.3	0.3	0.3	2.7	3.3	2.5
1934	19.5	10.9	0.6	0.1	0.0	0.1	0.6	3.3	5.1	3.7	2.8	3.8
1935	2.3	3.0	0.6	0.1	0.1	0.1	0.0	1.0	0.7	1.1	1.1	3.0
1936	2.3	14.3	5.6	0.4	0.1	2.4	0.7	0.1	0.5	1.2	1.1	1.9
1937	0.4	0.6	2.0	0.5	0.1	1.1	1.3	0.8	1.1	1.6	1.6	1.9
1938	2.5	5.8	1.4	0.3	0.8	6.7	3.0	0.8	0.6	1.8	9.6	5.7
1939	1.8	0.5	0.2	0.3	6.7	3.5	2.0	1.3	1.2	1.2	0.7	1.6
1940	0.5	3.9	0.6	0.3	0.1	0.0	3.1	1.9	2.5	2.6	2.7	2.9
1941	4.2	1.5	0.4	0.5	0.2	0.2	0.6	1.0	1.1	1.4	1.4	1.7
1942	1.3	0.4	0.6	5.9	1.4	0.1	0.5	0.4	0.4	0.4	1.0	5.2
1943	2.1	6.1	1.3	0.1	0.0	1.1	0.6	2.0	2.2	2.7	3.3	5.7
1944	4.2	0.6	0.1	0.0	0.0	0.0	0.1	2.8	2.9	3.0	3.7	3.6
1945	5.8	1.2	0.2	0.0	0.0	5.3	2.9	0.4	0.5	1.1	1.4	1.2
1946	0.7	0.3	0.1	0.0	0.2	6.3	4.2	2.1	2.1	3.8	2.7	3.0
1947	2.3	1.5	0.3	0.5	0.2	1.8	2.8	1.7	1.1	1.3	1.0	1.7
1948	9.1	2.9	0.2	0.3	0.1	0.0	0.4	1.1	0.9	0.7	0.7	0.7
1949	0.4	7.7	1.1	0.0	0.0	0.0	0.5	0.6	0.4	1.0	1.4	1.7
1950	4.2	5.8	0.6	7.6	1.8	1.4	0.6	1.1	2.0	5.6	4.3	6.3
1951	2.6	0.4	0.0	0.3	0.2	0.0	0.3	0.3	0.4	0.6	1.3	7.4
1952	3.9	4.7	0.9	0.2	0.3	0.1	0.6	0.4	0.7	3.8	4.0	4.9
1953	5.1	3.2	0.4	0.0	0.0	0.1	2.7	6.9	4.5	3.3	10.5	5.9
1954	1.3	1.1	0.2	0.5	6.8	1.5	0.3	0.5	0.9	1.6	2.4	2.9
1955	1.8	0.6	0.2	0.1	0.0	1.2	0.8	4.4	3.5	2.4	2.9	2.5
1956	4.3	0.7	2.7	0.4	0.5	0.4	0.6	2.1	5.7	4.6	5.2	7.5
1957	4.3	0.6	0.1	0.0	0.0	1.8	1.2	11.4	6.5	2.5	5.0	3.3
1958	2.2	0.5	0.2	1.0	3.0	4.2	7.3	5.4	3.1	8.1	7.6	4.7
1959	7.1	1.7	0.2	0.2	0.1	1.1	0.9	1.3	2.0	2.8	2.4	2.5
1960	1.1	2.3	1.9	1.3	0.3	0.3	0.9	1.8	1.7	2.3	3.3	3.3
1961	3.7	0.9	0.2	0.2	0.4	1.7	1.5	1.0	1.4	1.5	21.2	8.7
1962	6.8	6.4	0.6	0.4	0.1	3.0	2.2	2.0	1.7	2.4	2.2	0.8
1963	1.7	0.5	2.2	0.9	0.3	1.6	0.9	0.6	4.2	2.8	3.8	6.2
1964	3.8	1.9	0.3	0.1	0.3	0.9	1.0	2.0	2.0	2.0	2.4	1.4
1965	9.9	8.2	1.8	0.5	0.1	0.1	0.5	2.4	2.6	1.7	7.3	6.3
1966	1.8	0.4	0.1	0.0	0.3	1.9	22.4	11.6	5.3	5.5	5.2	5.5
1967	2.2	1.8	0.3	0.0	0.0	0.1	0.7	1.5	3.9	3.2	5.4	4.0
1968	1.7	3.4	0.5	0.0	0.1	0.1	0.4	0.4	1.9	1.6	2.4	2.0
1969	0.8	0.3	0.0	0.2	0.4	0.1	0.0	0.1	0.3	0.5	2.2	1.0
1970	1.7	0.4	0.4	0.2	2.2	2.3	5.7	5.1	3.8	9.1	11.8	5.8
1971	2.0	3.7	0.5	0.1	0.6	0.7	1.3	2.3	2.2	2.4	5.0	5.5
1972	1.5	0.8	0.2	0.1	0.0	0.0	0.5	0.6	1.2	1.5	2.6	2.7
1973	1.1	0.5	0.4	2.0	4.4	4.1	1.1	6.0	3.5	1.6	5.0	4.1
1974	1.7	0.7	0.2	0.2	0.1	0.0	0.2	0.9	1.4	2.0	6.1	7.2
1975	2.7	2.0	0.4	0.2	0.7	1.9	2.1	2.5	5.9	5.4	4.1	3.5
1976	9.8	5.7	0.7	0.2	4.2	1.9	1.7	10.0	5.8	3.2	3.3	3.3
1977	2.3	2.9	0.6	0.1	0.0	0.0	0.9	0.7	1.2	1.5	2.6	2.8
1978	2.3	0.5	0.8	0.4	0.7	0.2	0.0	1.2	1.1	5.6	5.9	5.2
1979	3.8	0.6	0.5	0.5	0.2	0.0	0.3	0.3	1.0	0.9	1.1	1.8
1980	2.3	8.7	2.2	12.7	8.6	7.7	15.4	8.7	4.4	4.0	10.7	6.3
1981	1.8	0.5	1.5	0.4	0.2	0.5	21.0	8.0	2.6	3.7	4.1	8.0
1982	4.3	0.5	0.2	0.0	0.2	0.1	0.3	1.4	2.4	3.9	3.7	5.9
1983	3.2	3.1	0.5	0.1	0.1	1.1	0.6	0.4	0.4	1.0	0.9	0.5
1984	1.6	0.4	0.2	4.2	4.3	0.3	2.5	1.5	1.8	6.1	4.1	1.6
1985	9.7	6.2	2.3	0.4	0.1	0.1	0.4	0.3	0.3	0.4	26.7	11.6
1986	4.7	1.5	0.2	0.0	0.0	0.0	4.3	2.8	1.7	1.8	3.3	4.3
1987	1.5	0.3	0.4	0.1	0.0	0.3	2.8	1.8	2.1	2.3	2.9	2.5
1988	1.6	0.4	0.5	0.4	0.2	0.5	5.0	2.8	1.4	1.6	2.0	1.5
1989	10.0	6.5	0.5	0.0	0.3	0.1	5.4	4.2	4.2	3.1	2.3	1.7
1990	1.2	0.4	0.4	0.5	0.5	0.1	0.0	0.3	0.4	0.6	0.5	0.3
1991	14.3	4.1	0.4	0.2	0.3	0.2	0.4	0.5	1.6	3.2	3.2	2.6
1992	10.1	6.7	0.6	0.1	0.1	0.0	9.6	5.9	2.4	2.4	2.6	3.7
1993	1.5	0.4	3.1	0.5	0.4	0.7	1.6	1.3	1.5	1.9	5.3	3.9
1994	2.9	0.5	5.6	1.2	0.8	2.4	3.5	4.1	2.7	2.1	2.1	2.3
1995	1.1	9.1	10.6	1.9	0.1	0.5	0.2	0.2	0.2	1.0	1.0	1.3
1996	5.9	16.8	3.9	0.1	0.1	1.0	1.0	1.8	2.6	4.5	5.0	3.1
1997	1.1	0.4	0.2	0.2	0.2	3.1	4.1	2.8	2.0	2.1	2.2	1.5
1998	0.4	1.8	1.7	0.8	2.3	2.0	1.7	1.3	1.2	1.5	1.6	1.9
1999	2.9	0.4	0.2	1.9	0.4	11.0	4.2	2.3	1.8	1.2	1.2	1.0
2000	1.0	2.1	0.6	0.2	0.0	0.1	2.6	1.3	0.8	0.9	3.4	2.7
2001	1.0	1.5	0.3	0.4	0.3	0.0	0.4	0.9	1.1	1.4	3.0	3.9
2002	1.0	0.4	0.3	0.3	0.1	17.0	7.8	6.0	4.0	2.6	3.2	2.1
2003	3.5	0.5	0.1	0.3	0.4	0.2	2.6	1.5	1.6	2.2	2.0	1.8
2004	12.0	3.2	24.7	8.9	0.3	0.6	4.5	3.6	3.4	2.6	2.3	1.7

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	0.5	0.0	1.8	0.0	3.8	1.7	5.1	2.5	4.2	3.5	3.7	3.4
1921	1.0	0.0	0.0	3.5	0.2	3.8	1.8	0.7	0.9	1.8	1.8	1.1
1922	0.9	2.1	0.0	0.0	0.0	0.0	1.5	3.2	3.6	2.8	2.3	1.1
1923	1.8	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.1	2.4
1924	0.4	0.5	0.0	0.0	0.0	0.4	0.3	0.0	0.7	0.7	1.2	2.4
1925	2.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.4	2.1
1926	5.5	2.6	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.4	1.3	1.0
1927	0.0	0.4	0.0	0.0	0.0	2.4	1.3	0.3	0.6	0.6	1.4	2.5
1928	0.8	23.6	10.5	0.0	0.0	0.0	0.0	0.5	1.5	5.0	5.0	3.2
1929	1.4	0.0	0.0	0.0	9.8	5.1	1.0	2.3	2.0	1.5	1.9	1.7
1930	3.0	0.1	0.0	0.0	0.0	2.1	6.5	2.6	1.1	3.2	2.9	2.6
1931	5.9	1.1	7.3	1.4	1.8	0.4	0.0	0.0	0.3	1.1	1.1	23.9
1932	9.0	0.4	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.6	4.5	2.4
1933	0.1	4.6	0.0	1.0	0.8	3.7	1.0	0.0	0.0	2.4	3.0	2.2
1934	19.2	10.6	0.0	0.0	0.0	0.0	0.0	2.8	4.8	3.4	2.5	3.5
1935	2.0	2.6	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.8	2.8
1936	2.0	14.1	5.3	0.0	0.0	1.6	0.7	0.0	0.0	0.9	0.8	1.6
1937	0.0	0.3	1.7	0.0	0.0	0.5	1.0	0.7	0.8	1.3	1.3	1.6
1938	2.2	5.5	1.0	0.0	0.2	6.6	2.7	0.5	0.3	1.5	9.3	5.4
1939	1.5	0.2	0.0	0.0	6.3	3.1	1.7	1.0	0.9	0.9	0.4	1.3
1940	0.2	3.6	0.0	0.0	0.0	0.0	2.2	1.7	2.2	2.3	2.4	2.6
1941	3.9	1.2	0.0	0.0	0.0	0.0	0.0	0.5	1.3	1.1	1.1	1.3
1942	1.0	0.0	0.0	5.9	1.1	0.0	0.0	0.1	0.1	0.1	0.7	4.9
1943	1.8	5.8	0.9	0.0	0.0	0.3	0.3	1.8	1.9	2.4	3.0	5.4
1944	3.8	0.1	0.0	0.0	0.0	0.0	0.0	1.9	2.6	2.6	3.4	3.3
1945	5.4	0.9	0.0	0.0	0.0	4.5	2.5	0.1	0.2	0.8	1.1	0.9
1946	0.4	0.0	0.0	0.0	0.0	5.5	3.9	1.8	1.9	3.5	2.4	2.7
1947	2.0	1.1	0.0	0.0	0.0	1.0	3.1	1.4	0.8	1.0	0.7	1.4
1948	8.8	2.6	0.0	0.0	0.0	0.0	0.0	0.4	0.6	0.4	0.4	0.4
1949	0.0	7.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.1	1.3
1950	3.9	5.5	0.2	7.4	1.4	1.1	0.3	0.8	1.7	5.3	4.0	6.0
1951	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	7.2
1952	3.5	4.4	0.5	0.0	0.0	0.0	0.0	0.0	0.2	4.2	3.7	4.5
1953	4.7	2.9	0.0	0.0	0.0	0.0	1.8	6.7	4.1	3.0	10.2	5.6
1954	1.0	0.8	0.0	0.0	6.6	1.2	0.0	0.1	0.6	1.3	2.1	2.6
1955	1.5	0.2	0.0	0.0	0.0	0.4	0.5	4.1	3.2	2.1	2.6	2.2
1956	4.0	0.3	2.3	0.0	0.0	0.1	0.3	1.8	5.5	4.3	4.9	7.2
1957	4.0	0.1	0.0	0.0	0.0	0.9	0.9	11.1	6.2	2.2	4.7	3.0
1958	1.9	0.0	0.0	0.3	3.1	3.9	7.0	5.1	2.8	7.8	7.3	4.4
1959	6.8	1.3	0.0	0.0	0.0	0.2	0.6	1.0	1.7	2.5	2.1	2.2
1960	0.8	1.9	1.5	1.0	0.0	0.0	0.4	1.6	1.5	2.0	3.0	3.0
1961	3.4	0.6	0.0	0.0	0.0	0.8	1.7	1.0	1.1	1.2	21.0	8.4
1962	6.5	6.1	0.0	0.0	0.0	2.7	2.4	1.7	1.3	2.1	1.9	0.5
1963	1.4	0.2	1.8	0.6	0.0	1.2	0.6	0.3	4.0	2.5	3.5	5.9
1964	3.4	1.6	0.0	0.0	0.0	0.1	0.7	2.0	2.0	1.8	2.0	1.1
1965	9.6	7.9	1.5	0.0	0.0	0.0	0.0	2.1	2.3	1.4	7.0	6.0
1966	1.5	0.0	0.0	0.0	0.0	1.0	22.2	11.3	5.0	5.2	4.9	5.2
1967	1.9	1.5	0.0	0.0	0.0	0.0	0.0	1.0	3.7	2.9	5.1	3.7
1968	1.4	3.1	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.3	2.1	1.7
1969	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.7
1970	1.4	0.0	0.0	0.0	1.3	2.9	5.4	4.8	3.5	8.8	11.5	5.5
1971	1.7	3.3	0.0	0.0	0.0	0.1	1.6	2.0	1.9	2.1	4.7	5.1
1972	1.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.3	2.3	2.4
1973	0.7	0.2	0.0	1.8	4.1	3.8	0.8	5.7	3.2	1.3	4.7	3.8
1974	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.8	5.8	6.9
1975	2.3	1.7	0.0	0.0	0.0	1.9	1.8	2.2	5.7	5.1	3.8	3.1
1976	9.5	5.4	0.4	0.0	3.7	1.6	1.4	9.7	5.5	2.9	3.0	3.0
1977	1.9	2.6	0.1	0.0	0.0	0.0	0.1	0.4	0.9	1.2	2.3	2.5
1978	2.0	0.1	0.5	0.0	0.3	0.0	0.0	0.4	1.1	5.4	5.6	4.9
1979	3.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.6	1.2	1.9
1980	2.0	8.4	1.8	12.4	8.2	7.3	15.1	8.4	4.1	3.7	10.4	6.0
1981	1.5	0.1	1.3	0.0	0.0	0.0	21.1	7.7	2.3	3.4	3.8	7.7
1982	4.0	0.1	0.0	0.0	0.0	0.0	0.0	0.7	2.2	3.6	3.4	5.6
1983	2.9	2.8	0.0	0.0	0.0	0.2	0.3	0.1	0.2	0.8	1.1	0.3
1984	1.3	0.0	0.0	3.9	4.0	0.0	2.2	1.2	1.5	5.8	3.8	1.3
1985	9.4	5.8	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.7	11.3
1986	4.4	1.2	0.0	0.0	0.0	0.0	3.5	2.5	1.4	1.5	3.0	4.0
1987	1.2	0.0	0.0	0.0	0.0	0.0	2.0	1.5	1.8	2.0	2.6	2.2
1988	1.3	0.0	0.0	0.0	0.0	0.0	5.4	2.5	1.1	1.3	1.7	1.2
1989	9.7	6.1	0.0	0.0	0.0	0.0	4.7	3.9	3.9	2.8	2.0	1.4
1990	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.1
1991	14.3	3.8	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.2	2.9	2.3
1992	9.8	6.4	0.1	0.0	0.0	0.0	8.8	5.6	2.1	2.0	2.3	3.4
1993	1.2	0.0	2.9	0.0	0.0	0.6	1.3	1.0	1.2	1.6	5.0	3.6
1994	2.6	0.0	5.4	0.8	0.5	2.1	3.2	3.8	2.4	1.8	1.8	2.0
1995	0.8	8.8	10.3	1.6	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.0
1996	5.6	16.5	3.6	0.0	0.0	0.2	0.7	1.5	2.4	4.2	4.7	2.8
1997	0.8	0.0	0.0	0.0	0.0	2.2	4.1	2.6	1.7	1.8	1.8	1.2
1998	0.1	1.5	1.4	0.5	2.0	1.7	1.4	1.0	0.9	1.2	1.3	1.6
1999	2.5	0.0	0.0	1.3	0.0	10.9	3.9	2.1	1.5	1.0	0.9	0.7
2000	0.7	1.8	0.3	0.0	0.0	0.0	1.7	1.1	0.7	0.6	3.1	2.4
2001	0.7	1.2	0.0	0.0	0.0	0.0	0.0	0.2	0.8	1.1	2.7	3.6
2002	0.6	0.0	0.0	0.0	0.0	16.9	7.5	5.7	3.7	2.3	2.9	1.7
2003	3.2	0.0	0.0	0.0	0.0	0.0	2.0	1.9	1.3	1.9	1.7	1.5
2004	11.7	2.9	24.4	8.6	0.0	0.1	4.3	3.3	3.2	2.3	2.0	1.4

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	0.0	0.0	0.2	0.0	0.0	0.9	4.9	2.3	4.0	3.3	3.5	2.7
1921	0.2	0.0	0.0	0.4	0.0	1.8	1.6	0.5	0.7	1.6	1.6	0.4
1922	0.2	1.3	0.0	0.0	0.0	0.0	0.0	2.9	3.4	2.6	2.1	0.4
1923	1.1	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.7
1924	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.7
1925	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.4
1926	4.8	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
1927	0.0	0.0	0.0	0.0	0.0	0.9	1.1	0.1	0.4	0.4	1.2	1.8
1928	0.1	22.9	9.8	0.0	0.0	0.0	0.0	0.0	0.0	4.8	4.8	2.5
1929	0.7	0.0	0.0	0.0	5.7	4.9	0.8	2.1	1.8	1.3	1.7	1.0
1930	2.3	0.0	0.0	0.0	0.0	0.6	6.3	2.4	0.9	3.0	2.7	1.8
1931	5.2	0.3	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	23.2
1932	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	1.7
1933	0.0	3.3	0.0	0.0	0.0	1.6	0.8	0.0	0.0	1.8	2.8	1.5
1934	18.5	9.9	0.0	0.0	0.0	0.0	0.0	1.1	4.6	3.2	2.3	2.8
1935	1.3	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1
1936	1.3	13.4	4.6	0.0	0.0	0.0	0.5	0.0	0.0	0.3	0.6	0.9
1937	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.1	1.1	0.9
1938	1.5	4.8	0.3	0.0	0.0	4.5	2.5	0.3	0.1	1.3	9.1	4.7
1939	0.8	0.0	0.0	0.0	2.2	2.9	1.5	0.8	0.7	0.7	0.2	0.6
1940	0.0	2.3	0.0	0.0	0.0	0.0	0.7	1.5	2.0	2.1	2.2	1.9
1941	3.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.9	0.6
1942	0.3	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8
1943	1.1	5.1	0.2	0.0	0.0	0.0	0.0	0.4	1.7	2.2	2.8	4.7
1944	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	2.4	2.4	3.2	2.6
1945	4.7	0.2	0.0	0.0	0.0	3.0	2.3	0.0	0.0	0.4	0.9	0.2
1946	0.0	0.0	0.0	0.0	0.0	3.9	3.7	1.6	1.7	3.4	2.2	2.0
1947	1.2	0.4	0.0	0.0	0.0	0.0	2.3	1.2	0.6	0.8	0.5	0.7
1948	8.1	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1949	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
1950	3.2	4.8	0.0	5.2	0.0	0.0	0.0	0.4	1.5	5.1	3.8	5.3
1951	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6
1952	2.8	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	3.5	3.8
1953	4.0	2.2	0.0	0.0	0.0	0.0	0.3	6.5	3.9	2.8	10.1	4.9
1954	0.3	0.0	0.0	0.0	2.1	0.9	0.0	0.0	0.1	1.1	1.9	1.9
1955	0.8	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.0	1.9	2.3	1.5
1956	3.3	0.0	1.2	0.0	0.0	0.0	0.0	0.1	5.4	4.1	4.7	6.5
1957	3.3	0.0	0.0	0.0	0.0	0.0	0.2	10.9	6.0	2.0	4.6	2.2
1958	1.1	0.0	0.0	0.0	0.0	2.2	6.8	4.9	2.6	7.6	7.1	3.7
1959	6.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.3	1.9	1.5
1960	0.0	1.2	0.8	0.0	0.0	0.0	0.0	0.0	1.2	1.8	2.8	2.3
1961	2.7	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.9	1.0	20.8	7.7
1962	5.8	5.4	0.0	0.0	0.0	1.2	2.1	1.5	1.1	1.9	1.7	0.0
1963	0.5	0.0	0.6	0.0	0.0	0.0	0.0	0.0	3.8	2.3	3.3	5.2
1964	2.7	0.8	0.0	0.0	0.0	0.0	0.0	0.8	1.8	1.6	1.8	0.4
1965	8.9	7.2	0.8	0.0	0.0	0.0	0.0	0.4	2.1	1.2	6.8	5.3
1966	0.8	0.0	0.0	0.0	0.0	0.0	21.5	11.1	4.8	5.0	4.7	4.5
1967	1.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	2.8	2.7	4.9	3.0
1968	0.7	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.9	1.0
1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1970	0.5	0.0	0.0	0.0	0.0	0.8	5.2	4.6	3.3	8.6	11.3	4.8
1971	1.0	2.6	0.0	0.0	0.0	0.0	0.0	1.5	1.7	1.9	4.5	4.4
1972	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.7
1973	0.0	0.0	0.0	0.0	0.1	3.6	0.6	5.5	3.0	1.1	4.5	3.1
1974	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5.6	6.2
1975	1.6	1.0	0.0	0.0	0.0	0.0	1.6	2.0	5.5	4.9	3.6	2.4
1976	8.8	4.7	0.0	0.0	0.0	0.8	1.2	9.5	5.3	2.7	2.8	2.3
1977	1.2	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.1	1.8
1978	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	5.4	4.2
1979	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
1980	1.3	7.7	1.1	10.7	5.5	7.1	15.0	8.2	3.9	3.5	10.2	5.3
1981	0.8	0.0	0.0	0.0	0.0	0.0	19.3	7.5	2.1	3.2	3.6	7.0
1982	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	3.4	3.2	4.9
1983	2.2	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
1984	0.2	0.0	0.0	0.8	1.3	0.0	1.8	1.0	1.3	5.6	3.6	0.6
1985	8.7	5.1	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	10.6
1986	3.7	0.5	0.0	0.0	0.0	0.0	1.9	2.3	1.2	1.3	2.8	3.3
1987	0.5	0.0	0.0	0.0	0.0	0.0	0.4	1.3	1.6	1.8	2.4	1.5
1988	0.5	0.0	0.0	0.0	0.0	0.0	3.6	2.3	0.9	1.0	1.5	0.5
1989	9.0	5.4	0.0	0.0	0.0	0.0	3.2	3.7	3.7	2.6	1.8	0.7
1990	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	11.7	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.0	2.7	1.6
1992	9.1	5.7	0.0	0.0	0.0	0.0	7.2	5.3	1.9	1.8	2.1	2.7
1993	0.4	0.0	1.4	0.0	0.0	0.0	0.0	0.5	1.0	1.4	4.8	2.9
1994	1.9	0.0	3.9	0.0	0.0	0.0	3.0	3.6	2.2	1.6	1.6	1.3
1995	0.0	8.1	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	4.3	15.8	2.8	0.0	0.0	0.0	0.0	0.5	2.2	4.0	4.5	2.1
1997	0.1	0.0	0.0	0.0	0.0	0.7	3.9	2.4	1.5	1.6	1.6	0.5
1998	0.0	0.2	0.7	0.0	0.0	0.0	0.8	0.8	0.6	1.0	1.1	0.9
1999	1.8	0.0	0.0	0.0	0.0	9.0	3.7	1.9	1.3	0.8	0.7	0.0
2000	0.0	1.0	0.0	0.0	0.0	0.0	0.2	0.9	0.5	0.4	2.9	1.6
2001	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.9
2002	0.0	0.0	0.0	0.0	0.0	15.4	7.2	5.5	3.5	2.1	2.7	1.0
2003	2.5	0.0	0.0	0.0	0.0	0.0	0.5	1.7	1.1	1.7	1.5	0.8
2004	11.0	2.2	23.7	6.9	0.0	0.0	2.3	3.1	3.0	2.1	1.8	0.6

7.2 HYDROLOGY

7.2.1 Low flows

Table 7.10 provides a summary of the changes in low flow that have occurred under the different scenarios.

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

Percentile	Monthly flow (m^3/s)					
	Natural	Present	1	2	3	4
30%	1.2	0.3	1.0	0.5	0.0	0.0
20%	0.8	0.1	0.6	0.3	0.0	0.0
10%	0.5	0.0	0.3	0.1	0.0	0.0
% Similarity in low flows		**13.5**	**77.1**	**37.1**	**0.0**	**0.0***

*No base flows up to 40%ile

Confidence: High

7.2.2 Flood regime

An evaluation of the 20 highest monthly flow volumes (as a proxy for floods) in the simulated data set show that floods occur relatively untransformed from Reference Condition to Present State and Future Scenarios 1 to 3 (**Table 7.11**). While under Scenario 4 there is about a 10% decrease from present.

Table 7.11 Summary of the ten highest simulated monthly volumes to the Duiwenhoks 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-86	77.8	75.0	77.8	71.6	71.6	67.06
Dec-04	67.7	66.2	67.7	66.2	65.3	63.44
Sep-32	65.0	62.6	65.1	62.6	61.9	60.13
Nov-28	64.4	61.9	64.4	61.8	61.1	59.34
Apr-67	64.3	61.8	64.0	57.9	57.6	55.84
Apr-82	60.3	58.0	60.1	54.5	54.7	55.63
Aug-62	58.6	56.9	58.8	56.9	56.1	50.08
Mar-03	54.3	52.0	53.9	45.6	45.2	49.56
Oct-34	54.0	52.2	54.1	52.2	51.4	41.12
Nov-96	45.1	43.5	45.0	43.5	42.7	40.86

Date	Monthly volume (million m^3/month)					
	Natural	Present	1	2	3	4
Apr-81	41.2	40.0	41.3	40.0	39.3	38.77
Oct-91	40.4	39.1	40.3	38.4	38.3	34.71
Nov-36	38.3	37.3	38.3	37.2	36.5	31.38
Jan-81	35.3	34.0	35.2	34.0	33.2	30.28
May-58	34.3	32.4	34.2	30.4	29.7	29.61
Oct-04	33.5	32.2	33.5	32.2	31.4	29.57
Aug-71	33.5	31.6	33.4	31.6	30.8	29.19
Apr-93	32.7	30.5	32.3	25.0	22.8	28.63
May-67	32.0	30.9	31.9	30.9	30.1	27.54
Dec-04	67.7	66.2	67.7	66.2	65.3	27.30
% Similarity in floods		**96**	**99**	**94**	**92**	**86**

Confidence: Medium

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	Confidence
a. % Similarity in period of low flows	60	14	77	37	0	0	M
b. % Similarity in mean annual frequency of floods	40	96	99	94	92	86	M
Hydrology score: weighted mean (a,b)		**47**	**86**	**60**	**37**	**34**	**M**

7.3 PHYSICAL HABITAT

A summary of the expected changes in the physical habitat of the Duiwenhoks 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 2 is not significantly different from the Present State (too small a change in effects to distinguish in the scoring). Scenarios 1 and 3 have additional 3% (positive) and 4% (negative) change effect respectively on flood regime which will translate into direct associated effects on sediment dynamics and morphology in the estuary. Similarly, Scenario 4 has a 10% negative change regarding floods w.r.t. present, with similar greater effects.
b. Intertidal areas and sediments	Same as for supratidal.
c. Subtidal area and sediments	Same as for supratidal.
d. Estuary bathymetry/water volume	Flood flows have relatively very short retention/traverse times within the estuary, thus virtually zero additional effect due to small flood regime changes. Increased low flows for Scenario 1 would tend to counter the small effect of the slightly larger ingress of marine waters due to the channel blasted through the rocks seaward of the mouth. Scenario 3 would also allow slightly larger marine waters and sediment ingress. Yet, overall all these effects are considered too small to alter the score from present (small percentage change on top of only a 5% change). Under Scenario 4 there would be slightly less flushing of sediments due to further floods reduction, thus reduced water volume.

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	82	85	82	78	72	L
b	Intertidal areas and sediments	82	85	82	78	72	L
c	Subtidal area and sediments	82	85	82	78	72	L
d	Estuary bathymetry/water volume	95	95	95	95	93	L
Physical habitat score: min (a to d)		**82**	**85**	**82**	**78**	**72**	**L**

7.4 HYDRODYNAMICS AND MOUTH CONDITION

The hydrodynamics and mouth condition health scores for the present and future scenarios are provided in **Table 7.15**.

Table 7.15 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	50	100	100	100	100	95	H
b	% similarity in the water column stratification		No resolution					
c	% similarity in water retention time		No data					
d	% similarity in water level (using tidal amplitude and symmetry)	50	90	90	90	90	92	M
Hydrodynamics and mouth: weighted mean (a to d)			**95**	**95**	**95**	**95**	**94**	**M**

7.5 WATER QUALITY

Table 7.16 provides a summary the occurrence of various abiotic states under reference, present and each of the future scenarios for the Duiwenhoks Estuary.

Table 7.16 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	0	22	5	9	33	49
State 2: Full salinity gradient	25	21	24	33	15	12
State 3: Partial salinity gradient	44	31	42	33	30	21
State 4: Limited salinity penetration	29	25	28	24	21	17
State 5: Freshwater dominated	1	1	1	1	1	1

Table 7.17 provides a summary of the expected average changes in various water quality parameters in different zones under present and future scenarios, while **Table 7.18** summarised the cause of such changes.

Table 7.17 Expected average changes in various water quality parameters in different zones under present and future scenarios

Zone	Volume weighting	Estimated salinity concentration based on distribution of abiotic states					
		Reference	Present	Scn 1	Scn 2	Scn 3	Scn 4
A	0.25	25	29	28	30	30	32
B	0.35	15	22	20	21	23	24
C	0.30	6	16	14	15	17	17
D	0.10	2	9	7	9	11	13

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	0.25	50	64	66	64	62	61
B	0.35	50	90	99	97	85	78
C	0.30	50	179	196	192	168	152
D	0.10	50	179	196	192	168	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	0.25	10	13	13	13	12	12
B	0.35	10	16	17	16	15	14
C	0.30	10	18	20	19	17	15
D	0.10	10	18	20	20	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	0.25	10	10	11	10	10	11
B	0.35	10	10	11	10	10	11
C	0.30	10	30	30	30	30	31
D	0.10	10	20	21	20	20	21

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	0.25	6	6	6	6	6	6
B	0.35	6	6	6	6	6	6
C	0.30	6	6	6	6	5	5
D	0.10	6	6	6	6	5	5

Table 7.18 Summary of water quality changes under future scenarios

Parameter	Summary of changes
Changes in longitudinal salinity gradient and vertical stratification	⇧ due to increase in low flow conditions, the mouth manipulations and the loss of the peat wetlands in the catchments that would have moderated baseflows Scenario 1 and 2 shows a ⇩ in salinity in Zone D similar to the Reference Conditions. While Scenario 3 and 4 shows and ⇧ due to significant increases in low flow conditions.
Inorganic nutrients in estuary	⇧ due to agricultural activity in the catchment and along the banks (Vermaaklikheid opposite Zone C) Slight “improvement” from Present in Scenario 4 as a result of reduction in enriched inflows
Turbidity in estuary	⇧ due to agricultural activity in the catchment and along the banks (Vermaaklikheid opposite Zone C)
Dissolved oxygen in estuary	No marked changes
Toxic substances in estuary	⇧ due to agricultural activity in the catchment and along the banks (Vermaaklikheid opposite Zone C)

The EHI scores for water quality are presented in **Table 7.19**.

Table 7.19 Water quality health scores for present and future scenarios

Variable		Weight	Scenario					
			Present	1	2	3	4	Confidence
1	**Similarity in salinity**	**40**	73	77	74	70	68	M
2	**General water quality min (a to d)**	**60**	71	68	70	73	76	M
a	DIN/DIP concentrations		71	68	70	73	76	M
b	Turbidity		81	81	81	81	80	M
c	Dissolved oxygen		99	100	99	98	96	M
d	Toxic substances		80	80	80	80	80	L
Water quality score weighted mean (1,2)			**72**	**72**	**72**	**72**	**73**	**M**

7.6 MICROALGAE

A summary of the expected changes under various scenarios for the microalgae component in the Duiwenhoks Estuary is provided in **Table 7.20**.

Table 7.20 Summary of change in microalgae under future scenarios

Scenario	Summary of changes
1	**Abundance:** Turbidity and herbicide levels are expected to remain unchanged. Flow is likely to decrease by 4% from reference resulting in slightly elevated nutrient levels compared to present (average weighted P; present = 16.1 µg/l and State 1 = 17.2 µg/l). This is likely to support microalgal growth, particularly in States 2 and 3. If a [P] of 16.1 µg/l resulted in a 27% increase in microalgal biomass (present), then a 17.2 µg/l is likely to result in a 29% increase. **Richness:** Elevated presence of dinoflagellates (stratified middle reaches), cyanobacteria and chlorophytes in response to 4% decrease in river flow and elevated nutrients (3% increase allowed for slight increase in nutrients).
2	**Abundance:** Turbidity and herbicide levels are expected to remain unchanged. Flow is likely to decrease by 18% from reference (similar to present). However, the shift in flow states is likely to result in slightly elevated nutrient levels compared to present (average weighted P; present = 16.1 µg/l and State 2 = 16.6 µg/l). This is likely to support microalgal growth, particularly in States 2 and 3. If a [P] of 16.1 µg/l resulted in a 27% increase in microalgal biomass (present), then a 16.6 µg/l is likely to result in a 28% increase. **Richness:** Elevated presence of dinoflagellates (stratified middle reaches), cyanobacteria and chlorophytes in response to 18% decrease in river flow and elevated nutrients (3% increase allowed for slight increase in nutrients).
3	**Abundance:** Turbidity and herbicide levels are expected to remain unchanged. Flow is likely to decrease by 29% from reference. The decreased flow and shift in flow states is likely to result in slightly decreased nutrient levels compared to present (average weighted P; present = 16.1 µg/l and State 3 = 15.4 µg/l). This is likely to support microalgal growth, particularly in States 2 and 3. If a [P] of 16.1 µg/l resulted in a 27% increase in microalgal biomass (present), then a 15.4 µg/l is likely to result in a 26% increase. **Richness:** Elevated presence of dinoflagellates (stratified middle reaches), cyanobacteria and chlorophytes in response to 29% decrease in river flow and elevated nutrients (3% decrease allowed for slight decrease in nutrients).
4	**Abundance:** Turbidity and herbicide levels are expected to remain unchanged. Flow is likely to decrease by 44% from reference. The decreased flow and shift in flow states is likely to result in slightly decreased nutrient levels compared to present (average weighted P; present = 16.1 µg/l and State 4 = 14.5 µg/l). This is likely to support microalgal growth, particularly in States 2, 3 and 4. If a [P] of 16.1 µg/l resulted in a 27% increase in microalgal biomass (present), then a 15.4 µg/l is likely to result in a 24% increase. **Richness**: Elevated presence of dinoflagellates (stratified middle reaches), cyanobacteria and chlorophytes in response to 44% decrease in river flow and elevated nutrients (5% decrease allowed for slight decrease in nutrients).

The EHI scores for microalgale under the various scenarios are presented in **Table 7.21**.

Table 7.21 Microalgae health scores for present and future scenarios

Variable	Scenario					
	Present	**1**	**2**	**3**	**4**	**Confidence**
Phytoplankton						
a. Species richness	100	100	100	100	100	M
b Abundance	73	71	72	74	76	M
c. Community composition	82	93	79	74	59	M
Benthic microalgae						
a. Species richness	85	97	85	76	95	L
b Abundance	73	71	72	74	76	M
c. Community composition	95	95	95	95	63	L
Microalgae score min (a to c)	**73**	**71**	**72**	**74**	**56**	**M/L**

7.7 MACROPHYTES

Species richness will likely stay the same between the different scenarios. Macrophyte abundance and community composition will change as described below (**Table 7.22**). Scenario 3 represents a significant increase in low flow conditions that will increase salinity leading to some loss of macrophyte biomass and productivity. However Duiwenhoks has always been a marine dominated estuary. Salt marsh will replace reeds and sedges as the estuary becomes more saline upstream. It is assumed that agricultural activities, grazing and trampling will remain in the floodplain areas.

Table 7.22 Summary of change in macrophytes under future scenarios

Scenario	Summary of changes
1	Scenario 1 shows a ⇩ in salinity in Zone D similar to the Reference Conditions because 50% of the low flow is returned due to a decrease in afforestation and water use. Reeds and sedges will flourish in the upper reaches however the largest macrophyte component i.e. the floodplain remains degraded.
2	Scenario 2 shows a slight ⇩ in salinity in Zone D. However, the shift in salinity was not sufficient to improve from Present State.
3	Scenario 3 shows an ⇧ in salinity due to increase in low flow conditions as there is a dam and water abstraction in place. There will be a loss of reeds and sedges in the upper reaches of the estuary. Salt marsh cover would be reduced with an increase in bare patches.
4	Scenario 4 shows an ⇧ in salinity due to increase in low flow conditions as this is a worst case dam scenario. There will be a loss of reeds and sedges in the upper reaches of the estuary. Salt marsh cover would be reduced with an increase in bare patches. Reduced flooding would cause saline conditions in the supratidal salt marsh.

The EHI scores for marcophytes under the various scenarios are presented in **Table 7.23**.

Table 7.23 Macrophyte health scores for present and future scenarios

Variable	Scenario					
	Present	1	2	3	4	Confidence
a. Species richness	85	85	85	85	80	M
b. Abundance	60	63	60	57	50	M
c. Community composition	63	66	63	60	55	M
Macrophyte score min (a to c)	**60**	**63**	**60**	**57**	**50**	**M**

7.8 INVERTEBRATES

A summary of the expected changes under various scenarios for the invertebrate component in the Duiwenhoks Estuary is provided in **Table 7.24**, while the health scores for the present and future scenarios are provided in **Table 7.25**.

Table 7.24 Summary of change in invertebrates under different scenarios

Scenario	Summary of changes
1	This scenario will result in a decrease in marine dominance during the summer months and the development of the REI. Consequently, the scenario represents a return towards the natural state. In the upper estuary, when there is marine dominance the REI will remain for much of the time and together with an increase in phytoplankton biomass, lead to an increase in zooplankton biomass. Reeds and sedges will extend further downstream compared to present, providing habitat for carid shrimps (increased biomass) such *as Palaemon capensis*. Reduced salinity and less development of macrophytes (compared to present) in the upper estuary it will lead to more available habitat for benthic species such as amphipods (*Corophium triaenonyx*, *Grandidierella lignorum* and *Melita zeylanica*). In summary, the invertebrate community will move along a trajectory more similar to natural when compared to Present State.
2	Under this scenario, marine dominance in summer will increase slightly compared to Scenario 1, but will remain significantly lower relative to the Present State. State 2 under his scenario (full salinity gradient present) is similar to the natural state and consequently, invertebrate response will result in a community similar to Scenario 1, but not reaching the same state of recovery towards the natural state.
3	There is a significant increase in low flow conditions under this scenario, particularly in summer. Marine dominance will also persist during most summers, and will occasionally occur during the winter months as well. Consequently, the scenario represents significantly greater marine dominance compared to present and therefore a greater deviation from natural. The absence of a REI zone during most summers will lead to suppressed zooplankton biomass. The reduction in the extent of reeds and sedges downstream will lead to a lower biomass of carid shrimps (*Palaemon capensis*) and therefore impact higher trophic levels negatively.
4	Low flow conditions persist for longer and marine dominance (State 1) occurs for 49% of the time, with a significant increase in spring –early summer The REI now occurs once every ten years. The scenario therefore, represents increasing marine dominance and loss of REI. Zooplankton biomass remains persistently low and invertebrates associated with the low salinity zone shrinks. Associated with increased marine dominance will be the decrease in the fringing vegetation and hence habitat available for carid shrimps (*Palaemon capensis*).

Table 7.25 Invertebrate health scores for present and future scenarios

Variable	Scenario					
	Present	1	2	3	4	Confidence
Zoo plankton						
a. Species richness	100	100	100	100	100	M
b Abundance	80	85	83	75	70	M
c. Community composition	75	80	78	70	65	M
Hyperbenthos						
a. Species richness	100	100	100	100	100	M
b. Abundance	80	85	83	75	70	M
c. Community composition	75	80	78	70	65	M
Benthos						
a. Species richness	100	100	100	100	100	M
b Abundance	70	80	75	65	55	M
c. Community composition	70	80	75	65	55	M
Invertebrate score min (a to c)	**70**	**80**	**75**	**65**	**55**	**M**

7.9 FISH

A summary of the expected changes under various scenarios for the fish component in the Duiwenhoks Estuary is provided in **Table 7.26**, while the health scores for the present and future scenarios are provided in **Table 7.27**.

Table 7.26 Summary of change in fish under different scenarios

Scenario	Summary of changes
1	More developed and persistent REI during the summer will see estuary residents e.g. *G. aestuaria* and those typical of the REI e.g. *Myxus capensis* be more dispersed in the estuary instead of being confined mostly to Zone D as in the present day. The fish community will shift slightly closer to reference with increased dominance of REI species. Increased micro-algal (benthic?) production should favour all mullet species and increased zooplankton production should favour juveniles and larvae of all fish species. Prey availability for adult benthic feeders e.g. *L. lithognathus* may decrease in that burrowing invertebrates may burrow deeper to preferred salinities, probably closer to Reference Conditions. Slight attenuation of floods by rehabilitation in catchment therefore cueing, connectivity and recruitment window incrementally enhanced.
2	Given seasonal and interannual variability, the salinity regime is identical to the present day. The REI fish community will remain dominant as it was under reference through to present but may benefit from a slight increase in the strength and persistence of the REI.

Scenario	Summary of changes
3	Loss of the REI for a large part of the year will see a switch to a fish assemblage dominated by the opportunistic *L. richardsonii* and two orders of magnitude decline in abundance of the REI species specifically *G. aestuaria* and *Myxus capensis*. Floods to be shorter and sharper than present therefore cueing, connectivity and recruitment windows likely to be dampened and shorter. New recruits have a slightly bigger chance of being flushed from the system. Increase in microalgae (benthic) will favour mullet grazers, but a decline in zooplankton abundance will mean food scarcity for all juvenile fish. Burrowing invertebrates are likely to become more available as prey to benthic feeders.
4	Complete loss of the REI and a more extreme version of Scenario 3 i.e. a switch to a fish assemblage dominated by the opportunistic *L. richardsonii* and REI species *G. aestuaria* and *Myxus capensis* disappear from the estuary. Floods lost and remaining ones shorter and sharper than present therefore cueing, connectivity and recruitment windows are likely to be dampened and shorter. New recruits have a slightly bigger chance of being flushed from the system. Increase in microalgae (benthic) will favour mullet grazers but a decline in zooplankton abundance will mean food scarcity for all juvenile fish. Burrowing invertebrates are likely to become more available as prey to benthic feeders.

Table 7.27 Fish health scores for present and future scenarios

Variable	Scenario					
	Present	1	2	3	4	Confidence
a. Species richness	89	90	89	70	60	M
b Abundance	70	80	75	60	50	M
c. Community composition	70	80	70	60	50	M
Fish scores min (a to c)	**70**	**80**	**70**	**60**	**50**	**M**

7.10 BIRDS

A summary of the expected changes under various scenarios for the bird component in the Duiwenhoks Estuary is provided in **Table 7.28**, while the health scores for the present and future scenarios are provided in **Table 7.29**.

Table 7.28 Summary of change in birds under different scenarios

Scenario	Summary of changes
1	Fish abundance lower than present, reducing numbers of piscivorous birds (majority of groups); waterfowl recover slightly due to fresher conditions; inverts lower, reducing wader numbers
2	Conditions similar to Present State.
3	More saline, less favourable for waterfowl than present; big decrease in smaller fish species has negative impact on many groups.
4	Same trajectory as Scenario 3, but more extreme changes.

Table 7.29 Bird health scores for present and future scenarios

Variable	Scenario					
	Present	1	2	3	4	Confidence
a. Species richness	95	95	95	90	90	L
b Abundance	78	74	78	54	44	L
c. Community composition	80	79	80	66	58	L
Bird scores min (a to c)	**78**	**74**	**78**	**54**	**44**	**L**

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 Duiwenhoks Estuary under each of the future scenarios (**Table 7.30**), again using the EHI.

Table 7.30 EHI score and corresponding Ecological Categories under present and future scenarios

Variable	Weight	Scenario					
		Present	1	2	3	4	Confidence
Hydrology	25	47	86	60	37	34	M
Hydrodynamics and mouth condition	25	95	95	95	95	94	M
Water quality	25	72	72	72	72	73	M
Physical habitat alteration	25	82	85	82	78	72	L
Habitat health score	**50**	**74**	**84**	**77**	**70**	**68**	
Microalgae	20	73	71	72	74	59	M/L
Macrophytes	20	60	63	60	57	50	M
Invertebrates	20	70	80	75	65	55	M
Fish	20	70	80	70	60	50	M
Birds	20	78	74	78	54	44	L
Biotic health score	**50**	**70**	**74**	**71**	**62**	**52**	
ESTUARY HEALTH SCORE		**72**	**79**	**74**	**66**	**60**	**M**
ECOLOGICAL CATEGORY		**C**	**B**	**B/C**	**C**	**C/D**	**M**

8 RECOMMENDATIONS

8.1 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 Duiwenhoks Estuary a **Category B** was proposed as the REC. **Applying this guideline, only Scenario 1** (see **Table 7.30**) *in the suite of scenarios evaluated as part of this study meets these criteria*. However, Scenario 2 was a hypothetical scenario assuming that 50% of the base flow could be returned to the estuary through removal of alien invasive plants, deforestation, as well as reducing run-off river abstraction during the low flow season. Considering the high demand for water in the catchment, this may not be a realistic option.

Scenario 2 (present flow including the river low flow EWR) resulted in a slight improvement in health, from a Category C to a Category B/C (just below a Category B). Scenario 2 returns some low flows to the estuary, and in doing so, addresses the key flow-related factor contributing to the changes in ecological health in this estuary (see **Section 5**). **Considering the significant contribution of non-flow related factors to changes in the present ecosystem health in the Duiwenhoks Estuary (Table 5.2), as well as the reversibility of some of these impacts, Scenario 2 was identified as the recommended flow requirement scenario (Table 8.1).**

Table 8.1 Recommended flow scenarios for the Duiwenhoks Estuary (Category B)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	19.1	23.2	23.5	12.4	9.9	16.5	22.2	11.5	6.5	9.0	26.3	23.1
99	15.2	17.9	13.1	9.5	8.8	11.9	21.2	11.4	6.0	8.3	22.1	13.6
90	9.3	6.6	2.5	1.8	2.7	4.1	5.4	5.7	4.3	4.6	6.0	6.3
80	4.8	4.8	1.6	0.5	0.7	2.4	3.2	3.0	3.5	3.5	5.0	5.5
70	3.8	3.0	0.6	0.4	0.4	1.7	2.5	2.4	2.4	2.8	4.0	3.9
60	2.6	1.9	0.5	0.3	0.3	1.1	1.6	1.9	2.0	2.4	3.3	3.3
50	2.3	1.4	0.4	0.2	0.2	0.5	1.0	1.3	1.6	2.1	2.8	2.8
40	1.8	0.7	0.4	0.2	0.1	0.2	0.6	1.1	1.2	1.6	2.4	2.5
30	1.5	0.5	0.3	0.1	0.1	0.1	0.6	0.8	1.1	1.4	2.1	1.9
20	1.1	0.5	0.2	0.1	0.0	0.1	0.4	0.5	0.8	1.1	1.5	1.7
10	0.8	0.4	0.2	0.0	0.0	0.0	0.2	0.3	0.5	0.9	1.1	1.3
1	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.7	0.5
0.1	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.3

However, in order to improve from a Category B/C (Scenario 2 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 for Scenario 2 to be selected as ecological flow requirement scenario:

- Peat land upstream of the estuary is rehabilitated to improve the regulation of river inflow to the estuary so as to maintain an REI zone for longer periods;
- At least 10% of degraded estuarine habitat in the riparian zones are rehabilitated, including the removal of alien vegetation;
- Control/reduce fishing effort through improved compliance monitoring of fishing activities;
- Implement an alien fish control programme;
- Institute a control programme to reduce the number of Egyptian geese in the surrounding habitat.

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, 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 through which to facilitate the implementation these interventions.

8.2 ECOLOGICAL SPECIFICATIONS

The Ecological Specifications (EcoSpecs), as well as the Thresholds of Potential Concern (TPs), representative of a **Category B** for the Duiwenhoks Estuary are presented in **Table 8.2**.

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

Component	EcoSpecs	Thresholds of Potential Concern
Hydrology	Maintain flow regime as per recommended ecological flow	River inflow: ▪ < 0.1 m^3/s for more than one month a year ▪ < 1.0 m^3/s for more than three months a year
Hydrodynamics	Maintain connectivity with marine environment	Average tidal amplitude < 10% of present observed data from the water level recorder in the estuary near the mouth during low flows (summer)

Component	EcoSpecs	Thresholds of Potential Concern
Sediments	▪ 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 (8 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 8 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 5 km upstream from mouth > 20 more than three months of the year
	System variables (pH, dissolved oxygen and turbidity) not to cause exceedance of TPCs for biota (see below)	River inflow: ▪ 6.0 < pH > 7.5 ▪ 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: ▪ NOx-N >150 µg/ℓ over 2 consecutive months ▪ NH3-N > 20 µg/ℓ over 2 consecutive months ▪ PO4-P > 20 µg/ℓ over 2 consecutive months Estuary (except during upwelling or floods): ▪ Average NOx-N > 150 µg/ℓ single concentration > 200 µg/ℓ ▪ Average NH3-N > 20 µg/ℓ during survey, single concentration > 100 µg/ℓ ▪ Average PO4-P > 20 µg/ℓ during survey, single concentration > 50 µg/ℓ

Component	EcoSpecs	Thresholds of Potential Concern
	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 SA 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 five sites) exceeds 3.5 µg/ℓ ▪ Median intertidal benthic chlorophyll a (minimum five sites) exceeds 42 mg/m^2 ▪ Site specific chlorophyll a concentration exceeds 20 µg/ℓ and cell density exceeds 10 000 cells/ mℓ
Macrophytes	▪ Maintain the distribution of macrophyte habitats, particularly the salt marsh, reeds and sedges. ▪ Maintain the integrity of the salt marsh. ▪ Maintain the reed and sedge stands in the middle and upper reaches of the estuary. ▪ Rehabilitate 10% of the floodplain habitat by removing any agricultural berms and invasive plants. ▪ Maintain the integrity of the riparian zone	▪ Greater than 20 % change in the area covered by salt marsh and reeds and sedges (2013 survey) ▪ Increase in bare areas in the salt marsh because of a decrease in moisture and increase in salinity. Hypersaline sediment caused by evaporation, infrequent flooding or rainfall on this area. ▪ Loss and die-back of reeds fringing the estuary 5-10 km upstream from the mouth; salinity should not be greater than 20 for three months. ▪ Drying of floodplain habitat. Invasive plants (e.g. black wattle, prickly pear, Tamarix) cover > 5% of total floodplain area. ▪ Unvegetated, cleared areas along the banks caused by human disturbance.
Invertebrates	▪ Maintain presence of sand prawn *Callichirus kraussi* on sand banks in lower estuary ▪ Maintain the presence of REI species in the upper estuary for specific invertebrate communities associated with REI (zooplankton and benthos)	▪ Sand prawn density should not deviate from average baseline levels (as determined in the eight visits undertaken in the first two years) by more than 40 % in each season ▪ Dominant species in the REI zone (zooplankton and benthos) should not deviate from average baseline levels (as determined in the 8 visits undertaken 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. Numerically assemblage should comprise: ▪ Ia estuarine residents (50-80%) ▪ Ib marine and estuarine breeders (10-20%) ▪ IIa obligate estuarine-dependent (10-20%) ▪ IIb estuarine associated species (5-10%), ▪ IIc marine opportunists (20-80%) ▪ 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 < 50% ▪ IV indigenous fish < 1% ▪ V catadromous species < 1% 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 groups. 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 50 birds.	▪ Numbers of birds other than gulls, terns and regionally increasing species fall below 50 for three consecutive counts. ▪ Numbers of waterbird species drop below ten 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 are provided in **Table 8.3.** These components are all important to improve the confidence overall, particularly the sediment dynamics and invertebrate components which are of a high priority. The recommended long-term monitoring programme, the purpose of which is to test for compliance with EcoSpecs and TPC 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**, are 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 mechanisms to coordinate and execute this long-term monitoring programme.

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

Component	Action	Temporal scale (frequency and when)	Spatial scale (No. stations)
Sediment dynamics	Bathymetric surveys: Series of cross section profiles and a longitudinal profile collected at fixed 500m intervals, but in more detail in the mouth including the 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 organic content (and ideally origin, i.e. microscopic observations)	Once-off	Entire estuary
Water Quality	Collect samples for pesticides/herbicide and metal determinations in river inflow	Once-off	Near head of estuary (gauging station H8H001)
	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 (13 stations, coinciding with microalgae and invert sampling sites)
	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 (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, High Performance Liquid Chromatography or 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) ▪ Collect grab samples (5 replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each sample to be sieved through 500 µm) ▪ 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. ▪ Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton)	Quarterly, preferably over two years	Minimum of 3 sites along length of entire estuary. For hole counts – three sites on sandy substrata near the mouth (western shore).

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

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (No. stations)
Hydrodynamics	Record water levels	Continuous	Near the mouth of the estuary
	Measure freshwater inflow into the estuary	Continuous	Near head of estuary (H8H001)
	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 (No. stations)
	Bathymetric surveys: Series of cross section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detail in the mouth including the 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 organic content (and ideally origin, i.e. microscopic observations)	Every three years	Entire estuary
Water quality	Collect data on 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 (H8H001)
	Collect samples for pesticides/herbicide and metal determinations in river inflow	Every 3 – 6 years if baseline shows contamination	Near head of estuary (H8H001)
	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 (above 16 km from mouth)
	Record longitudinal *in situ* salinity and temperature pH, DO, turbidity profiles	Seasonally	Entire estuary (13 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 (13 stations, coinciding with microalgae and invert sampling sites)
	Measure pesticides/herbicides and metal accumulation in sediments (for metals investigate establishment of distribution models – see Newmand and Watling, 2007)	Every 3 – 6 years, if results show contamination	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, High Performance Liquid Chromatography of 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 reaches (5-10 km). 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 thetransects 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 (transect sites as shown in Appendix C of this report)

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (No. stations)
Invertebrates	▪ Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh) ▪ Collect grab samples (5 replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each sample to be sieved through 500 μm). ▪ 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. ▪ Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton)	Every two years mid-summer	Minimum of three sites along length of entire estuary. For hole counts – three sites on sandy substrata near the mouth (western shore).
Fish	▪ Record species and abundance of fish, based on seine net and gill net sampling. Sampling with a small beam trawl for channel fish should also be considered. ▪ Seine net specifications: 30 m x 2m, 15 mm bar mesh seine with a 5 mm bar mesh with a 5mm bar mesh 5 m either side and including the cod-end ▪ Gill nets specifications: Set of gill nets each panel 30 m long by 2 m deep with mesh sizes of 44 mm, 48 mm, 51 mm, 54 mm, 75 mm, 100 mm and 145 mm ▪ Trawl specification: 2 m wide by 3 m long, 10 mm bar nylon mesh in the main net body and a 5 mm bar in the cod-end	Twice annually, Spring/Summer and autumn/winter	Entire estuary (10 stations) Spacing of station Stations ~ length/10
Birds	Undertake counts of all non-passerine water birds, identified to species level (see Appendix F of this report)	Annual winter and summer surveys	Entire estuary (about six sections, must be standardised)

9 REFERENCES

Adams, J.B. Bate, G.C. and M. O'Callaghan. 1999. Estuarine Primary Producers. In: (B.R. Allanson and D. Baird). Estuaries of South Africa. Cambridge University Press. pp 91-118. ISBN 978-0-521-58410-4.

Bate, G.C., Smailes, P.A. and Adams, J.B. 2004. Benthic diatoms in the rivers and estuaries of South Africa. WRC Report No. TT 234/04. Water Research Commission, Pretoria. 175 pp.

Carter, RA. and Brownlie, S. 1990. Estuaries of the Cape: Part II: Synopses of available information on individual Systems. Report number 34: Kafferkuils (CSW 24) and Duiwenhoks (CSW 23). Heydorn, AEF and Morant, PD (eds.). Stellenbosch, CSIR Report 433.

Coetzee D.J. 1983. Zoplankton and environmental conditions in a Southern Cape coastal Lake system. Journal of the Limnological Society of South Africa 9. 1-11.

Day J.H. 1981. Summaries of current knowledge of 43 estuaries in southern Africa. In: Estuarine Ecology with particular reference to southern Africa (ed. Day, J.H.), pp. 251-329. A.A. Balkema, Cape Town.

De Villiers S and Thiart C. 2007. The nutrient status of South African rivers: concentrations, trends and fluxes from the 1970s to 2005. South African Journal of Science 103: 343-349.

Department of Water Affairs (DWA), 2013. Reserve Determination Studies for Surface Water, Groundwater, Estuaries and Wetlands in the Gouritz Water Management Area: Inception Report. Prepared by AECOM (Pty) Ltd. and Scherman Colloty & Associates cc. Report no. RDM/WMA16/00/CON/0113.

Department of Water Affairs (DWA), 2014. Reserve Determination Studies for the Selected Surface Water, Groundwater, Estuaries and Wetlands in the Gouritz Water Management Area: Delineation Report, Volume 1. Prepared by Scherman Colloty & Associates cc. Report no. RDM/WMA16/00/CON/0313, Volume 1.

Department of Water Affairs and Forestry (DWAF) 2008. Resource Directed Measures for Protection of Water Resources: Methodologies for the determination of ecological water requirements for estuaries. Version 2. Pretoria.

Department of Water Affairs and Forestry (DWAF) 1995. South African Water Quality Guidelines for Coastal Marine Waters. Volume 1: Natural Environment. Pretoria.

Eagle GA and Bartlett PD. 1984. Preliminary chemical studies in four Cape estuaries. CSIR Report T/SEA 8307. CSIR, Stellenbosch.

Evans P.R. 1997. Improving the accuracy of predicting the local effects of habitat loss on shorebirds: Lessons from the Tees and Orwell estuary studies. In: JD Goss-Custard, R Rufino and A Luis (Eds), *Effect of habitat loss and change on waterbirds*, pp. 35–44. The Stationery Office, London.

Harrison, T.D., Hohls, D.R., Meara, T.P. and Webster, M.S. 2001. *South African Estuaries: Catchment Land-cover,* National Summary Report. DEAT, Cape Town.

Harrison, TD. 1999. A preliminary survey of the estuaries on the south coast of South Africa, Cape Agulhas – Cape St Blaize, Mossel Bay, with particular reference to the fish fauna. Transactions of the Royal Society of South Africa, 54 (2): 285-310.

Hart R.C. Allanson B.R. 1976. The distribution and diel vertical migration of *Pseudodiaptomus hessei* (Mrázek)(Calanoidea,; Copepoda) in a subtropical lake in southern Africa. Freshwater Biology 6. 183-198.

Hart R.C. 1979. The invertebrate communities: zooplankton, zoobenthos and littoral fauna. In: Lake Sibaya. (B.R. Allanson, ed.), W. Junk, The Hague: 108-161.

Hockey P.A.R. and Turpie J.K. 1999. The ecology of estuarine birds. In: BR Allanson and D Baird (Eds), *Estuaries of South Africa*. Cambridge University Press.

James, N.C and Harrison, T.D. 2008. A preliminary survey of the estuaries on the south coast of South Africa, Cape St Blaize, Mossel Bay – Robberg Peninsula, Plettenberg Bay, with particular reference to the fish fauna. Transactions of the Royal Society of South Africa 63(2): 111-127.

Kibirige I. and Perissinotto R. 2003. The zooplankton community of the Mpenjati Estuary, a South African temporary open/closed system. Estuarine, Coastal and Shelf Science 58: 727-741.

Lange-Bertalot, H. (ed.) 2000. Iconographia Diatomologica, Volume 7. Koeltz Scientific Books, Germany. 925 pp.

Lemley, DA. 2015. Assessing symptoms of eutrophication in estuaries. MSc thesis, Nelson Mandela Metropolitan University, Port Elizabeth.

Naidoo, L. 2014. Vegetation and sediment characteristics of the salt marshes of the Duiwenhoks Estuary. Unpublished Honours project. Department of Botany, Nelson Mandela Metropolitan University, Port Elizabeth. pp. 53.

Newman, BK and Watling, RJ. 2007. Definition of baseline metal concentrations for assessing metal enrichment of sediment form south-eastern Cape coastline of South Africa. Water SA 33: 675-691.

Ryan, P.G., Underhill, L.G., Cooper, J. and Waltner, M. 1988. Waders (Charadrii) and other waterbirds on the coast, adjacent wetlands and offshore islands of southwestern Cape Province, South Africa. *Bontebok* **6**: 1-19

Sims, P.A. (ed.) 1996. An Atlas of British Diatoms. Biopress Ltd., Bristol, England. 601 pp.

Snow, GC. 2008. Contribution to the use of microalgae in estuarine freshwater reserve determinations. Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy, Nelson Mandela Metropolitan University, Port Elizabeth.

Summers, R.N., Pringle, J.S. and Cooper, J. 1976. *The status of coastal waders in the South Western Cape South Africa*. Cape Town. Percy FitzPatrick Institute of African Ornithology. 162pp.

Tabot, P.T. and Adams J.B. 2013. Ecophysiology of salt marsh plants and predicted responses to climate change in South Africa. *Ocean and Coastal Management* 80: 89-99.

Taylor, G.C., Archibald, C.G.M. and Harding, W.R. 2007. An illustrated guide to some common diatom species from South Africa. WRC Report No. TT 282/07. Water Research Commission, Pretoria. 212 pp.

Turpie J.K. and Hockey P.A.R. 1997. Adaptive variation in the foraging behaviour of Grey Plovers *Pluvialis squatarola* and Whimbrels *Numenius phaeopus*. *Ibis* **139**: 289–298.

Turpie, JK. and Clark, B. 2007. Development of a conservation plan for temperate South African estuaries on the basis of biodiversity importance, ecosystem health and economic costs and benefits. Report prepared by Anchor Environmental Consultants CC for the C.A.P.E. Regional Estuarine Management Programme and CapeNature.

Underhill, L.G. and Cooper J.1984. Counts of waterbirds at coastal wetlands in Southern Africa 1978-1981. Western Cape Wader Study Group and Percy FitzPatrick Institute of African Ornithology, Cape Town (unpublished report).

UNEP/Nairobi Convention Secretariat and CSIR. 2009. Guidelines for the Establishment of Environmental Quality Objectives and Targets in the Coastal Zone of the Western Indian Ocean (WIO) Region, UNEP, Nairobi, Kenya, 169p.

Van Niekerk, L, Taljaard, S, Adams, JB, Fundisi, D, Huizinga, P, Lamberth, SJ, Mallory, S, Snow, GC, Turpie, JK, Whitfield, AK and Wooldridge, TH. 2014. Desktop provisional EcoClassification of the temperate estuaries of South Africa. Water Research Commission Report No. K5/2187. Pretoria.

Van Niekerk L and Turpie JK. (eds). 2012. National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report Number CSIR/NRE/ECOS/ER/2011/0045/B. Council for Scientific and Industrial Research, Stellenbosch. Available at: http://bgis.sanbi.org/nba/project.asp.

Wentworth CK. 1922. A scale of grade and class terms for clastic sediment. Journal of Geology 30: 377-392.

Wooldridge T.H. and Loubser, H. 1996. Larval release rhythms and tidal exchange in the estuarine mudprawn *Upogebia africana*. Hydrobiologia 337. 113-121.

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 (Annexure A2) CSIR unpublished data
Continuous flow gauging: Minimum of 5 years depending on mouth closure	Available from 1967	DWS flow gauge:H8H001
Water level recordings and mouth observations: Minimum of 5 years depending on rate of mouth closure	Not available	
Water levels along estuary: Manually/digital recorded over one spring tidal cycle and one neap tidal cycle or continuous recordings over two weeks	Not available	
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	EC, pH Inorganic Nutrients (1977-2013)	DWA water quality monitoring programme (H8H001) De Villiers and Thiart (2007)
Longitudinal salinity and temperature profiles (in situ) collected over high and low flow period (or closed state for temporarily open estuaries)	May 2003, Jan 2004, May 2004, Aug 2004, Mar 2006, Feb 2007, Aug 2008, Dec 2009,Mar 2011 Mar and Aug 1985 Dec 2013	CSIR and DAFF (unpublished data) Carter and Brownlie (1990) This study (see Annexure A2 for data)

Data required	Availability	Reference
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 (Jan 2004, Mar 2004) pH DO, Inorganic Nutrients (Mar and Aug 1985) pH, Turbidity, DO, Inorganic Nutrients (Dec 2013)	CSIR and DAFF (unpublished data) Carter and Brownlie (1990) This study (see Annexure A2 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 BATHYMETRY

A.2.1 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 has been 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 is used. The rangefinder is used to determine the positions of the soundings (usually recorded as *distance [in m] from west bank*) across a section. The position of each cross section is usually verified using geographical position fixing systems (GPS). At the time of the survey, the water level is also recorded at the mouth so as to correct the data to mean sea level (MSL). However, 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 is within 0.10 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 types 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 is normally pre-determined on an ortho-photo map. The cross section is then surveyed in the field at the approximate location. The cross section positions are given in **Figures A.1** and **A.2**.

A.2.2 Mouth surveys

The mouth surveys were done using a 'wading survey' technique, which is performed by using standard line surveying techniques (**Figure A.3**). A survey team member transverses the survey lines holding a rod supporting a surveying prism, stopping at appropriate intervals to allow an instrument operator to read and record the distance and horizontal and vertical angles. The wading survey is continued seaward into the water until the rod holder can no longer stand steady with the survey rod. The land section is done preferably at low tide so that readings extend as far seaward as possible. The electronic surveying instrument provides distance measurement accuracies of 5 mm. The angle measurements were done with an electronic single second theodolite.

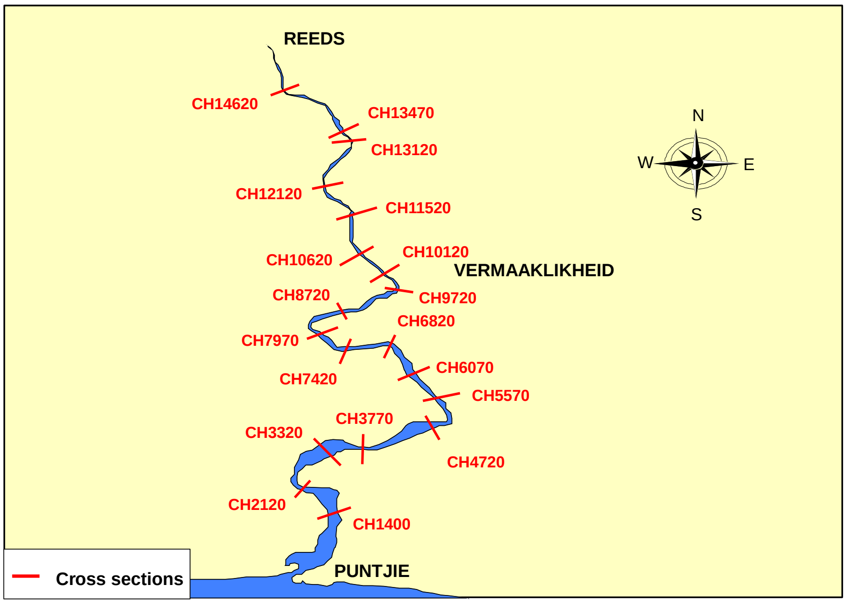


Figure A.1 Location of cross-section profiles taken in the Duiwenhoks Estuary

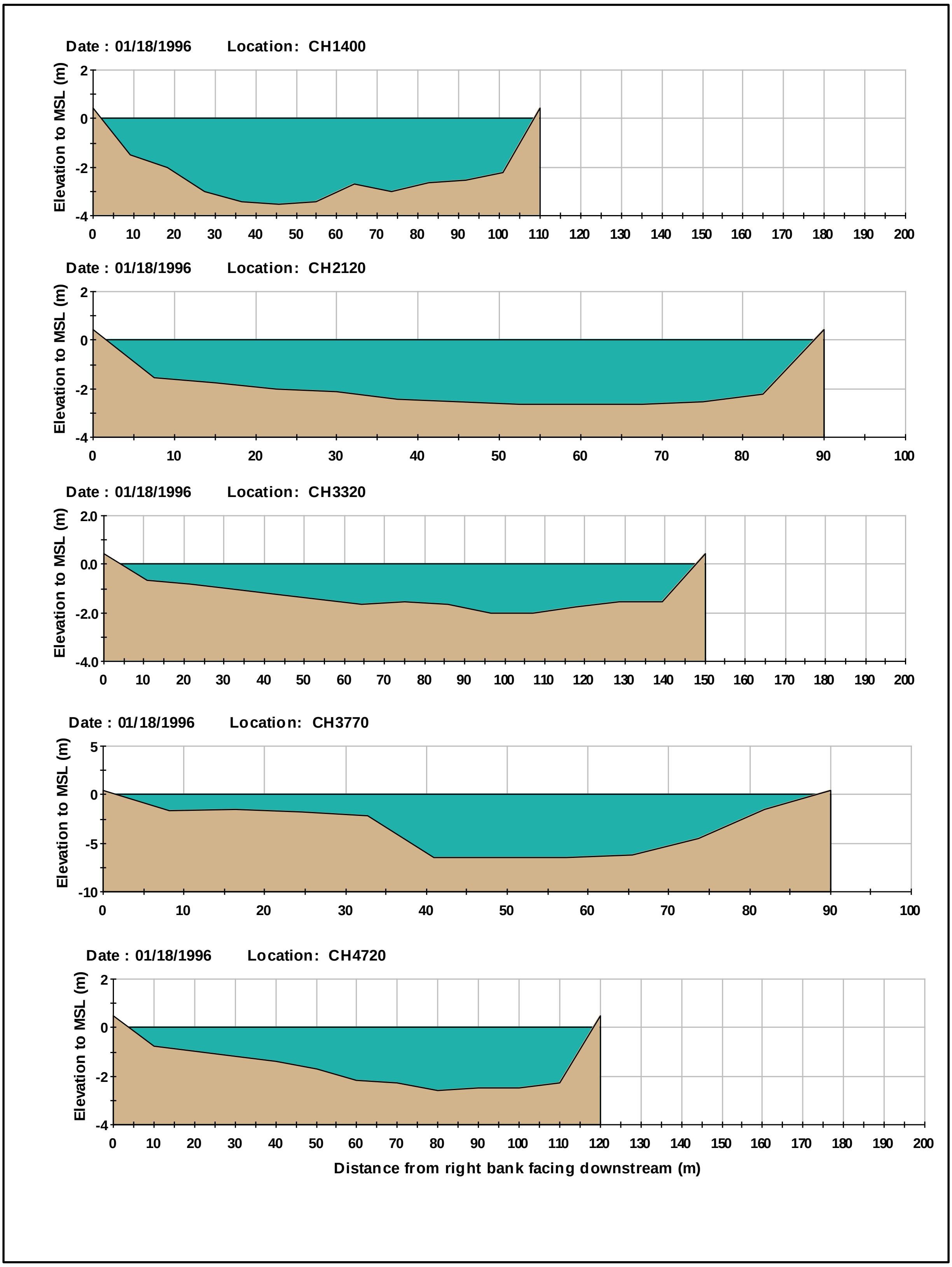


Figure A.2a Duiwenhoks Estuary: Cross section profiles – 18 January 1996

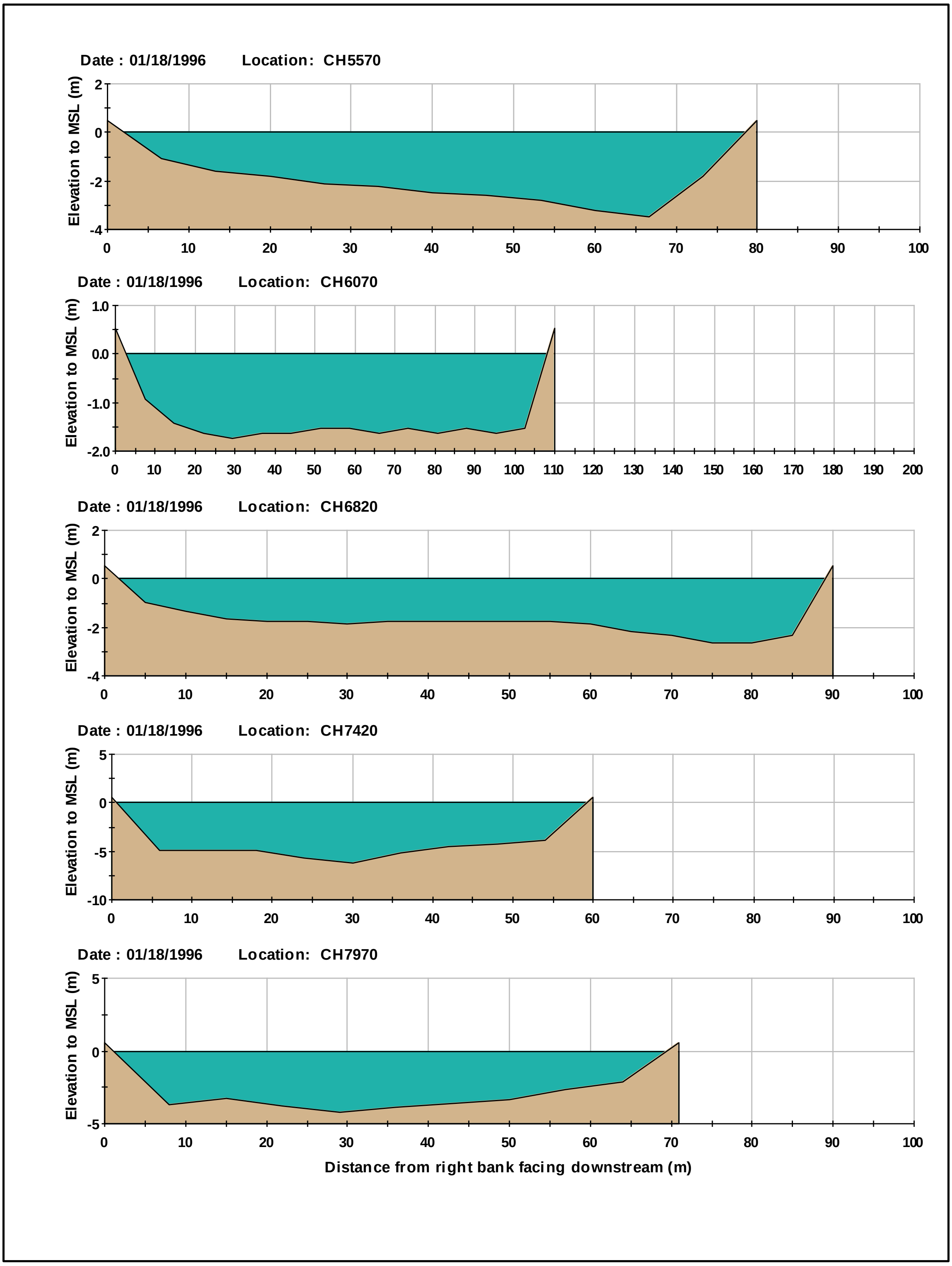


Figure A.2b Duiwenhoks Estuary: Cross section profiles – 18 January 1996

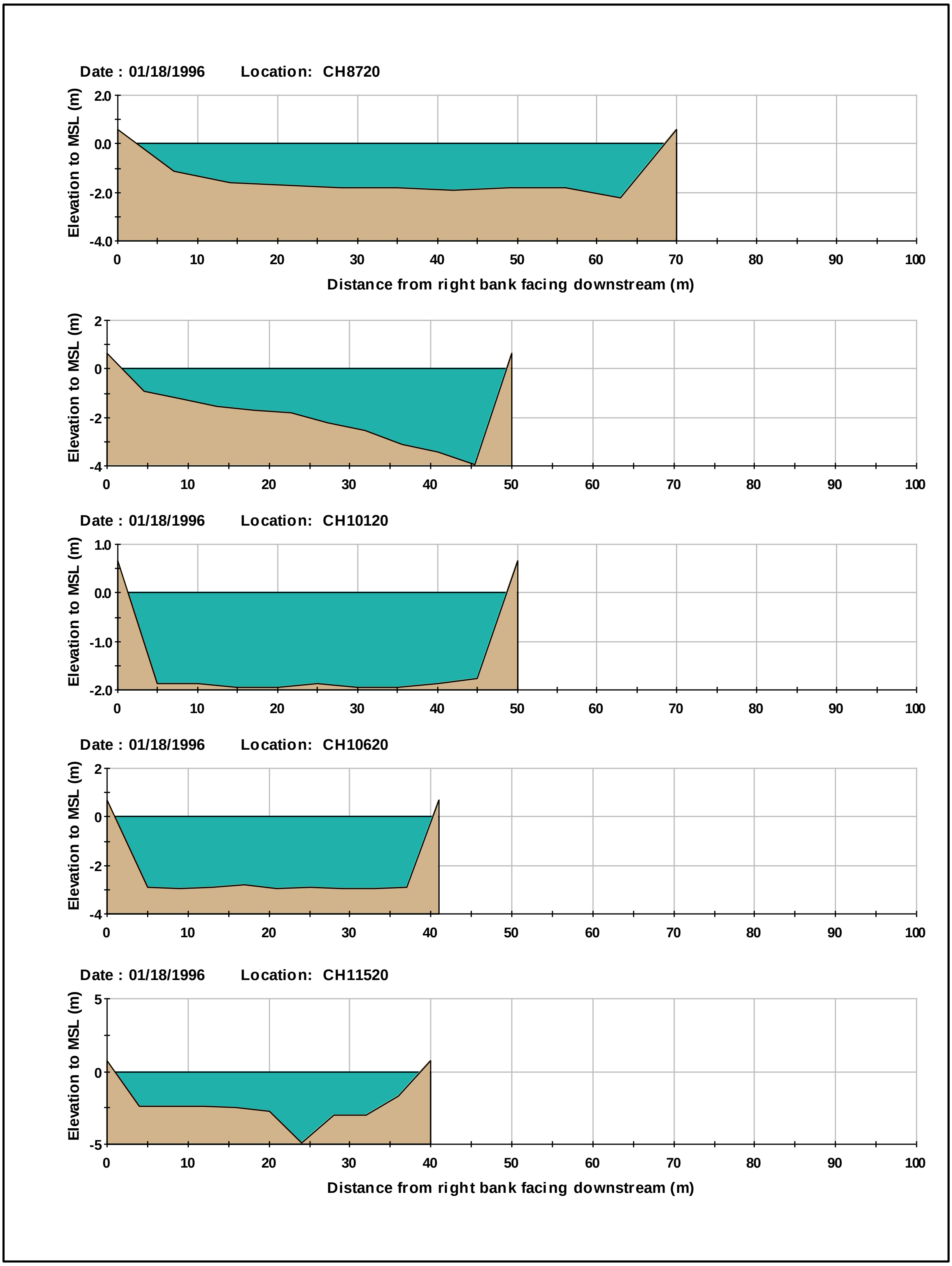


Figure A.2c Duiwenhoks Estuary: Cross section profiles – 18 January 1996

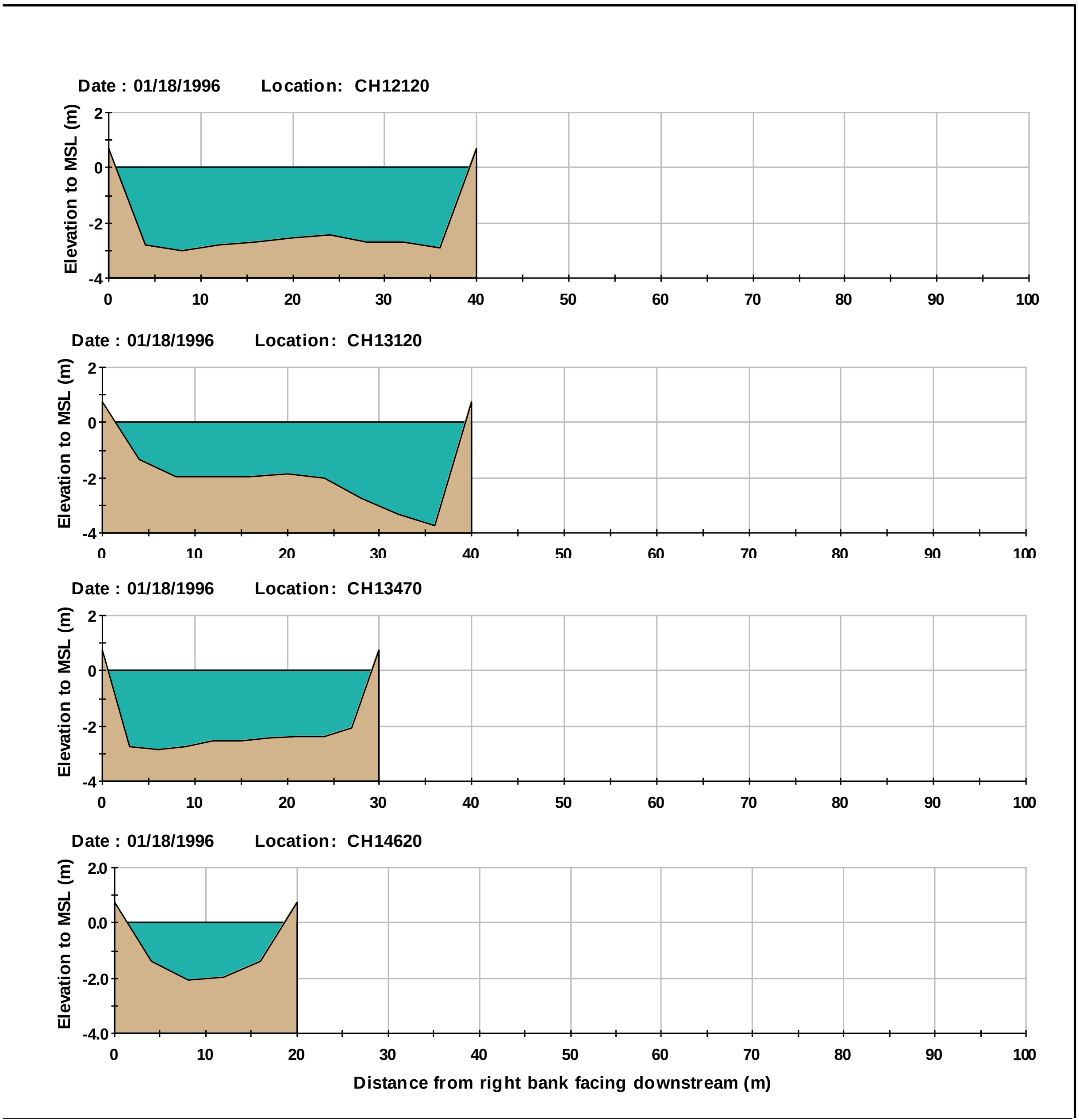


Figure A.2d Duiwenhoks Estuary: Cross section profiles - 18 January 1996

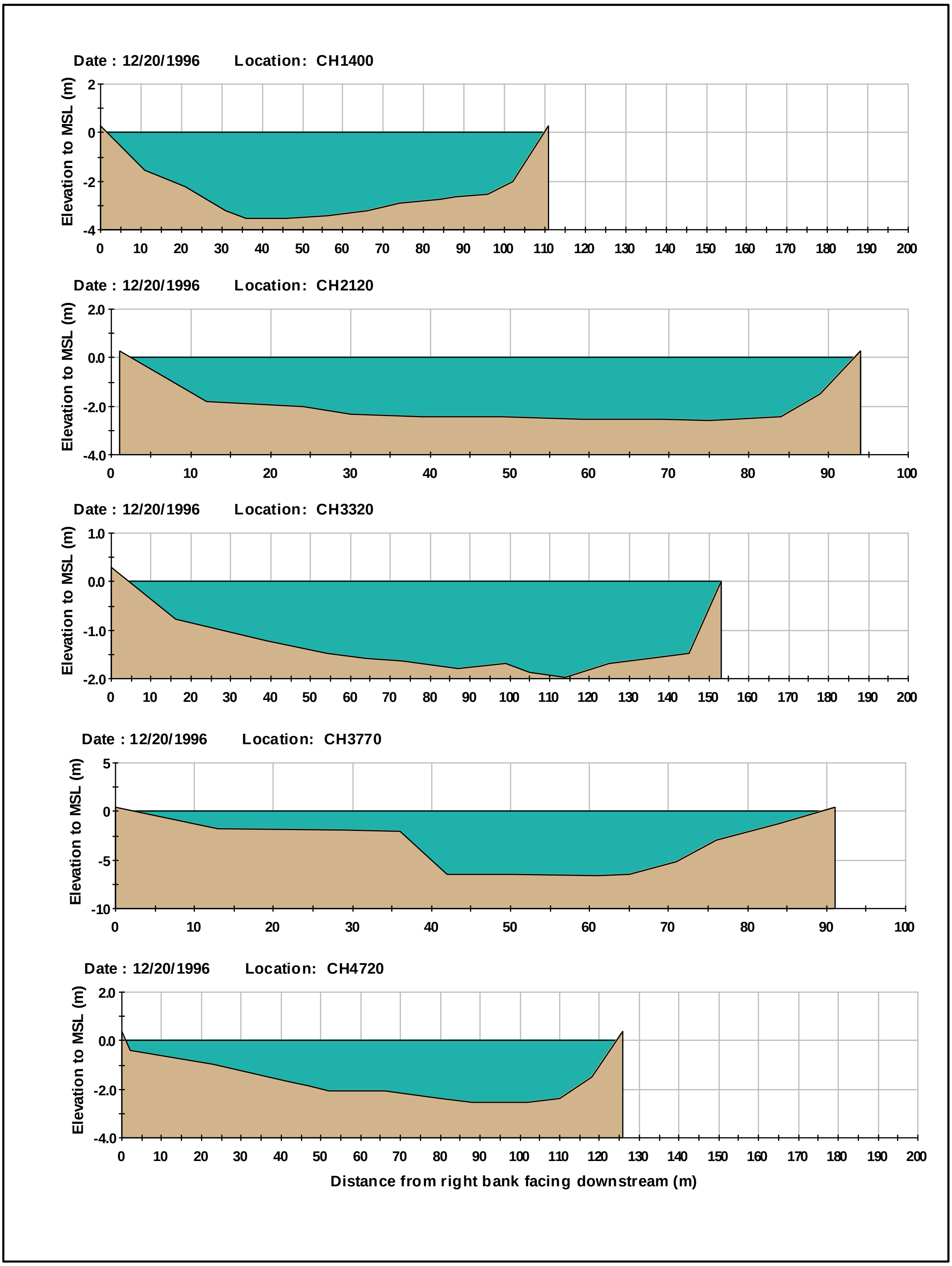


Figure A.2e Duiwenhoks Estuary: Cross section profiles – 12 December 1996

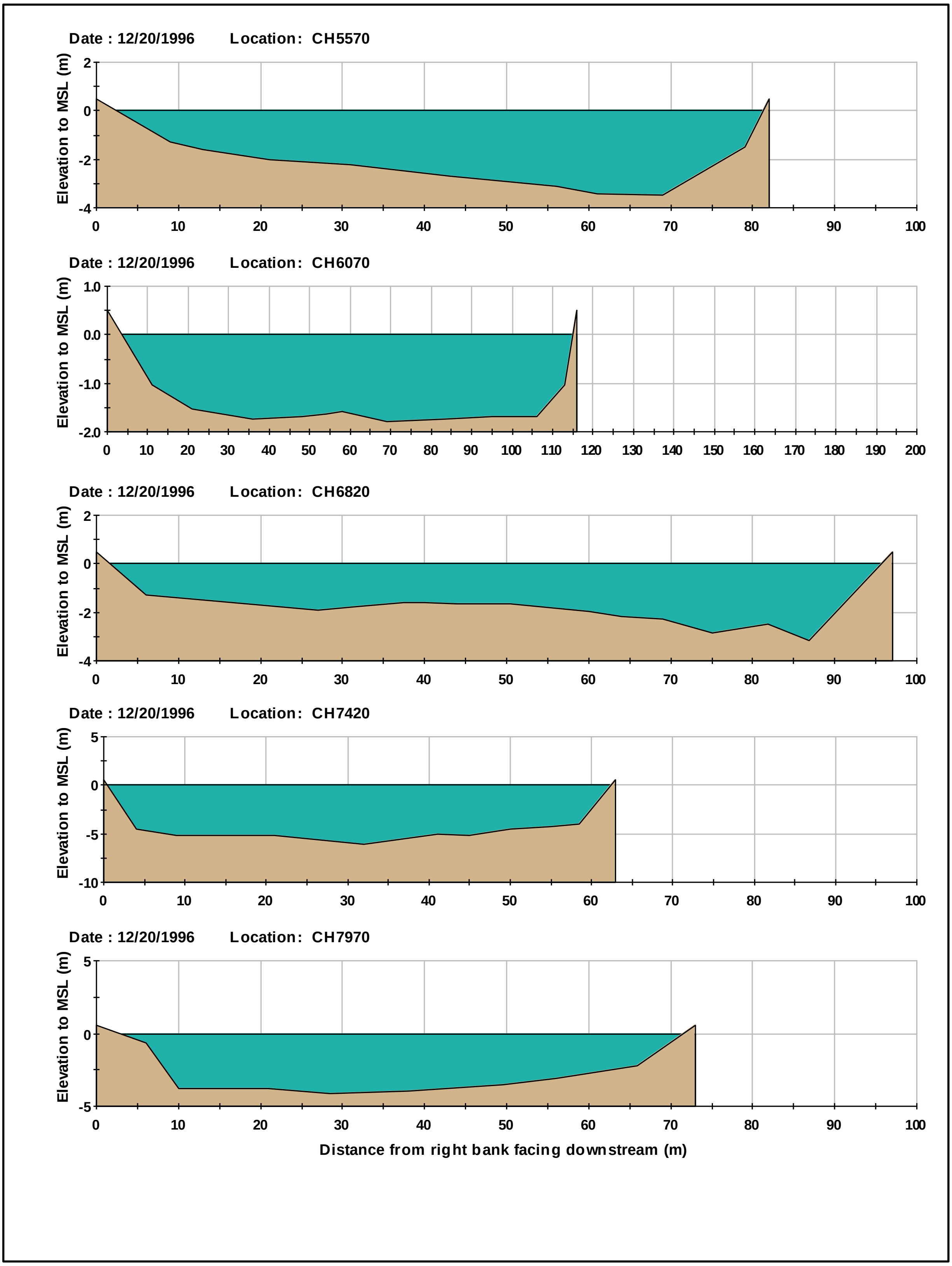


Figure A.2f Duiwenhoks Estuary: Cross section profiles – 12 December 1996

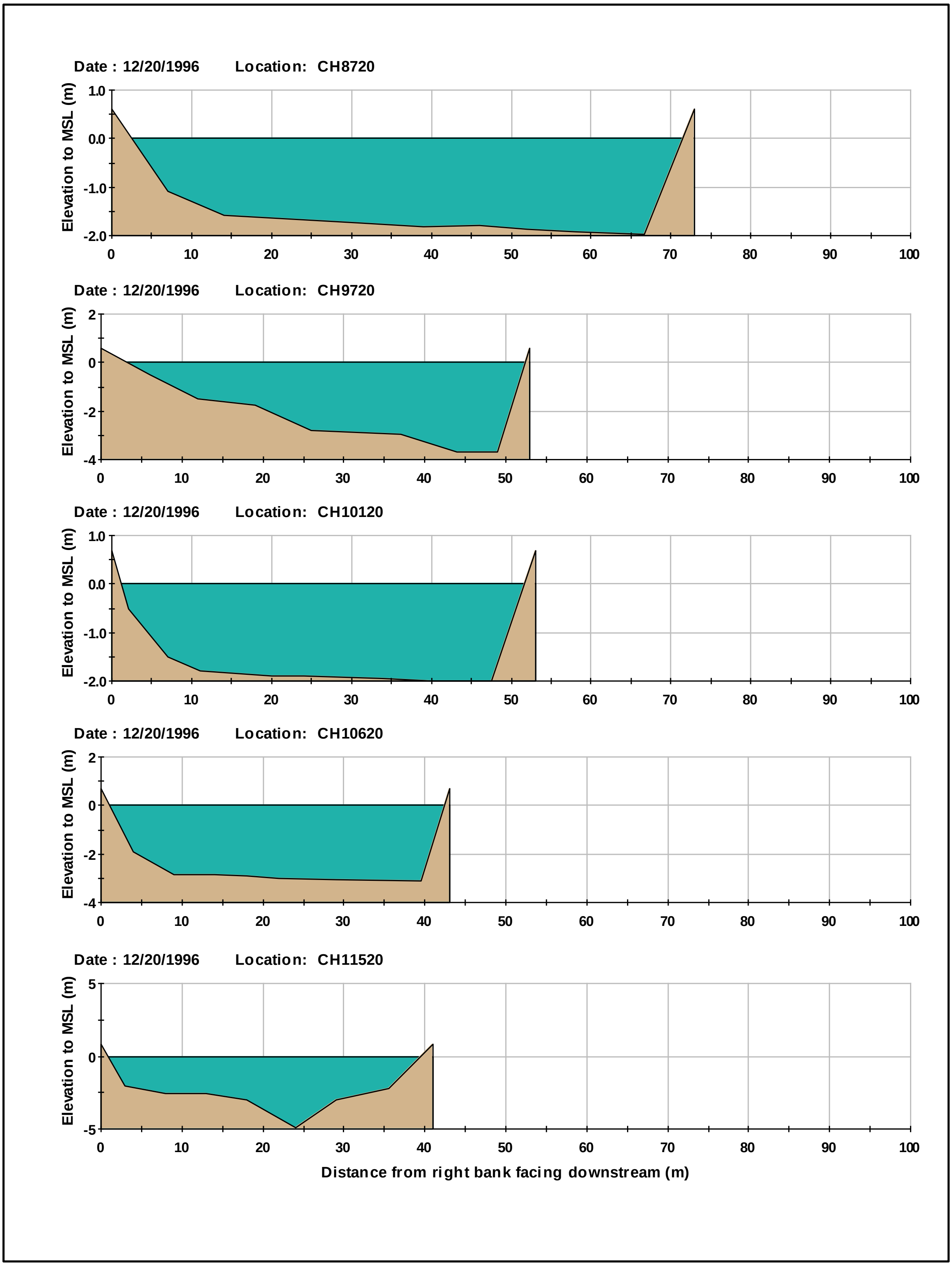


Figure A.2g Duiwenhoks Estuary: Cross section profiles – 12 December 1996

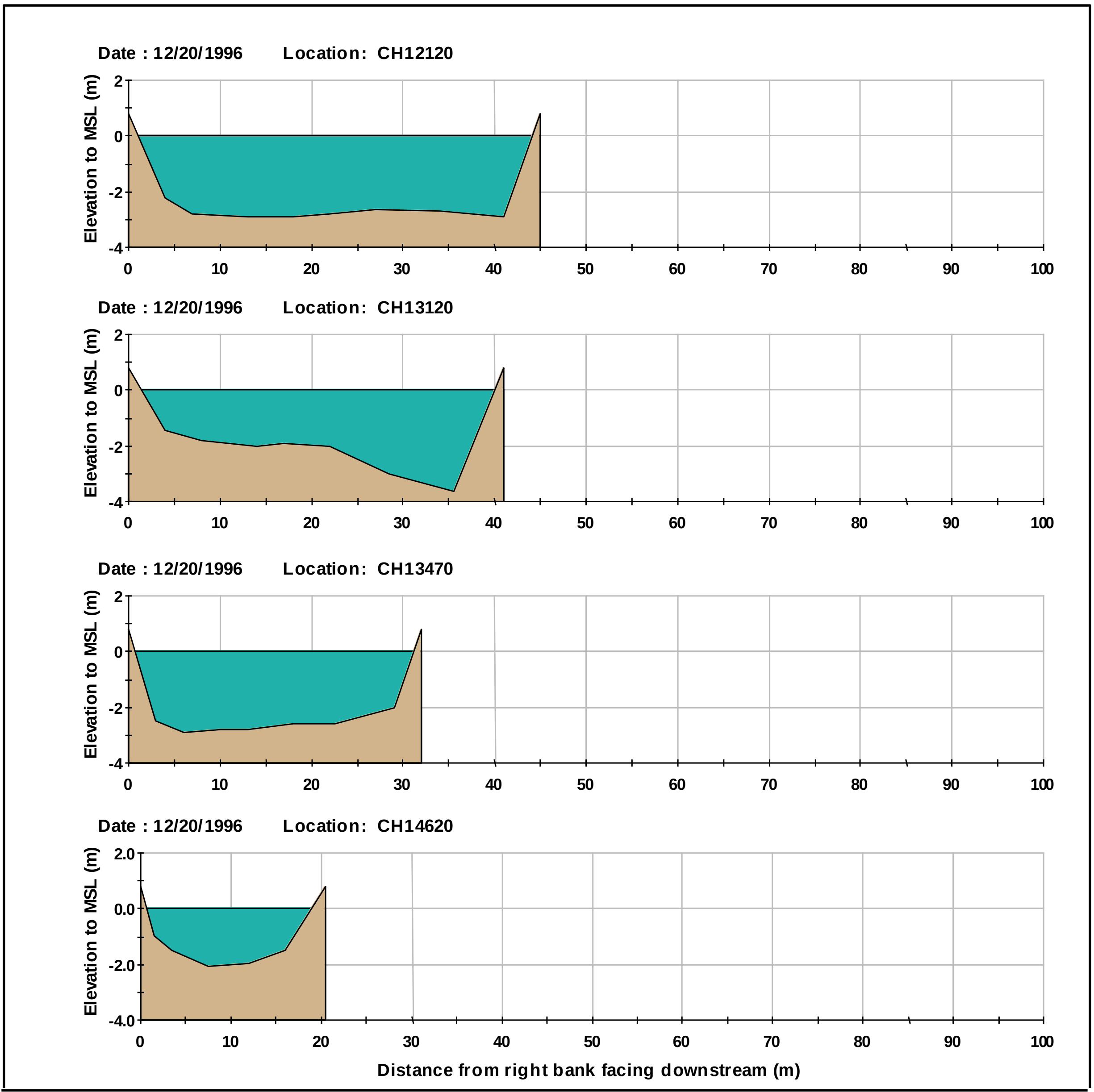
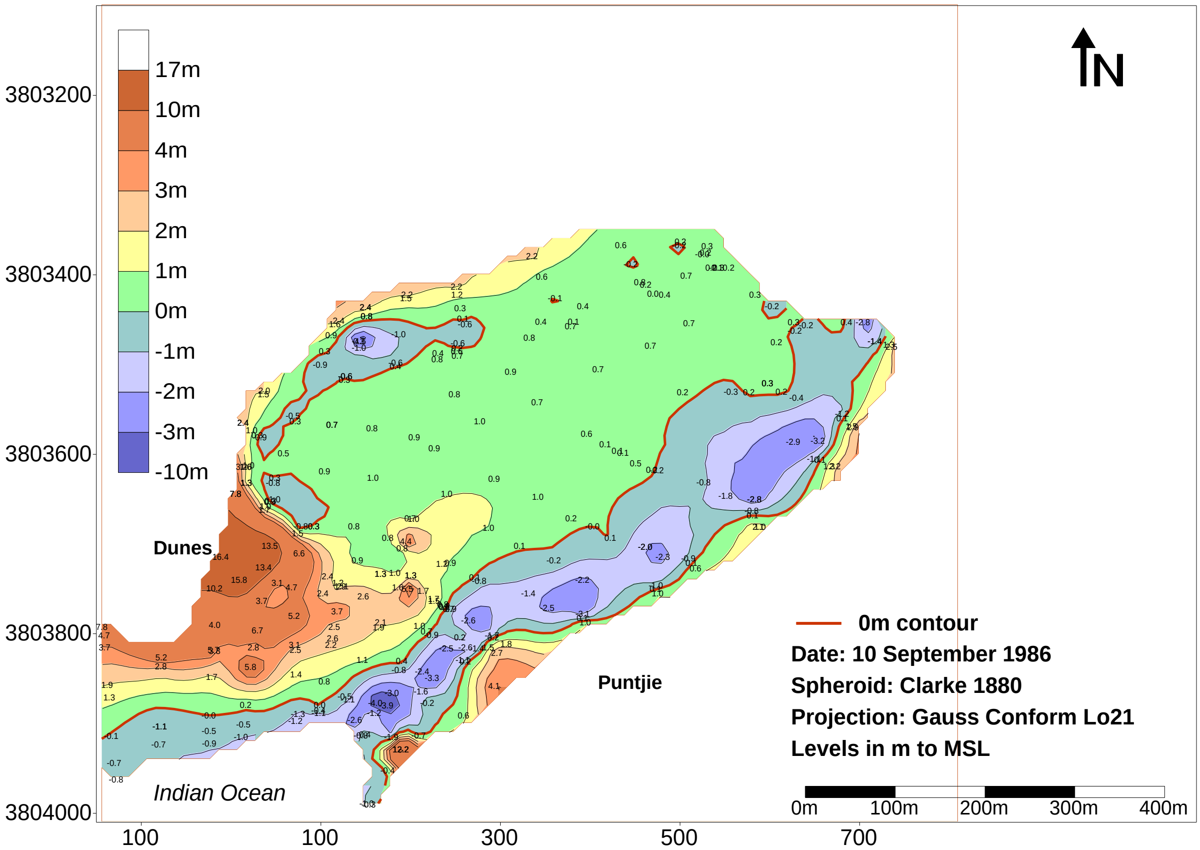


Figure A.2h Duiwenhoks Estuary: Cross section profiles – 12 December 1996



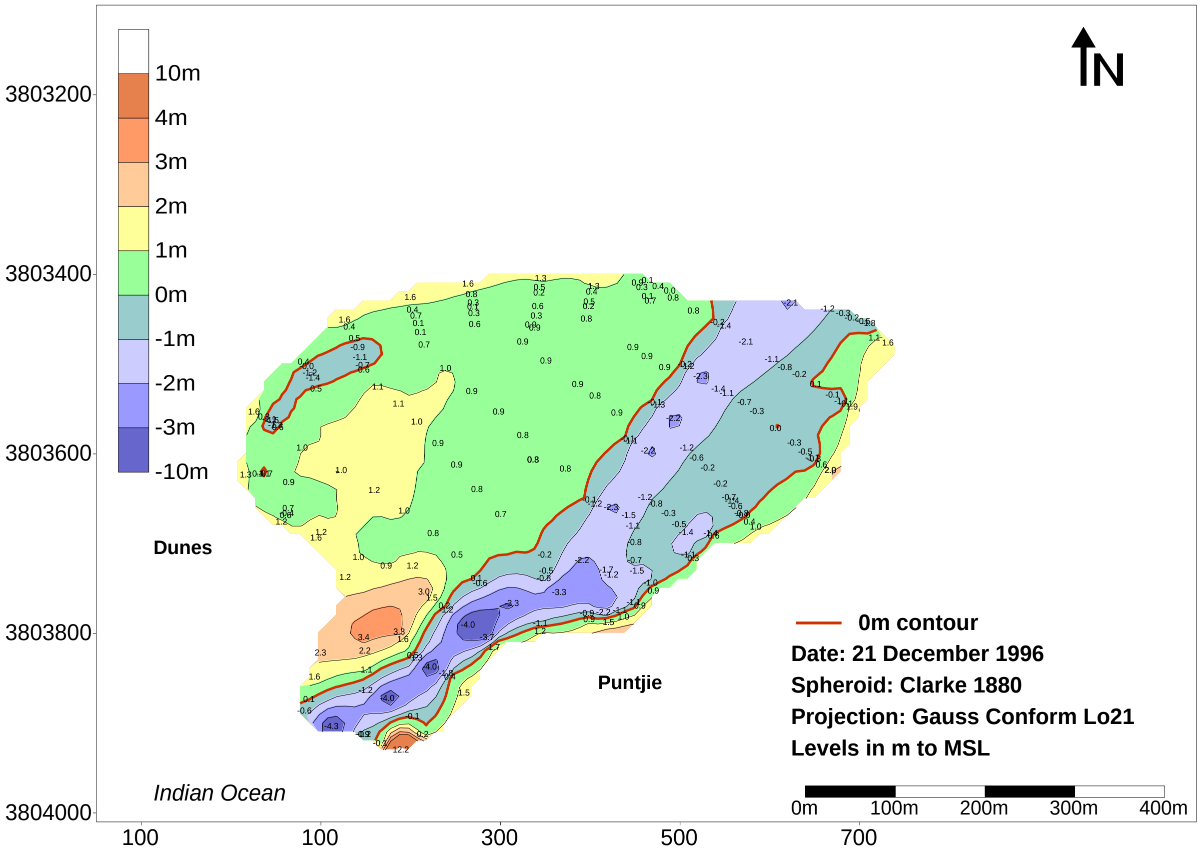


Figure A.3 Duiwenhoks Estuary: Mouth survey contour plots – 1986 and 1996

A.3 SEDIMENT DYNAMICS

Very little quantitative data is available on sediment dynamics and estuarine morphology of the Duiwenhoks Estuary. The main sources of information on these aspects are Carter and Brownlie (1990). Sediment samples were collected in the mouth (between the high and low water mark) of the Duiwenhoks Estuary. Sediment grain size analyses for January 1996 are listed in **Table A.1**, while data collected in the estuary on 4 December 2013 are presented in **Annexure A1**.

Table A.1 Sediment grain size analysis – 18 January 1996

Percentage distribution	Grain size in (µm)
D_{10}	177
D_{16}	190
D_{25}	206
D_{35}	220
D_{50}	241
D_{60}	254
D_{65}	260
D_{75}	275
D_{84}	294
D_{90}	327

A.3.1 Pertinent morphologic and sediment dynamics characteristics and drivers

The bathymetric surveys conducted in January and December of 1996 (**Figure A.2**) indicate that from about 1.5 km upstream of the mouth to the head of the estuary, the main channel configuration did not change significantly, besides typical smaller local variations in the bottom. The bathymetric surveys of the basin area adjacent to the mouth conducted in September 1986 and December 1996 showed more pronounced changes in the main channel configuration, but entirely typical of the dynamics related to river floods and tidal flows. Based on the bathymetric surveys reported (**Figure A.2**), it can be said that the main estuary channel has depths ranging from about -1.5 m to -5 m to MSL, with most of the channel having depths of -2 m to -3 m to MSL. Besides the basin area adjacent to the mouth, the widest point in the estuary is at about 3.3 km upstream of the mouth where the channel width is in the order of 150 m. At about 7 km from the mouth the channel width is typically in the order of 90 m from where it progressively narrows to about 20 m near the head of the estuary some 14.6 km upstream of the mouth.

The Duiwenhoks River upper catchment consists of Table Mountain sandstone; the river then passes through 13 km of highly erosive Cretaceous sedimentary rocks of the Enon formation which particularly consist of clays and conglomerates, followed by 20 km of shales (Carter and Brownlie, 1990). The estuarine reaches cut through limestone overlain by Quaternary sands.

The sediment sample collected from the mouth area on 18 January 1996 had a median grain size of 0.24 mm which is just inside the limit of fine sands based on the Udden-Wentworth classification (Wentworth, 1922).

Significant changes in morphologic and sediment dynamics characteristics and drivers:

- No large dams; the Duiwenhoks Dam has a capacity of about 6 million m^3, thus about 7% of natural MAR. Farm dams, run-of-river abstraction and Duiwenhoks dam reduce MAR by 18%. Evaluation of the 95%ile, 99%ile and 99.9%ile shows that flood events occur relatively untransformed from Reference Condition to Present State, i.e. between 5 and 7% change from Reference. The 10 largest floods over the preceding 85 years have reduced floods by an average of about 4%. Thus slightly reduced mobility and flushing of sediments in the estuary, and increased penetration of marine sediments.
- The dams will preferentially trap a larger proportion of the coarser sediments, but have low sediment trapping efficiency and capacity.
- Significant agricultural activities in the catchment (nearly 50% cultivation) lead to increased land erosion and thus sediment yield to the estuary.
- A 10 m wide channel was blasted through the reefs on the seaward side of the mouth to allow for launching of fishing boats from the estuary. This channel is likely to slightly reduce the asymmetry of the tidal flow regime in the estuary by slightly increasing the velocity of the ebb-tide outflow, thus affecting sediment transport.
- Also, the channel blasted through the reefs adjacent to the mouth will tend to keep the mouth opposite this channel, thus reducing natural mouth location variations.
- A further effect related to this is that the mouth channel is less likely to meander to the western side of the mouth area. Thus the remnant channel on the western side of the large sandbank just inside the mouth (western side) in less likely to be “rejuvenated” and this sandbank may become more stable and colonised by vegetation.
- Short section of access road constructed along the eastern bank of the estuary in the lower reaches (Zone A).
- Limited agricultural cultivation within the floodplain.
- Limited grazing and trampling of salt marshes.

A.4 WATER QUALITY

Sampling position for the December 2013 survey (see **Annexure A2** for data) are indicated in **Figure A.4**.

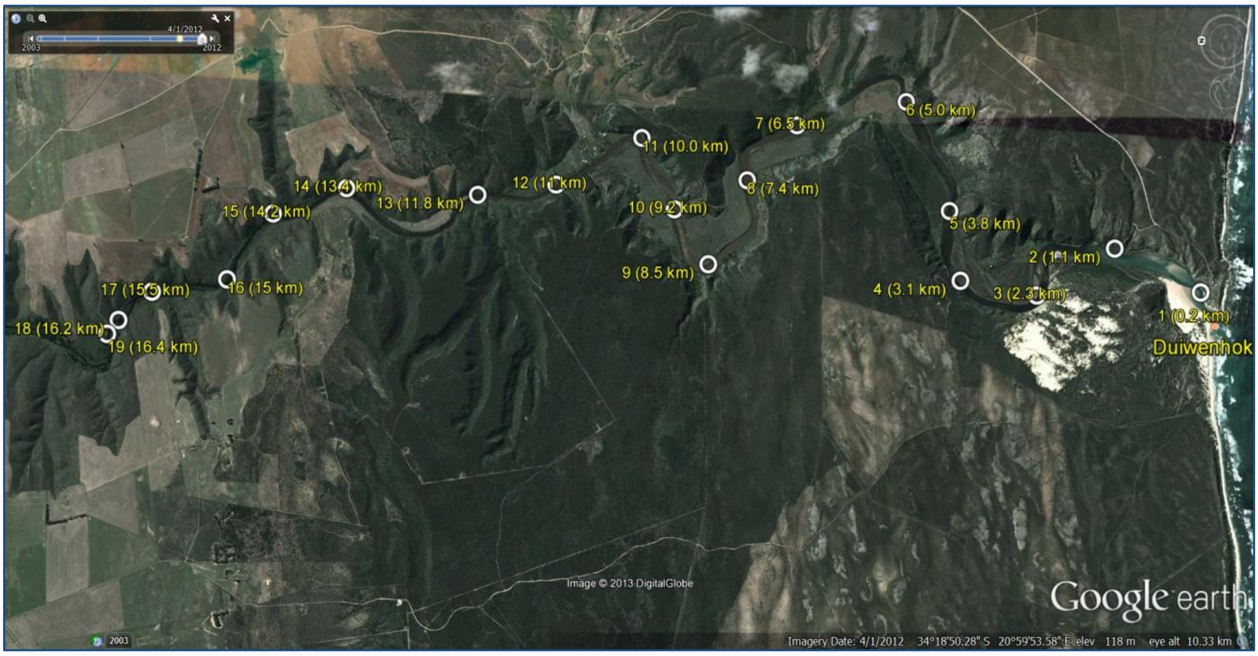


Figure A.4 Position of water quality sampling stations in the Duiwenhoks Estuary

A.4.1 Electrical Conductivity/Salinity

Variability in Electrical Conductivity (EC) measured in the Duiwenhoks River (at a position approximately 19 km from the mouth [H8H001]) is presented in **Figure A.5a**.

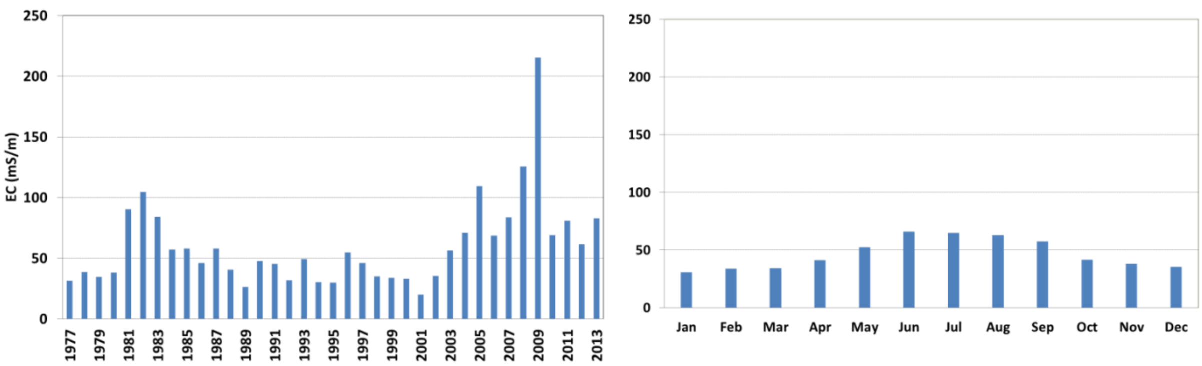


Figure A.5a Median annual and median monthly Electrical conductivity measured in the Duiwenhoks River (H8H001) (Source: http://www.dwaf.gov.za/iwqs/wms/data/WMS_pri_txt.asp)

Median annual levels show two periods when EC in the system was relatively higher, namely 1981-1984 and again 2005-2009 (**Figure A.5b**). Also, EC shows a marked seasonal pattern with highest values during the low flow period (Jun-Aug) in winter when the influence of anthropogenic sources on EC (e.g. agricultural return flows) will be most pronounced (such sources comprise a relatively larger fraction of inflow during low flow compared with high flow) Salinity profiles measured in the Duiwenhoks Estuary between 2003 and 2013 was correlated with river inflow (H8H001) and grouped in representative salinity distributions for the systems.

Under extreme low flow conditions, i.e. flows of about 0.1 m^3/s, salinity penetrates up the entire estuary, with salinity of 35 in Zone A, 35 to 30 in Zone B, 30 to 20 in Zone C and 10 to 15 in Zone D (**Figure A.5b**). Under these low flow conditions there is no River-Estuary Interface (REI). The salinity distribution is well mixed with little stratification. **Figure A.5b** also show salinity creep with measurements taken under 46 days of low flow conditions 5 to 10 higher than measurements taken under 20 days of a similar flow conditions.

Under the influence of between river inflow between 0.1 and 1.0 m^3/s salinity is 35 to 30 in Zone A, 30 to 20 in Zone B, 25 to 10 in Zone C and 20 to 0 in Zone D (**Figure A.5c**). A REI zone may develop under these flow conditions. The salinity distribution is well mixed with little stratification.

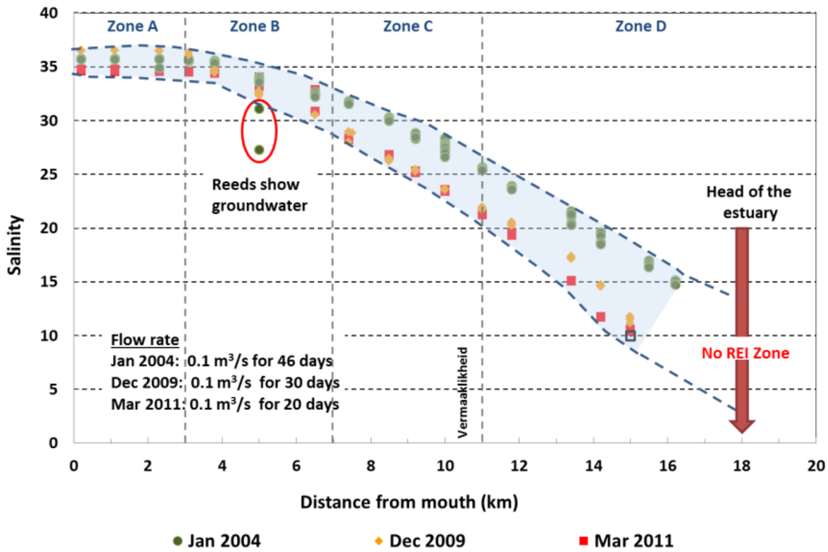


Figure A.5b Salinity distribution in the Duiwenhoks Estuary under very low flow conditions (~0.1 m^3/s)

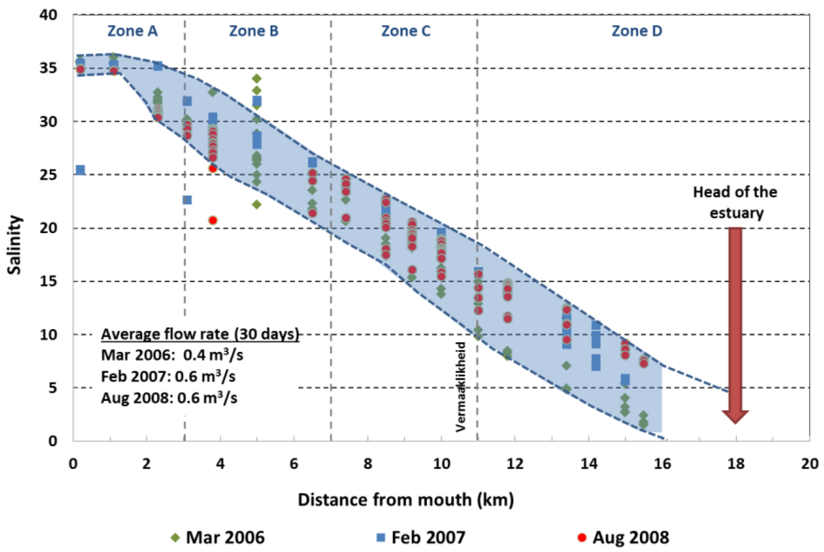


Figure A.5c Salinity distribution in the Duiwenhoks Estuary under low flow conditions (< 1.0 m^3/s)

Under the influence of river inflow between 1 and 3 m^3/s salinity is 35 to 30 in Zone A, 30 to 15 in Zone B, 20 to 5 in Zone C and 10 to 0 in Zone D (**Figure A.5d**). A REI zone will develop in the upper 4 to 6 km from the mouth. Strong stratification will develop in the deeper areas of the estuary, e.g. about 5, 10 and 13 km from the mouth. In these sections of the system, pockets of more saline water will form, while the surface water will become significantly fresher. In addition, strong lateral fronts will form in the stretch between 3 and 5 km from the mouth on the flood tide, with penetrating marine water hugging the outer bend, while the fresher resident water hugs the inner bend.

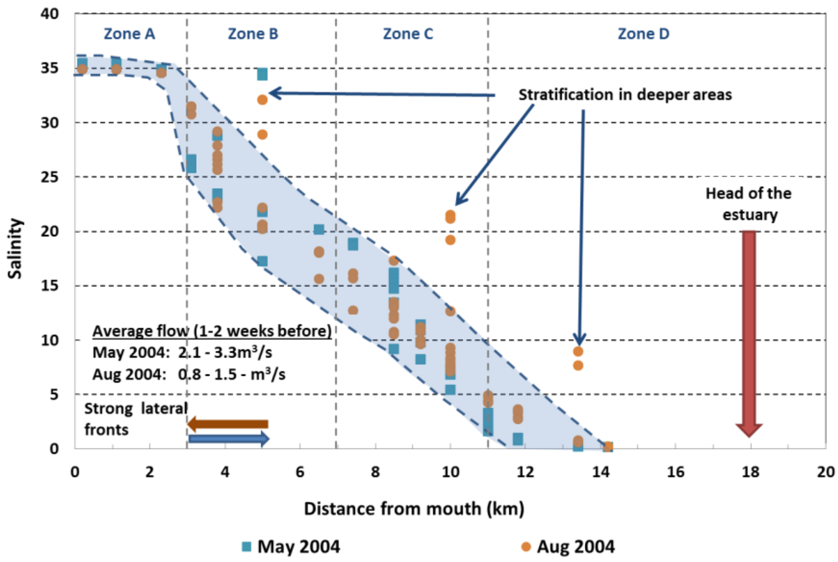


Figure A.5d Salinity distribution in the Duiwenhoks Estuary under average flow conditions (1.0 - 3.0 m^3/s)

Under the influence of river inflow greater than 10 m^3/s salinity is 35 to 10 in Zone A, 30 to 5 in Zone B, 25 to 0 in Zone C and 0 in Zone D (**Figure A.5e**). A REI zone will develop in the upper 8 to 10 km from the mouth. Very strong stratification will develop in the lower and middle reaches of the estuary. In addition, strong lateral fronts will form in the stretch between 3 and 5 km from the mouth on the flood tide, with penetrating marine water hugging the outer bend, while the fresh water persists along the inner bend.

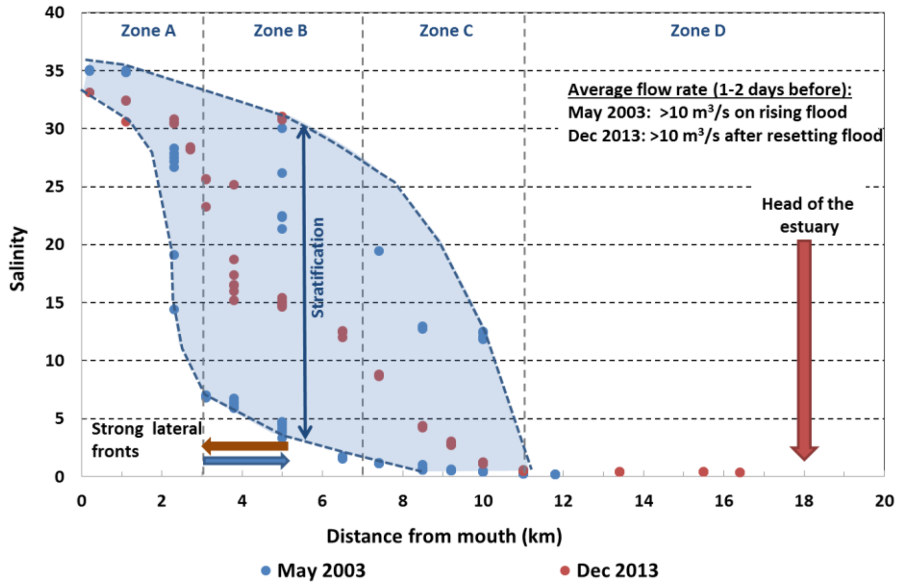


Figure A.5e Salinity distribution in the Duiwenhoks Estuary under high flow conditions (~10.0 m^3/s)

A.4.2 Temperature

Temperature measurements collected in the Duiwenhoks Estuary during once-off surveys in 1985 and 2013 are presented in **Figure A.6** (Carter and Brownlie,1990; this study).

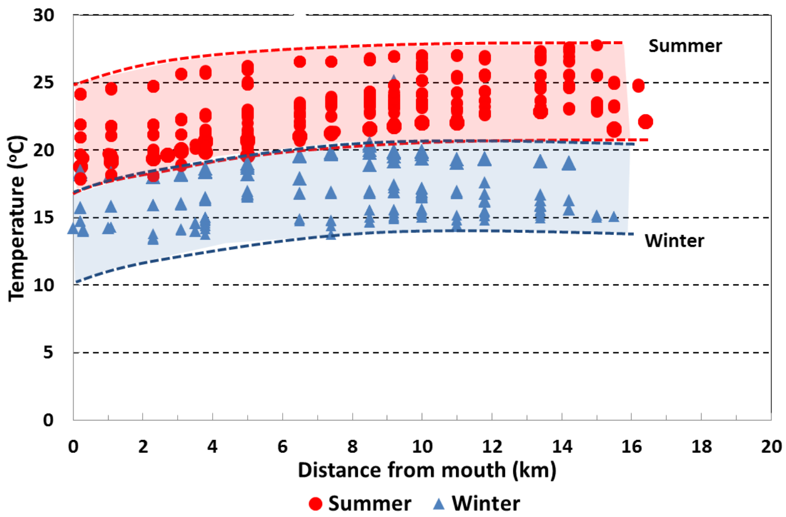


Figure A.6 Temperature measured along length of estuary of the Duiwenhoks Estuary during summer and winter surveys (Dec 2013 as well as DAFF unpublished)

Results show strong seasonal signals with highest temperature during summer (Dec/Mar) and lowest during winter (May/Aug). During the summer survey, temperature increased with decrease in salinity, showing the influence of colder (< 20°C) seawater in the lower reaches up to 4 km from the mouth. Such temperature can be significantly lower due to upwelling in summer when cold water (well below ambient temperature) is introduced to the estuary. Temperature during the winter (Aug) was < 15°C. Water temperature in the system therefore is primarily influenced by atmospheric condition and seawater temperature (lower reaches).

A.4.3 pH

Variability in pH measured in the Duiwenhoks River (approximately 19 km from the mouth [H8H001]) is presented in **Figure A.7a**.

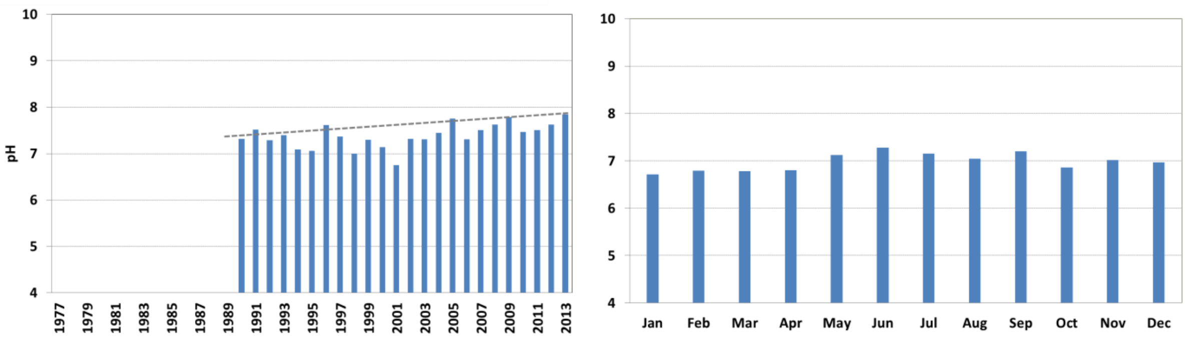


Figure A.7a Median annual and median monthly pH levels measured in the Duiwenhoks River (H8H001) (Source: http://www.dwaf.gov.za/iwqs/wms/data/WMS_pri_txt.asp)

Although low pH levels recorded in the river prior to 1990, are most likely attributed to a systematic error in measurement technique and where therefore not included (M Silberbauer, DWS, pers. comm.). Since 1990 there appears to be a gradual increase river pH. Low pH levels (acidic) are expected in a black water system like the Duiwenhoks. However, marked increase in agricultural activities in the catchment is most likely the reason for the gradual increase in pH in this weakly buffered system. Median monthly data suggest a weak seasonal signal, with highest pH levels during the low flow periods (winter). Monthly median pH levels ranged from 6.9 to 7.2.

pH levels measured in the Duiwenhoks Estuary generally increased with increase in salinity, ranging between 7 and 8 (**Figure A.7b**) This is expected as pH in seawater is generally higher (8.0-8.2) compared with freshwater (< 8.0). There was also no marked difference between high and low flow periods.

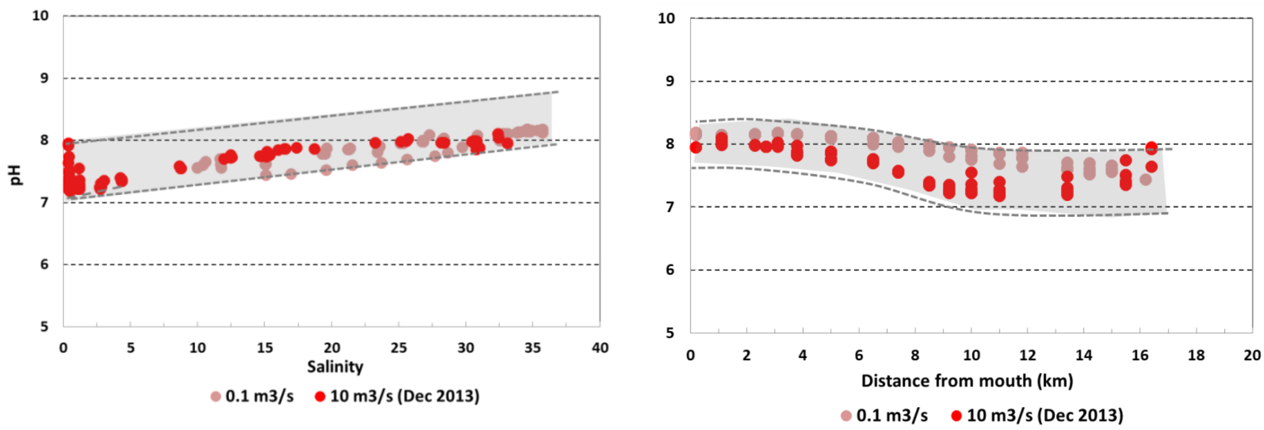


Figure A.7b pH levels measured against salinity (left) and along length of estuary (right) in the Duiwenhoks Estuary during Dec 2013, as well as previous surveys (DAFF, unpublished data)

A.3.4 Dissolved oxygen

Dissolved oxygen (DO) concentrations in the Duiwenhoks Estuary reflect well-oxygenated conditions (**Figure A.8**).

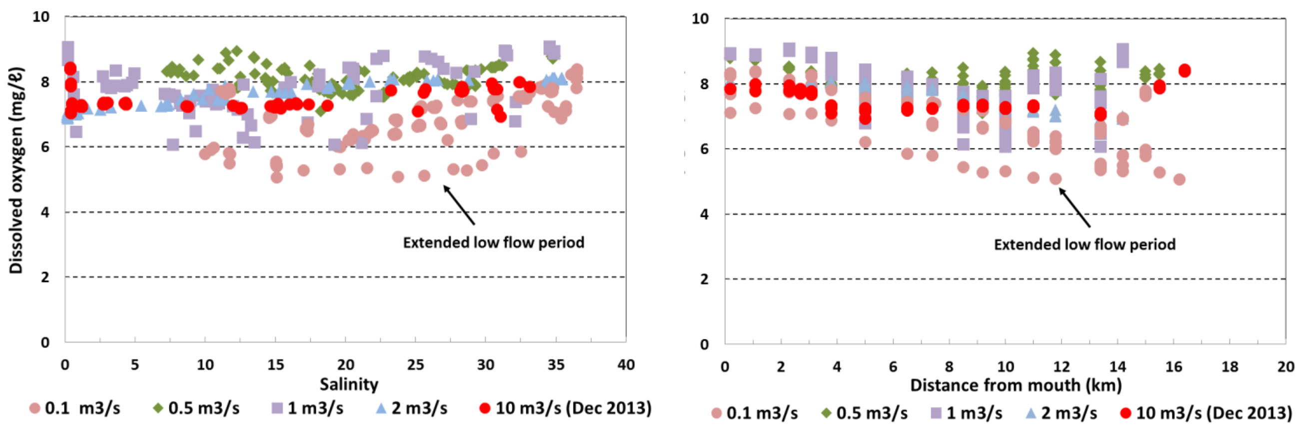


Figure A.8 Dissolved oxygen measured against salinity (left) and along length of estuary (right) in the Duiwenhoks Estuary during Dec 2013 and previous historical surveys organised in terms of average flow rate (DAFF, unpublished data)

DO concentrations were usually above 6 mg/ℓ, even in bottom waters (4-6 m water depth). The only exception was January 2004 when oxygen concentrations dropped to ~5 mg/ℓ. This was during an extended low flow period (~ 0.1 m^3/s for 46 days). These results suggest a well flushed system, except during extended period of low flow (e.g. during summer). DO levels were generally higher in winter compared with summer, reflecting the higher solubility of DO in colder waters.

A.4.5 Turbidity (suspended solids)

Turbidity and suspended solid concentrations measured in the Duiwenhoks Estuary during December 2013 are presented in **Figure A.9**.

Turbidity generally decreased with an increase in salinity, suggesting that the river was introducing more turbid waters into the system, compared with the sea. However, as with pH there was an unexpected decrease in turbidity from 10 km upstream of the mouth during the December 2013 survey. This strengthened the observation for pH, 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. Just prior to the survey in December 2013, the system experienced a significant flood event (when higher turbidity is expected). At the time of the December survey, however, the river flow was lower again (when lower turbidity is expected). Extrapolating from the property-salinity plot, it is estimated that turbidity levels during the high flow event were around 70 NTU. Historical data do suggest that during summer the middle reaches (8-12 km from the mouth) tend to show some turbidity maximum (~20 NTU), but not as high as in the December 2013 survey. This higher turbidity is most likely associated with agricultural activities at Vermaaklikheid (adjacent to this part of the estuary). These activities may also have contributed to the high turbidity measured during December 2013.

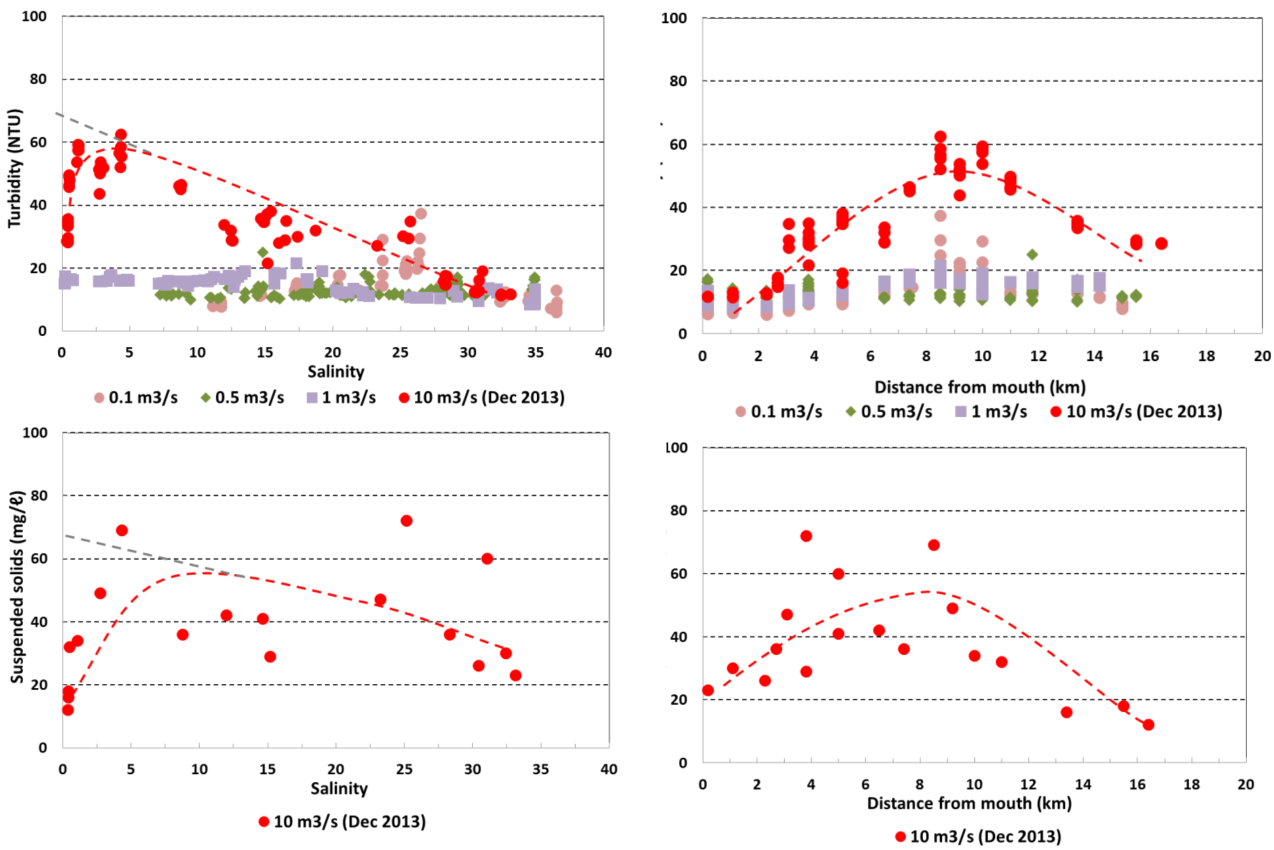


Figure A.9 Turbidity (top) and suspended solid (bottom) concentrations measured against salinity (left) and along length of estuary (right) in the Duiwenhoks Estuary during Dec 2013 and previous historical surveys organised in terms of average flow rate (DAFF, unpublished data)

Suspended solid concentrations tended to show a similar trends to that of turbidity, although much weaker. Correlation between suspended solids and turbidity was also weak possibly suggesting that the origin of turbidity was different in different section of the estuary (i.e. water of different character). Extrapolating from the property-salinity plot, it is estimated that suspended solid concentrations during the high flow event were around 70 mg/ℓ.

A.4.6 Dissolved inorganic nutrients

Variability in dissolved inorganic nutrients measured in the Duiwenhoks River (approximately 19 km from the mouth [H8H001]) is presented in **Figure A.10a**.

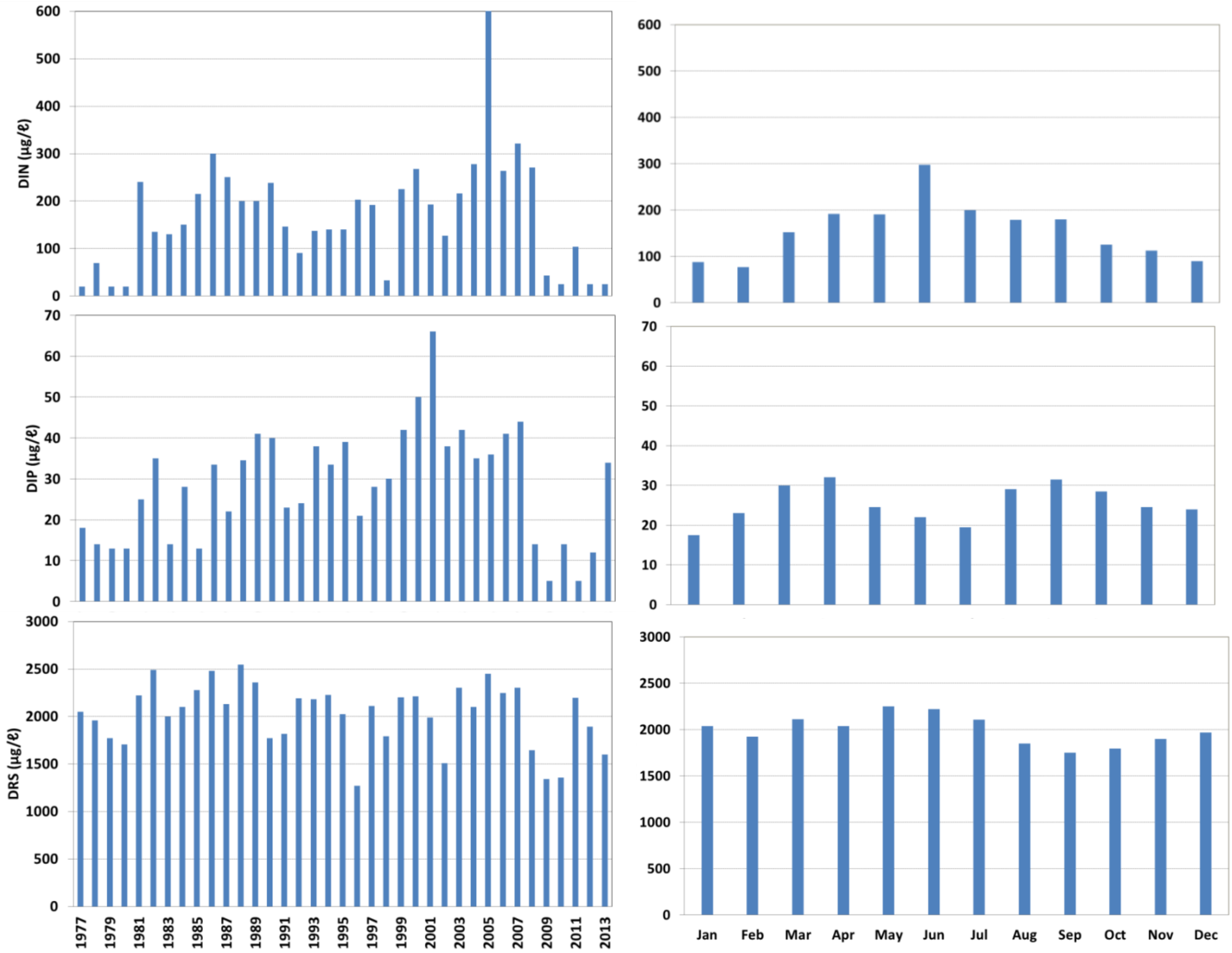


Figure A.10a Median annual and median monthly dissolved inorganic nitrogen (NH4-N, NOx-N, DIN), dissolved inorganic phosphate-P (DIP) and dissolved reactive silicate-Si (DRS) measured in the Duiwenhoks River (H8H001) (Source: http://www.dwaf.gov.za/iwqs/wms/data/WMS_pri_txt.asp)

Dissolved inorganic nitrogen (DIN)

Since the early 1980s median annual DIN concentrations (dominated by NO_x-N) in the Duiwenhoks River (H8H001) increased from ~50 µg/ℓ to >300 µg/ℓ. However, concentrations again decreased significantly from 2009 to present (possibly linked to improved agricultural practices in the catchment). DIN concentrations show a marked seasonal pattern with highest values during the low flow period in winter (Jun-Aug) when anthropogenic influences (e.g. WWTW discharge and agricultural return flows) will be highest given the mobility of DIN. De Villiers and Thiart (2007) estimated natural concentrations of DIN in these 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 relatively low - 50-100 µg/ℓ - except during upwelling (e.g. DWAF, 1995).

DIN concentrations in the Duiwenhoks Estuary (also dominated by NO_x-N), generally increased with a decrease in salinity moving upstream (from <100 µg/ℓ to 200-300 µg/ℓ), suggesting the river as major DIN source to the system (**Figure A.10b**). During Dec 2013 there was a strong linear relationship between DIN and salinity (concentrations in the systems are largely a function of mixing between river and seawater). This was expected as the survey was preceded by a major flood event and retention times remained low preventing any significant influence of *in situ* processes on DIN distribution patterns.

Dissolved inorganic phosphate (DIP)

Since the early 1980s median annual DIP concentrations in the Duiwenhoks River (H8H001) also increased markedly from 10-20 µg/ℓ to >50 µg/ℓ (**Figure A.10a**). Between 2009 and 2012, DIP concentrations decreased again, but returned to the earlier higher level in 2013. DIP concentrations show a marked seasonal pattern with lowest values during the low flow period in winter (Jun-Aug). This is the inverse observed for DIN, suggesting that DIP is mobilised during periods of high flow. 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 concentrations in seawater along this part of the coast are expected to be relatively low - approximately 10-20 µg/ℓ (e.g. DWAF, 1995).

DIP concentrations in the Duiwenhoks Estuary generally increased with a decrease in salinity moving upstream (from <10 µg/ℓ to 30 µg/ℓ), suggesting the river as major DIP source to the system (**Figure A.10b**). During Dec 2013, there was an unexpected decrease in DIP from 10 km upstream of the mouth. This strengthens earlier motivations presented for pH and turbidity, 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. Just prior to the survey in December, the system experienced a significant flood event (higher DIP concentrations expected) but at the time of the December survey river flow were lower again (lower DIP concentrations expected).

Dissolved reactive silicate (DRS)

DRS concentrations in the Duiwenhoks River were high as expected for fluvial systems linked to catchment geological characteristics (Eagle and Bartlett, 1984). Median annual concentrations over the period 1977 to 2013 did not show any marked trends although median monthly concentrations suggest highest DRS concentrations during lower winter flows (mid-year).

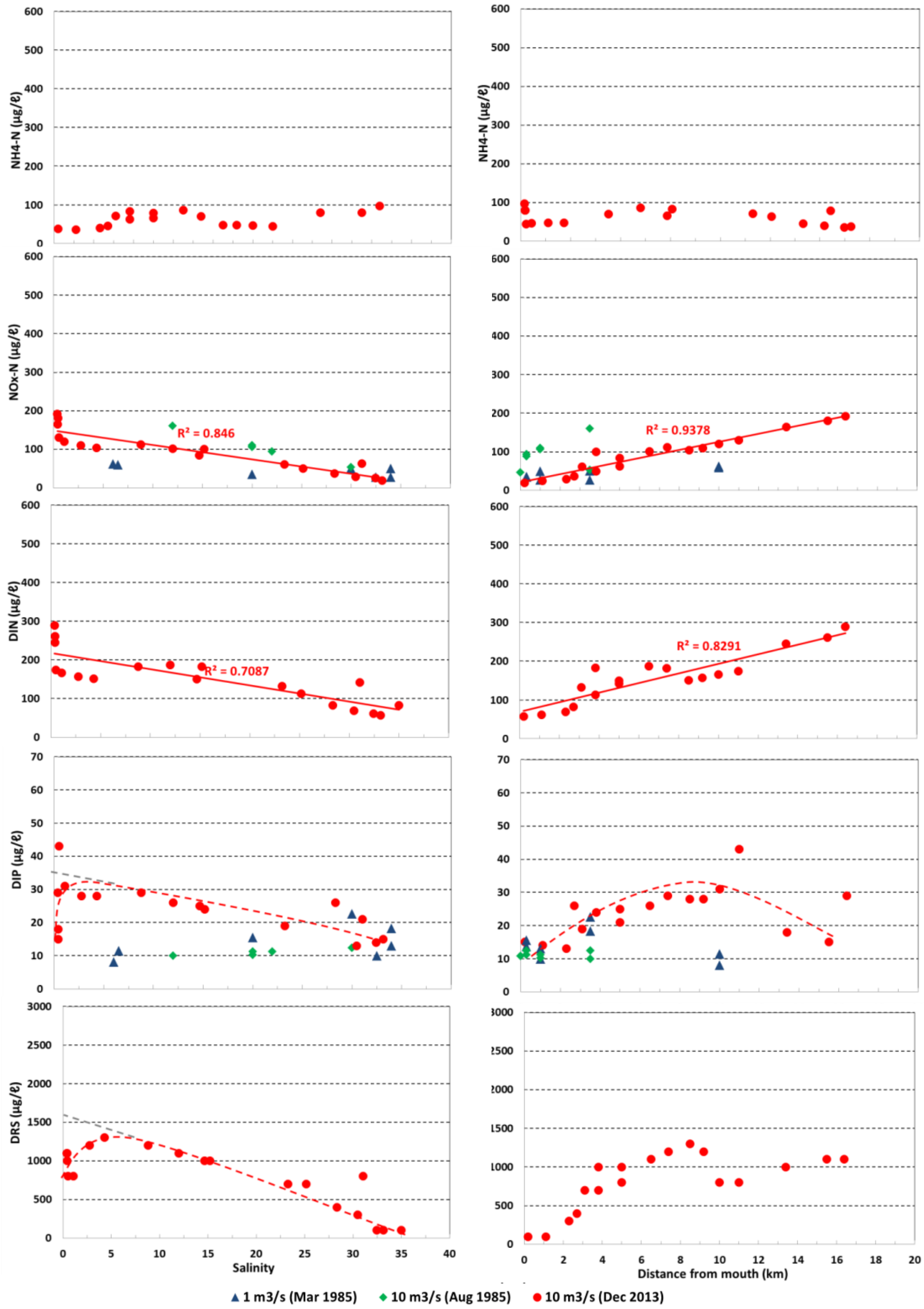


Figure A.10b Dissolved inorganic nitrogen-N (NH4-N, NOx-N, DIN), dissolved inorganic phosphate-P (DIP) and dissolved reactive silicate-Si (DRS) measured in Duiwenhoks Estuary in Dec 2013, Mar 1985 and Aug 1985 (Carter and Brownlie, 1990)

As expected DRS concentrations in the Duiwenhoks Estuary generally increased with a decrease in salinity moving upstream, suggesting the river as major source of DRS to the system (**Figure A.10b**). During December 2013, there was an unexpected decrease in DRS from 10 km upstream of the mouth. This strengthens earlier motivations presented for pH, turbidity 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.4.7 Toxic substances

No data was available on levels of toxic substances in the Duiwenhoks 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 most likely be a source of metal pollution.

Annexure A1: Sediment grain size and TOM data collected on 4 December 2013 (stations Figure A.4 approximately mid channel)

Station	TOM	Gravel	Sand	Mud	Sediment size fractions (%)														
	(%)	(%)	(%)	(%)	>4000 µm	>2000 µm	>1140 µm	>1000 µm	>710 µm	>500 µm	>300 µm	>250 µm	>212 µm	>180 µm	>150 µm	>125 µm	>90 µm	>63 µm	<63 µm
1	17.2	0.0	100.0	0.0	0.0	0.0	0.0	1.1	0.9	1.6	8.7	44.6	25.3	12.7	5.3	0.2	0.0	0.0	0.0
2	12.4	0.1	99.8	0.1	0.0	0.1	0.6	0.6	0.7	1.5	5.3	50.3	22.9	12.7	5.3	0.2	0.0	0.0	0.1
3	19.0	0.0	100.0	0.0	0.0	0.0	0.2	0.4	1.1	2.1	5.9	37.6	26.8	16.1	9.5	0.5	0.0	0.0	0.0
5	29.6	34.0	57.4	8.6	0.0	34.0	6.1	4.9	4.0	4.1	3.5	6.9	2.9	2.0	3.6	2.9	7.4	9.2	8.6
6	20.7	0.6	99.4	0.0	0.0	0.6	1.1	1.4	3.7	7.6	22.8	58.1	2.6	0.8	0.5	0.0	0.2	0.5	0.0
7	21.4	0.7	98.8	0.5	0.0	0.7	0.3	0.5	0.4	1.6	26.0	62.4	4.9	1.3	0.9	0.0	0.3	0.3	0.5
8	17.7	15.7	84.2	0.2	0.0	15.7	1.0	1.8	3.6	11.4	34.9	29.4	1.6	0.5	0.5	0.0	0.0	0.0	0.2
9	16.5	0.1	99.7	0.2	0.0	0.1	0.2	0.7	3.1	11.5	52.4	30.9	0.8	0.2	0.2	0.0	0.0	0.0	0.2
11	16.2	0.1	99.9	0.0	0.0	0.1	0.2	0.6	0.6	0.9	10.3	64.4	17.5	4.7	1.2	0.0	0.0	0.0	0.0
12	9.7	1.3	97.7	1.0	0.0	1.3	1.8	7.4	24.9	34.3	19.8	6.0	0.7	0.4	0.5	0.1	0.8	0.9	1.0
14	16.7	12.2	87.8	0.0	0.0	12.2	7.7	18.2	27.5	18.1	8.5	3.9	0.7	0.6	1.0	0.6	0.9	0.3	0.0
15(B)	15.6	22.1	77.8	0.1	0.0	22.1	15.6	18.4	21.0	14.5	6.5	1.9	0.1	0.0	0.1	0.0	0.0	0.0	0.1
16(A)	3.3	89.7	10.3	0.0	0.0	89.7	3.5	2.3	1.4	1.1	0.7	1.0	0.2	0.1	0.2	0.0	0.0	0.0	0.0
16(B)	10.2	18.4	81.6	0.0	0.0	18.4	14.4	21.3	26.4	16.1	3.1	0.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0
17(B)	17.4	71.2	28.2	0.5	0.0	71.2	5.2	3.9	3.9	4.2	4.1	3.8	1.0	0.6	0.6	0.2	0.5	0.3	0.5
Sandbank (inside mouth - southern side)	15.9	0.0	100.0	0.0	0.0	0.0	1.2	1.2	0.9	2.0	16.2	41.7	21.5	10.6	4.9	0.1	0.0	0.0	0.0
Beach (1)	15.1	0.9	99.0	0.1	0.0	0.9	0.6	1.0	1.0	6.5	31.8	40.3	10.7	5.8	1.7	0.0	0.0	0.0	0.1

Annexure A2: Water quality data collected on 4 December 2013 (stations Figure A.4)

Stn	Depth (m)	Temp	Salinity	pH	Turbidity (NTU)	SS (mg/l)	DO (mg/l)	DO (%)	NO2-N (µg/l)	NH4-N (µg/l)	NOX-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tot P (µg/l)
SEA	0.0		35.0						1	70	12	4	100	
1	2.0	18.8	33.1	8.0	11.7		7.8	102						
1	0.0	18.8	33.1	8.0	11.7	23	7.8	102	1	38	19	15	100	<250
2	1.6	19.1	32.4	8.1	11.7		8.0	105						
2	0.0	19.1	32.4	8.0	11.4	30	8.0	105	1	36	25	14	100	<250
3	3.0	19.4	30.6	8.0	13.0		7.8	101						
3	2.0	19.3	30.6	8.0	12.3		7.8	101						
3	1.0	19.4	30.8	8.0	12.7		7.8	101						
3	0.0	19.4	30.5	8.0	12.4	26	7.9	103	1	40	29	13	300	<250
3A	3.5	19.6	28.3	8.0	17.7		7.7	100						
3A	3.0	19.6	28.4	8.0	17.4		7.7	100						
3A	2.0	19.6	28.2	8.0	15.8		7.7	100						
3A	0.0	19.6	28.3	8.0	14.8		7.7	100						
3A	0.0	19.6	28.3	8.0	14.7	36	7.8	101	1	45	37	26	400	<250
4	2.0	19.9	25.7	8.0	34.8		7.8	99						
4	1.0	20.0	25.6	8.0	29.5		7.7	97						
4	0.0	19.9	23.3	8.0	27.1	47	7.7	98	1	71	61	19	700	<50
5	6.0	19.8	25.2	8.0	30.2	72	7.1	87	1	63	50		700	140
5	5.0	20.6	18.7	7.9	31.9		7.3	88						
5	4.0	20.5	17.4	7.9	30.0		7.3	90						
5	3.0	20.6	16.6	7.9	35.0		7.3	90						
5	2.0	20.7	16.5	7.9	29.0		7.3	90						
5	1.0	20.7	16.0	7.8	28.0		7.3	90						
5	0.0	20.7	15.2	7.8	21.6	29	7.3	89	2	83	100	24	1000	960
6	7.0	19.6	31.1	7.9	19.0	60	6.9	91	1	79	63	21	800	<250
6	6.0	19.6	30.8	7.9	16.1		7.1	93						
6	5.5	20.6	15.4	7.8	38.1		7.2	88						
6	5.0	20.7	15.1	7.7	37.1		7.2	88						
6	4.0	20.7	15.0	7.8	36.1		7.2	87						
6	3.0	20.8	14.9	7.8	34.7		7.2	88						
6	2.0	20.8	14.9	7.8	34.7		7.2	88						
6	1.0	20.8	14.8	7.8	35.2		7.3	88						
6	0.0	20.8	14.7	7.8	35.8	41	7.3	88	2	66	84	25	1000	60
7	2.4	21.0	12.5	7.8	29.0		7.2	87						
7	2.0	21.0	12.6	7.7	28.8		7.2	87						
7	1.0	21.0	12.5	7.7	32.0		7.2	87						
7	0.0	21.0	12.0	7.7	33.7	42	7.3	88	2	86	101	26	1100	<50
8	2.0	21.2	8.7	7.6	46.2		7.3	86						
8	1.0	21.2	8.8	7.6	45.0		7.2	86						
8	0.0	21.2	8.8	7.6	46.4	36	7.2	86	3	70	112	29	1200	<50
9	3.6	21.6	4.2	7.4	56.6		7.3	85						
9	3.0	21.6	4.3	7.4	62.5		7.3	85						
9	2.0	21.5	4.4	7.4	58.5		7.3	85						
9	1.0	21.6	4.4	7.3	55.5		7.3	85						
9	0.0	21.6	4.3	7.3	52.0	69	7.4	86	2	47	104	28	1300	<50
10	6.0	21.7	3.0	7.4	51.8		7.4	85						
10	5.0	21.7	2.8	7.3	50.0		7.3	85						
10	4.0	21.8	2.8	7.3	52.1		7.3	85						
10	3.0	21.8	2.8	7.3	53.7		7.3	87						
10	2.0	21.8	2.7	7.2	51.4		7.3	84						
10	1.0	21.8	2.8	7.2	51.0		7.3	85						
10	0.0	21.8	2.8	7.2	43.7	49	7.4	85	3	47	110	28	1200	<50
11	6.5	22.0	1.2	7.6	59.3		7.3	84						
11	5.0	22.0	1.2	7.4	59.1		7.2	84						
11	4.0	22.0	1.2	7.3	59.0		7.2	83						
11	3.0	22.0	1.2	7.3	58.8		7.2	83						
11	2.0	22.0	1.2	7.3	57.5		7.2	83						
11	1.0	22.0	1.2	7.2	57.5		7.2	83						
11	0.0	22.0	1.1	7.2	53.7	34	7.2	83	3	46	120	31	800	<50
12	3.4	22.0	0.5	7.4	45.7		7.3	84						
12	3.0	22.0	0.6	7.3	48.0		7.3	84						
12	2.0	22.0	0.5	7.2	49.6		7.3	84						
12	1.0	22.0	0.5	7.2	49.0		7.3	84						
12	0.0	22.0	0.5	7.2	46.3	32	7.3	84	3	44	130	43	800	<50
13														
14	4.8	22.8	0.4	7.5	35.6		7.1	83						
14	4.0	22.8	0.4	7.3	35.6		7.1	82						
14	3.0	22.8	0.4	7.3	35.3		7.0	82						
14	2.0	22.8	0.4	7.2	34.8		7.1	82						
14	1.0	22.8	0.4	7.2	34.1		7.0	82						
14	0.0	22.8	0.4	7.2	33.4	16	7.1	82	6	80	165	18	1000	<50
15														
16														
17	3.0	21.5	0.4	7.7	29.6		8.0	90						
17	2.0	21.5	0.4	7.5	28.2		7.9	90						
17	1.0	21.6	0.4	7.4	28.5		7.9	89						
17	0.0	21.6	0.4	7.4	29.1	18	7.9	90	6	80	181	15	1100	<50
18														
19	1.7	22.1	0.4	8.0	28.5		8.4	97						
19	1.0	22.1	0.4	7.9	28.6		8.4	96						
19	0.0	22.1	0.4	7.6	28.4	12	8.4	96	5	97	192	29	1100	<50

APPENDIX B: MICROALGAE SPECIALIST REPORT

Prepared by G Snow
Wits University/Nelson Mandela Metropolitan University

B.1 AVAILABLE DATA

Microalgae data requirements for Intermediate level assessment (DWAF, 2008), as well as availability of data for this study are 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 Just after high flow period	Carter and Brownlie (1990) Harrison (unpublished data) 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)	Just after high flow period	This study

There are little historic data associated with microalgae available for the Duiwenhoks Estuary. Carter and Brownlie (1990) refer to phytoplankton biomass as being low and in agreement with generally high turbidity caused by high inorganic particle loads. The information was drawn from Carter and Blownlie (1990) (chlorophyll *a* data) and records of diatoms by Grindley (unpublished data). The chlorophyll *a* data (**Table B.1**) ranged from 0.42 µg/ℓ (measured at the surface 3.5 km from estuary mouth) to 1.02 µg/ℓ (bottom, 3.5 km) in summer, and from 0.12 µg/ℓ (surface, 0.3 km) to 1.56 µg/ℓ (bottom, 0.3 km) in winter. The average chlorophyll *a* measured at four sites in summer was 0.71 µg/ℓ, and 0.75 µg/ℓ in winter. Grindley (unpublished data) recorded a list of diatoms collected in 1969 (Carter and Brownlie, 1990).

Table B.1 Duiwenhoks Estuary physico-chemical data (including phytoplankton chlorophyll a); ECRU survey March (summer) and August (winter) of 1985 (Carter and Brownlie, 1990)

Stn No.	Distance from mouth (km)	Sample	Temp. (°C)	Sal	pH	Secchi depth (m)	DO (mg/ℓ)	NO3-N (µM//ℓ)	PO_4-P (µM//ℓ)	Chl. *a* (µg/ℓ)
Summer										
1	0.3	S	19.4	20.0	8.05	0.8	7.75	2.53	0.50	0.67
		B	19.4	-	-		-	2.47	0.44	0.50
2	1.0	S	19.7	34.0	8.12	0.5	8.19	3.54	0.42	1.18
		B	19.8	32.5	-		8.45	1.96	0.32	0.38
3	3.5	S	20.4	30.0	8.20	1.0	8.10	3.60	0.73	0.42
		B	20.1	34.0	-		8.11	1.96	0.59	1.02
4	10.0	S	21.9	6.5	7.17	0.3	6.76	4.24	0.37	0.79
		B	21.9	6.0	-		6.24	4.43	0.26	0.75
Winter										
1	0.3	S	14.1	22.0	8.18	-	6.91	6.70	0.36	0.12
		B	14.0	-	-	-	6.96	6.32	0.40	1.56
2	1.0	S	14.2	20.0	7.84	-	7.02	7.84	0.33	0.68
		B	14.2	20.0	7.85	-	6.73	7.59	0.36	1.16
3	3.5	S	14.0	12.0	6.95	-	6.93	11.46	0.32	0.50
		B	14.9	30.0	7.95	-	6.71	3.79	0.40	0.50
Mouth			14.2	-	-	-	-	3.29	0.35	0.70

Harrison (unpublished data) sampled two sites in the Duiwenhoks Estuary on 12 June 1994 (winter). The sites were 1.3 m and 0.4 m deep and Secchi depth was 1.2 m at the deeper of the two sites indicating relatively clear water, presumably near-marine water close to the mouth of the estuary. The pH was 8.0, temperature 15ºC, salinity 30, and dissolved oxygen 12 mg/ℓ. This suggests that the sites were well mixed with strong marine intrusion diluted with fresh riverine water. Nutrient concentrations were low (NH_3-N = 0 µg/ℓ; PO_4-P = <30 µg/ℓ; NO_3-N = 0 µg/ℓ) and phytoplankton chlorophyll *a* was below detectable limits.

B.2 RESULTS AND DISCUSSION

Lemley (2015) sampled five sites within the Duiwenhoks Estuary (**Figure B.1**) on 04 December 2013 and measured water quality and microalgal variables. These data included phytoplankton and microphytobenthos (MPB) biomass using chlorophyll *a* as an indicator, phytoplankton groups, and dominant (> 10% of relative abundance) benthic diatoms.

The phytoplankton community in the lower reaches (Sites 1 and 2) of the Duiwenhoks Estuary was dominated by flagellates (> 60% relative abundance) (**Figure B.2**). In the fresher middle to upper reaches (Site 3 to 5), chlorophytes were the dominant group (> 98% RA) and the colony-forming *Sphaerocystis* sp. was the dominant species. The vertically averaged phytoplankton cell density ranged from 60 cells/mℓ (Site 2) to 44930 cells/mℓ (Site 4). An assessment of possible microalgal bloom conditions showed that the middle to upper reaches (Sites 3 to 5) exceeded the proposed cell density threshold (> 10 000 cells/mℓ). However the corresponding average phytoplankton biomass levels were below bloom limits (≤ 20 µg/ℓ) (**Table B.2**).

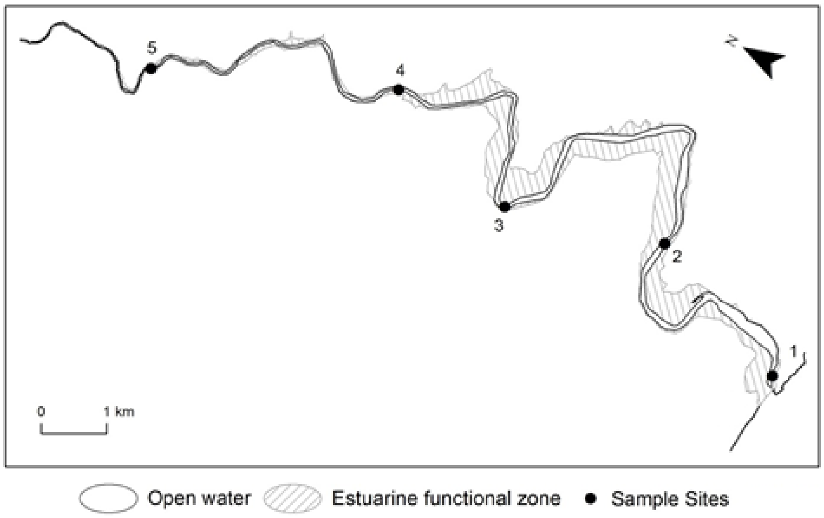


Figure B.1 Study site map of the Duiwenhoks Estuary indicating the locations of sampling stations (see Table B.2 for distance from mouth)

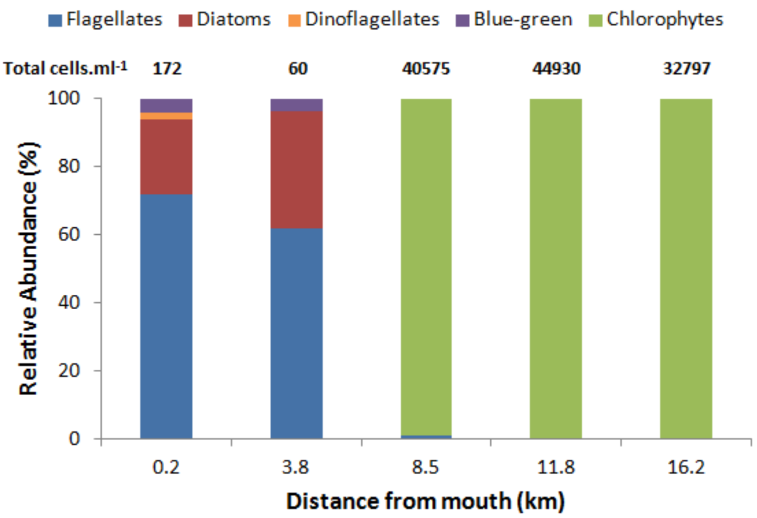


Figure B.2 Relative abundance (%) of phytoplankton groups at five sites in the Duiwenhoks Estuary, 04 December 2013. Total cell density data are included (total cells.ml-1) (Lemley, 2015)

Table B.2 Summary of the relationships between phytoplankton indicators within the Duiwenhoks Estuary (shaded cells indicate potential bloom conditions)

Station	Distance from mouth (km)	Vertically averaged cell density (cells/ml)	Potential bloom conditions (> 10 000 cells/ml)	Corresponding average chlorophyll *a* biomass (µg/ℓ ± SE)	Dominant group
1	0.2	172	No	0	Flagellates
2	3.8	60	No	0	Flagellates
3	8.5	40575	Yes	0.6 ± 0.4	Chlorophytes
4	11.8	44930	Yes	0	Chlorophytes
5	16.2	32797	Yes	0	Chlorophytes

In the Duiwenhoks Estuary the benthic chlorophyll *a* (**Figure B.3**) ranged from 0 to 17.0 mg/m^2. The chlorophyll *a* values associated with the middle reaches (Sites 2 [3.8 km], 3 [8.5 km] to 4 [11.8 km]) were significantly higher ($F = 22.42$; $P < 0.001$; df = 4) than those observed in both the lower and upper reaches. Additionally, the intertidal zone of the estuary had higher chlorophyll *a* ($F = 7.46$; $P < 0.05$; df = 1) than the subtidal zone.

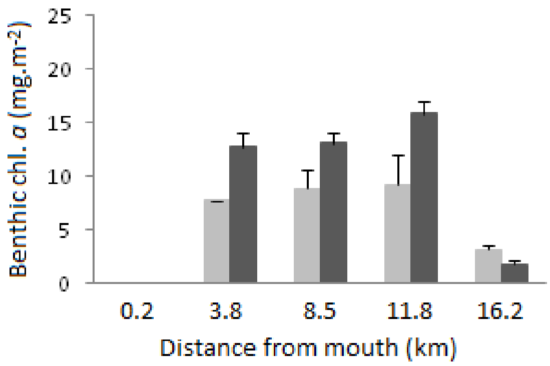


Figure B.3 Benthic chlorophyll a along the length of the Duiwenhoks Estuary, 4 December 2013 (light grey bars – subtidal; dark grey bars – intertidal)

The Shannon Diversity Index and Evenness scores for the benthic diatoms in the Duiwenhoks Estuary were 2.26 and 0.74 respectively.

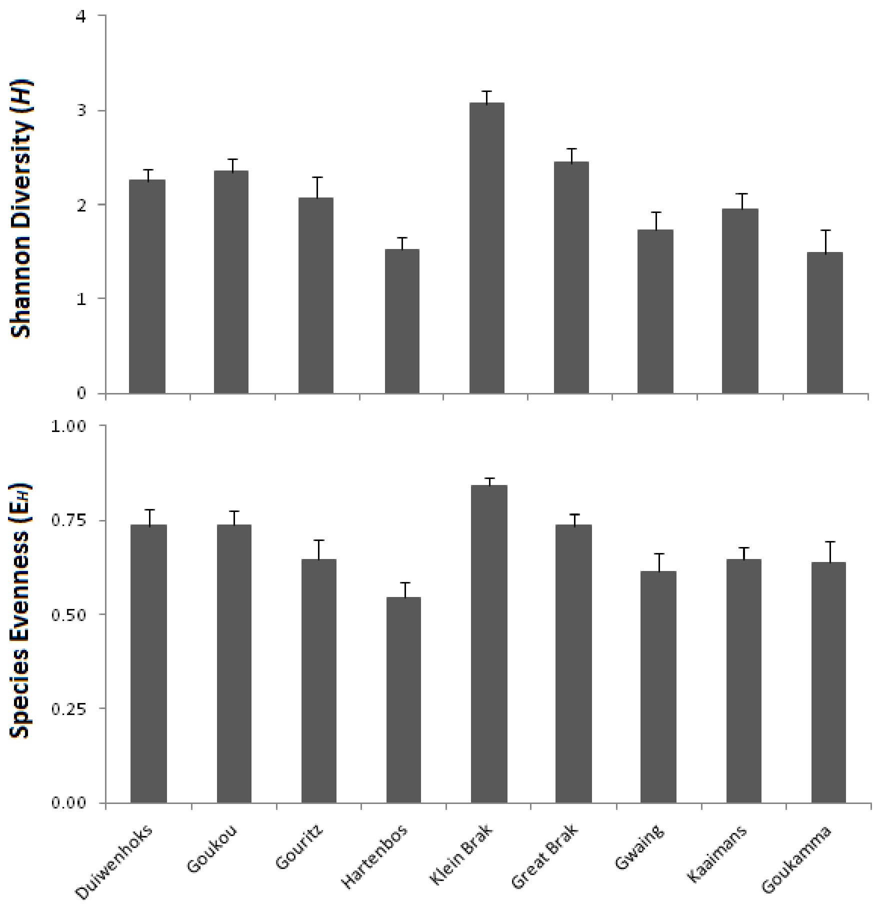


Figure B.4 Benthic diatom Shannon Diversity Index and Evenness scores for nine estuaries within the Gouritz Water Management Area, December 2013

APPENDIX C: MACROPHYTE SPECIALIST REPORT

Prepared by J B Adams and N Gordon
Nelson Mandela Metropolitan University, Port Elizabeth

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)	Assessed in previous study	Naidoo (2014)
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.	Previous study Summer (December 2013)	Naidoo (2014) 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).	Previous study Summer (December 2013)	Naidoo (2014) This study

C.2 HABITAT AREA

Previous estimates of the total open water surface area for the Duiwenhoks Estuary **(Figure C.1)** were 72 ha with 24 ha of salt marsh (Carter and Brownlie, 1990) and a tidal reach that extended 14 km upstream. Harrison *et al*. (2001) estimated the Duiwenhoks to have an open water surface area of 203 ha. Present calculations of habitat area include all floodplain area within the 5 m contour line. The distribution of the past (1942) and present (2009) habitats were mapped using ESRI™ ArcGIS 10.2 (2012) in combination with Google Earth 2009 images. More recent images could not be used due to cloud cover which was present on the 2013 images. By comparing past and present habitat area and distribution, changes in macrophyte health could be assessed for the Duiwenhoks Estuary. It should be noted that past aerial photography only covered the mouth and lower reaches of the estuary. Past photographs are also in black and white and of lower quality (resolution), making habitat identification difficult. Consequently, a lower confidence level is assigned to the area data obtained for the different habitat types in 1942. Nevertheless, these data provide a point of reference to work from in order to determine the extent of anthropogenic impacts and changes in habitat.

In 2009 the open water surface area was 40 ha and the salt marsh covered 26 ha. Sand and mudflats, salt marsh and riparian vegetation increased from 1942 to 2009. Degraded floodplain and dune vegetation decreased in area cover with the degraded floodplain showing the greatest decrease since 1942 as farmlands were abandoned and colonised by riparian vegetation. **Table C.1** gives a breakdown of the different macrophyte habitat areas for the Duiwenhoks Estuary as assessed by Naidoo (2014). The 1990 vegetation map indicated dune pioneers located west of the mouth of the estuary and consisted of primary dune scrub and secondary dune fynbos. There were also many endemic plant species found in this area that included *Apodolirium lanceolatum*, *Euryops muirii*, and *Agathosma muirii* (Carter and Brownlie, 1990).

Figure C.1 A view of the Duiwenhoks Estuary from the middle reaches towards the ocean showing cultivation within the floodplain areas (CapeNature, 2006)

Table C.1 Macrophyte habitat areas for the Duiwenhoks Estuary

Habitat type	Defining features, typical/dominant species	Area (ha)			
		1942	1990	2001	2009
Open surface water area	Serves as a possible habitat for phytoplankton.	41	72	203	40
Sand and mud banks	Intertidal zone consists of sand/mud banks. This area provides habitat for microphytobenthos.	16			29
Macroalgae	The estuary was sampled after a flood in December 2013 and thus no macroalgae were observed.				
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 e.g. *Zostera capensis.*				

Habitat type	Defining features, typical/dominant species	Area (ha)			
		1942	**1990**	**2001**	**2009**
Salt marsh	Salt marsh extends from the lower to upper reaches of the estuary and had distinct zones along the elevation gradient. Dominant species occurring from the lower intertidal to upper intertidal were *Spartina maritima, Triglochin bulbosa, Cotula coronopifolia, Poeciolepis ficoidea, Sarcocornial tegetaria* and *Bassia diffusa*. The dominant supratidal species was *Sarcocornia pillansii*.	22	24		26
Reeds and sedges	The following species have been recorded, and belong to the families Cyperaceae, Juncaceae and Poaceae: *Schoenoplectus scirpoides, Juncus kraussii* and *Phragmites australis.*				3
Floodplain	This is a mostly grassy area which occurs within the 5 m contour line. It also includes dune vegetation at the mouth and riparian vegetation along the middle and upper reaches of the estuary.	34			6
Riparian vegetation	This has replaced areas that were previously used for agriculture and thus represents degraded habitat.	0			27
Dune vegetation	This is used as a mapping unit, but is not part of the assessment of estuarine health.	36			21
Total area		**149**	**96**	**203**	**152**

(1997 – Carter and Brownlie, 1990; 2001 – Harrison et al, 2001; Naidoo, 2014)

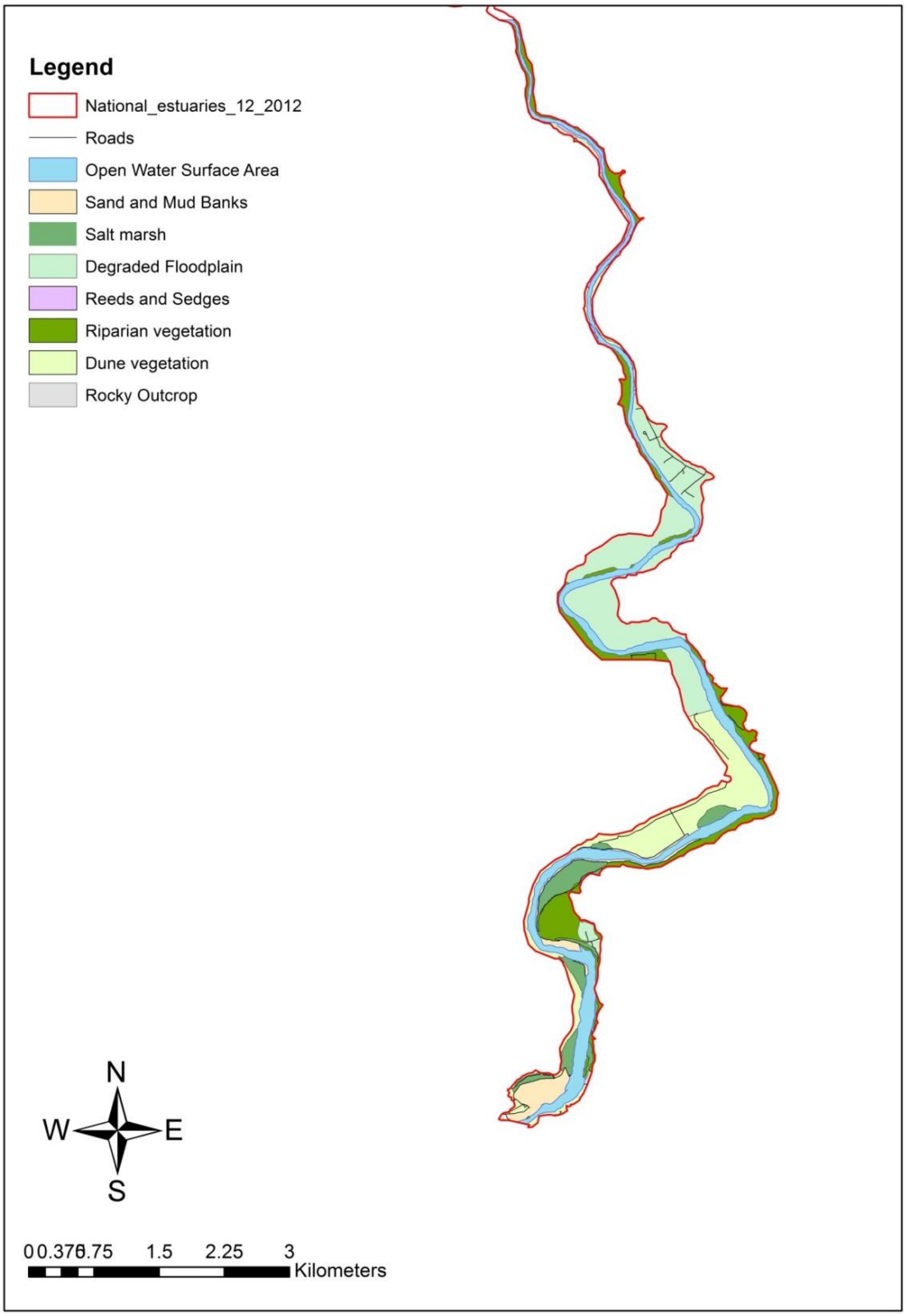


Figure C.2 Present vegetation map of the Duiwenhoks Estuary (from Naidoo, 2014)

C.3 SPECIES COMPOSITION AND DISTRIBUTION

Macrophytes fulfil important roles in the estuarine environment by acting both as a buffer that protects the inland areas from erosion, and preventing or reducing the effect of flooding from the seawards side. Submerged macrophytes colonise mudflats and sandflats as these plants are rooted in the subtidal and lower intertidal soft substratum with their leaves and stems submerged in water for extended periods of time (Adams *et al*., 1999). Important species are *Zostera capensis* and *Ruppia cirrhosa*. Submerged macrophytes oxygenate the water column, trap sediment in the mudflats and sand flats, and serve as a source of food and habitat for many fish and bird species (Adams *et al.*, 1999). Reeds and sedges colonise the banks particularly in the middle and upper reaches where salinity is less than 15. Permanently open estuaries such as the Duiwenhoks contain distinctive salt marsh habitats. Zonation along salt marshes is determined by the tolerance of species to abiotic stress factors such as salinity and inundation. Species composition changes in relation to these factors as well as sediment characteristics and depth to groundwater. Salt marshes are typically characterised by low diversity in plant species as they are stressful environments.

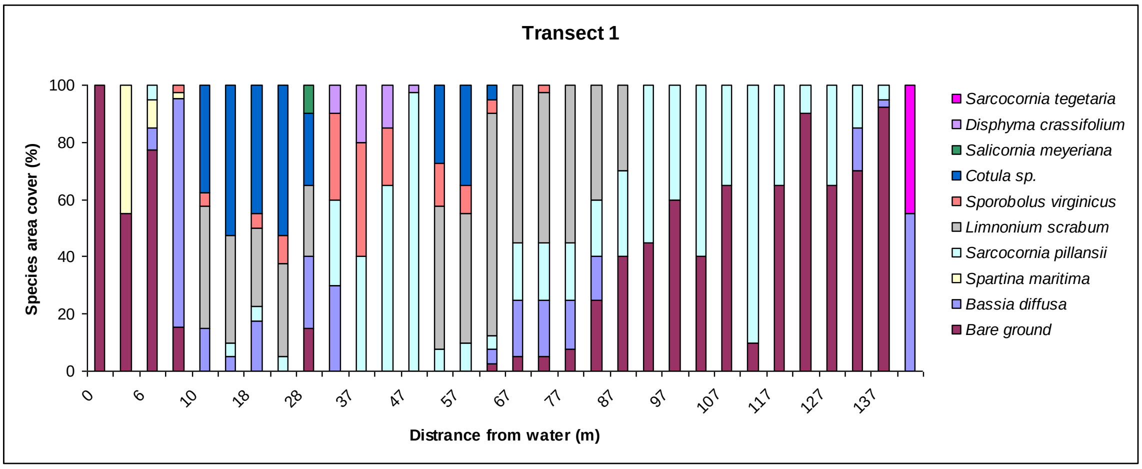
The distribution of salt marsh species along the elevation gradient was measured at two transects in the Duiwenhoks Estuary. Transect 1 was closer to the mouth and extended from the water (34^o2041.567 S 21^o0009.319 E) to the terrestrial vegetation at 34^o2043.791 S 21^o0014.471 E. Transect 2 was further upstream, started at 34^o1955.289 S 21^o0126.046 E and ended at 34^o1954.237 S 21^o0127.244 E. Macrophyte cover was measured as average percentage cover in duplicate 1 m^2 quadrants placed at 5 m intervals along each of the transects. 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 salt marsh 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 Gardner (1965 – sediment moisture content), Briggs (1977 – sediment organic matter) and The Non-Affiliated Sediment analyses Working Committee (1990 – sediment electrical conductivity). In situ measurements of the groundwater salinity and electrical conductivity were conducted using a handheld multiprobe.

The majority of salt marsh species reported previously were recorded in 2013 during the field sampling. The only species which was not observed was *Z. capensis*, the reason for this is that the submerged zone was not sampled. *Limonium linifolium* was found which was not reported previously. Other species recorded along the banks of the estuary were rushes (e.g. *Juncus kraussii*) and sedges (e.g. *Schoenoplectus scirpoides*). Alien invasive plants such as *Opuntia ficus-indica, Tamarix ramosissima (***Plate C.1**)*, Acacia* spp. and *Eucalyptus* occurred sporadically along the banks. Thick stands of reeds and sedges occurred in Zone C approximately 10 km upstream from the mouth. Salt marsh species that were dominant throughout the estuary were *Spartina maritima*, *Triglochin* sp., *Salicornia meyeriana*, *Cotula coronopifolia*, *Poeciolepis ficoidea, Limonium scrabum*, *Bassia diffusa*, *Disphyma crassifolium*, *Sarcocornia tegetaria*, *S. pillansii* and *Sporobolus virginicus*.

Figure C.3 shows the distribution of macrophytes measured along two transects in the Duiwenhoks Estuary. Salt marsh consisted of distinct zones which were characterised by dominant species in each zone. For Transect 1 the lower intertidal (Zone 1) extended from the water's edge to ~ 6 m inland, and consisted of bare ground (100%), interspersed with patches of *S. maritima*. The upper intertidal zone (i.e. Zone 2 at 19 m) was covered by *Cotula coronopifolia* (45%), while the supratidal zone (i.e. Zone 3 at 33 m) consisted of *S. pillansii*. For Transect 2 the lower intertidal zone consisted of *Triglochin bulbosa*, *S. tegetaria* and *C. coronopifolia.* The upper intertidal zone (40 m) consisted of *B. diffusa* and the supratidal zone (48 m) consisted of *S. pillansii*.

Plate C.1 Invasive *Tamarix ramosissima* along the estuary bank

Plate C.2 Narrow intertidal and supratidal area with fringing pristine vegetation



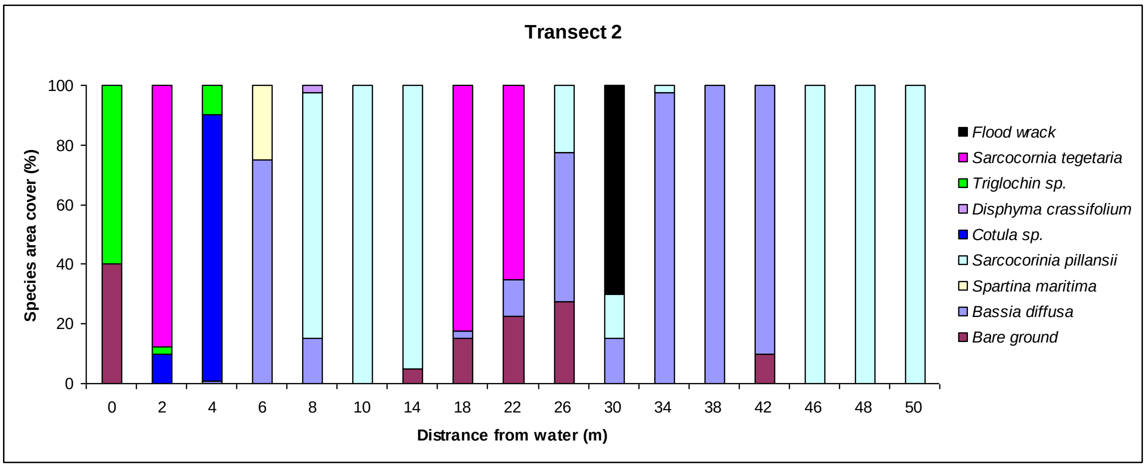


Figure C.3 Species area cover (%) for the lower reaches of the Duiwenhoks Estuary

C.4 ENVIRONMENTAL DRIVERS FOR HABITAT TYPES

The topography of the floodplain of the Duiwenhoks Estuary is steep, rising between 50 and 80 cm within the first 10 m from the water's edge (**Figure C.4**). Depth to groundwater was relatively shallow, and increased away from the water's edge. The deepest depth to groundwater was recorded in the supratidal salt marsh of Transect 2 at 50 cm. Sediment moisture content (%) was relatively high at all the sites, ranging between 30 and 45%. Sediment organic content (%), however, ranged between 3 and 10% and did not show any relation to sediment moisture content. Sediment electrical conductivity (mS/cm) varied considerably between the two transects in the lower reaches of the estuary. For Transect 1 electrical conductivity was highest further from the water's edge (~40 mS/cm), whereas for Transect 2, electrical conductivity remained fairly similar along the transect and relatively low (~15 mS/cm). Groundwater salinity (ppt) followed a similar pattern as for sediment electrical conductivity, with much higher recordings along Transect 1 (~ 38) compared with Transect 2 (~18). However, between the boreholes for each transect, there was no significant differences in salinity measurements.

C.5 CHANGES OVER TIME IN MACROPHYTE HABITATS

The area of sand and mudbanks, salt marsh and riparian vegetation increased from 1942 to 2009. The greatest increase was observed for the riparian vegetation (27 ha), especially in the tidal reaches of the eastern shore. Degraded floodplain (agriculture) was replaced by riparian vegetation (**Table C.4**).

Previous surveys of the Duiwenhoks Estuary report the presence of *Zostera capensis* in the lower reaches of the estuary, on the sand and tidal flats. In 2013 no *Z. capensis* was visible possibly due to flooding prior to sampling. Usually it occurs throughout shallow areas from 0.5 – 7 km from the mouth. The increase in salt marsh along the lower and middle reaches of the Duiwenhoks Estuary could be related to reduced freshwater inflow and more stable sediment conditions which would allow the plants to grow and expand. Reed and sedge habitats could not be identified in past and present images.

Historically, agricultural activity was present along the estuary which can be seen in the 1942 map as indicated by the degraded floodplain which was previously farm land. There were distinct changes in the various vegetation types between 1942 and 2009 where degraded floodplain was replaced by riparian vegetation consisting of riparian thicket and dune fynbos. Past aerial photographs (**Figure C.5**) indicate changes that have occurred at the Duiwenhoks Estuary mouth over time (i.e. 1942, 1976, 1979 and 1981). There has been an expansion of vegetation on the large dunefields on the western shore of the estuary. However the large sandbank on the western shore in the lower reaches of the system has hardly changed over time. The mouth of this estuary remains permanently open due to the rocky outcrop on the eastern shore as observed in the aerial photographs. Overall the area of sand and mudbanks increased from 1942 to 2009.

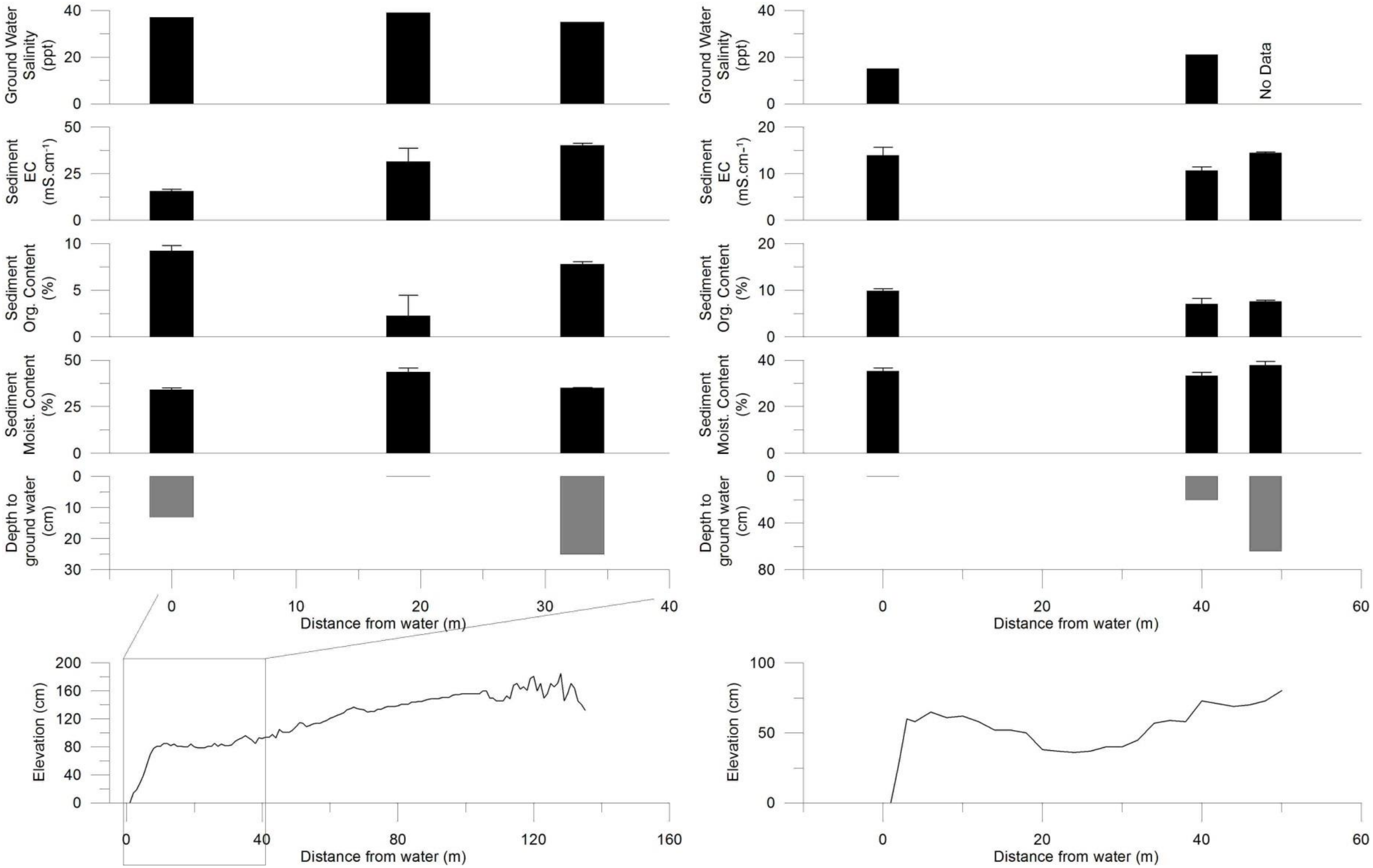


Figure C.4 Environmental variables measured along the lower reaches (Transect 1 and 2) of Duiwenhoks Estuary

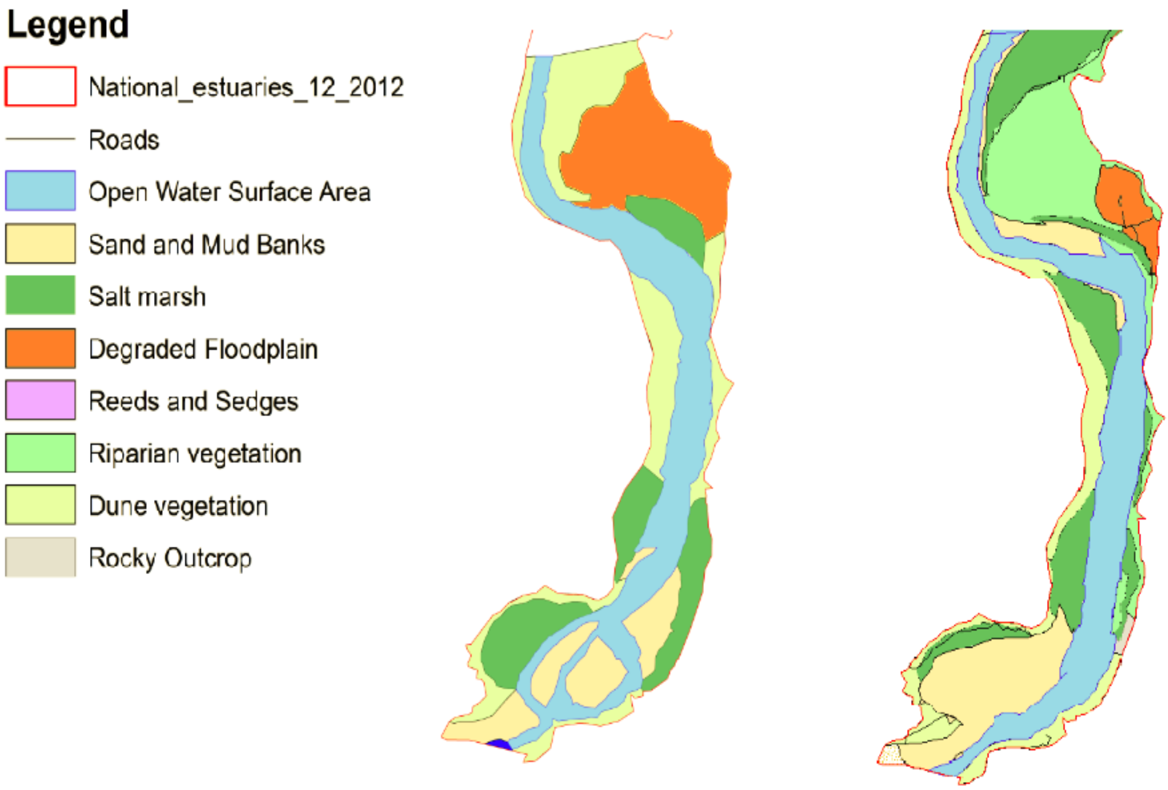


Figure C.5 Comparison of estuary habitat distribution for 1942 and 2009

Table C.3 Area covered by different habitats in the Duiwenhoks Estuary in 2014 compared with 1942

Habitat	Area (ha) in 1942	Area (ha) in 2009	% Change
Floodplain agriculture	34	6	-84.5
Riparian vegetation	0	27	100
Dune vegetation	36	21	-42.7
Intertidal and supratidal salt marsh	22	26	15.5
Submerged macrophytes	-	-	-
Reeds and sedges	-	-	-
Mud and sandbanks	16	29	44.8
Open water surface area	41	40	-2.4
Total functional estuarine area	**149**	**149**	

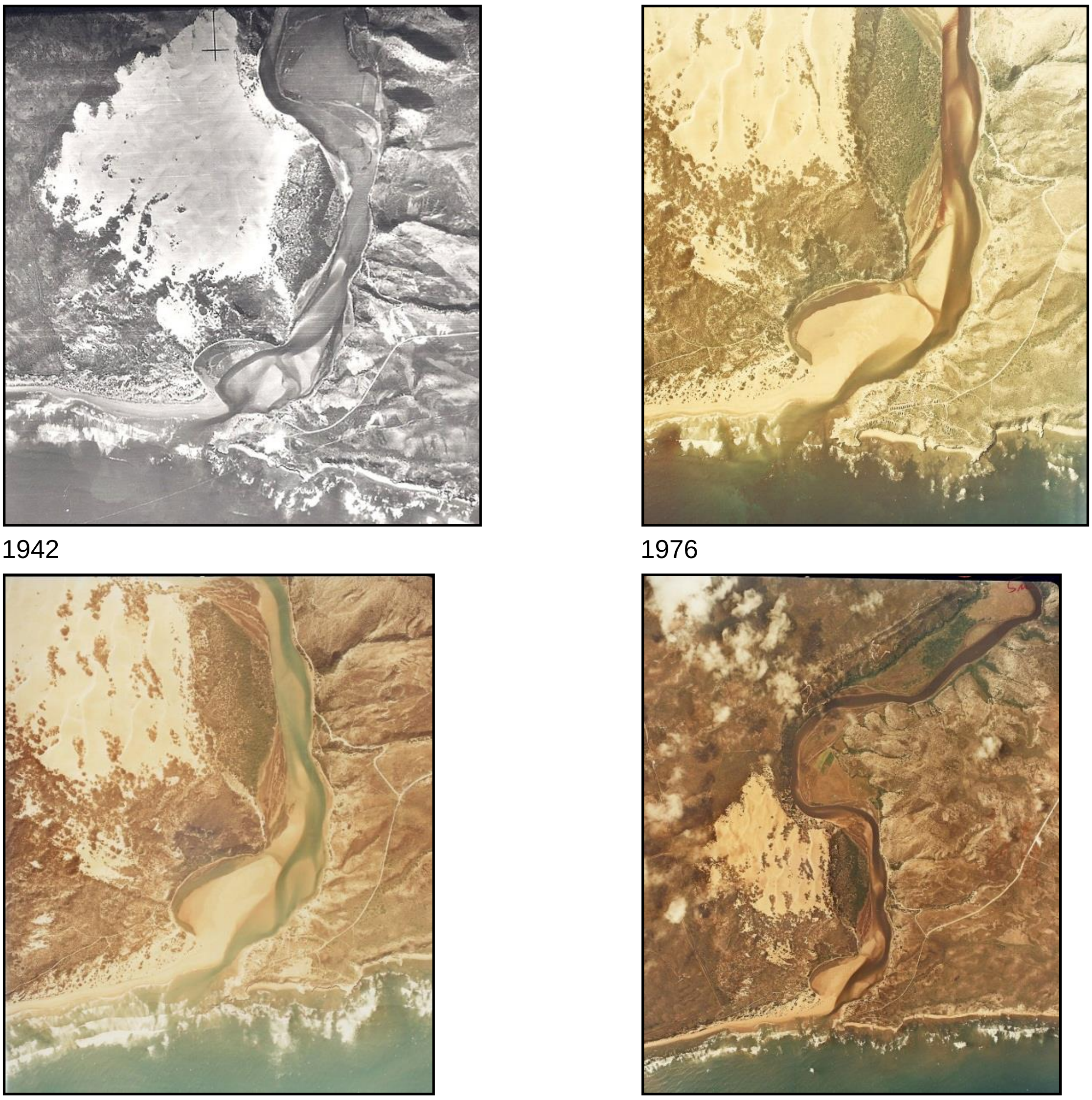


Figure E.5 Changes over time for the lower to middle reaches of the Duiwenhoks Estuary

C.6 CONCLUSIONS

The Duiwenhoks Estuary has intact salt marshes occurring along some steep gradients with distinct zonation. The salt marsh zones were typical for that found in permanently open Cape estuaries (Tabot and Adams, 2013). Species composition showed a direct relationship with changes in elevation and depth to groundwater. Along both Transect 1 and 2 three zones could be identified based on the elevation and dominant species within the lower, upper and supratidal zones. Distribution of lower intertidal salt marsh species (e.g. *C. coronopifolia*) was limited to areas in which the depth to groundwater was low (< 14 cm), while supratidal species such as *S. pillansii* occurred in areas where the depth to groundwater was higher (> 30 cm).

Optimal management of these estuarine habitats requires an understanding of the influence of changes in future climate such as rainfall patterns on salt marsh. A rise in sea level will cause the intertidal zone to transform into a subtidal zone and supratidal zones becoming intertidal, thereby affecting species distribution along the estuary. Upper intertidal salt marsh species such as *B. diffusa* and *Limonium linifolium* would not be able to survive the submerged conditions of the lower intertidal zone and would need to migrate inland (Talbot and Adams, 2013). Future water management scenarios should include climate change effects. If there is reduced flooding and freshwater input over consequent years, it could lead to a decrease in the depth to groundwater and hence cause a threat to the growth and survival of supratidal species such as *S. pilllansii*. An increase in salinity and change in the salinity gradient in the estuary would lead to a loss of biodiversity. Salt marsh species that prefer brackish conditions such as *Cotula coronopifolia* would be lost.

Other impacts on salt marshes include grazing and trampling by cattle and sheep. These activities need to be controlled in the surroundings of the Duiwenhoks Estuary as salt marshes fulfil important functions such as acting as a buffer and protecting inland areas from erosion as well as preventing or reducing the effects of flooding from the seaward side.

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, once servey 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

The earliest published records of invertebrates from the Duiwenhoks Estuary were reported in Carter and Brownlie (1990). However, no intensive surveys were undertaken and the study provides tabulated non-quantitative information on species present in the estuary. Zooplankton data for example, formed part of a broader and basic survey on this group originally collected in 1969 by Grindley (**Table D.1**).

Unfortunately, no quantitative data are available for invertebrates, although an average biomass value is provided for zooplankton present in the estuary. Access to the estuary is also difficult and this has undoubtedly also led to limited utilisation of invertebrate resources along the estuary. Strong tidal currents also characterise the lower reaches. The permanently open estuary is approximately 14 km long and incised in a deep valley.

Table D.1 Zooplankton species recorded by Grindley (collected in 1969)

NEMATODA	species not identified
ANNELIDA	olychaete larvae
OSTREACODA	species not identified
COPEPODA	Harpacticoids *Pseudodiaptomus hessei* Nauplii larvae
INSECTA	Chironomid larvae
MOLLUSCA	Lamellibrabch and Gastropod larvae present
PISCES	Fish larvae

During the survey, 12 taxa were recorded and this is considered low (19 taxa from the nearby Goukou Estuary collected during the same survey). Mean biomass for the Duiwenhoks was ca 10 mg DW/m^{-3} compared to 52 mg DW/m^{-3} in the Goukou (N=5 sites in each case).

The macrozoobenthic survey of the estuary was not exhaustive and probably led to some species not being recorded. Four burrowing bait organisms were recorded (the bloodworm *Arenicola loveni*, the mudprawn *Upogebia africana*, sandprawn *Callianassa kraussi* and pencil bait, *Solen capensis*). A list of recorded species is given in **Table D.2**.

Table D.2 Macrozoobenthic species recorded in the Duiwenhoks Estuary during this study

Species	Comments
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 estuary
Chthalamus denteatus	Present in lower estuary
Urothoe sp.	Sandbanks in lower estuary
Rhopalophthalmus terranatalis	Near *Zostera* beds
Alpheus crassimanus	Near *Zostera* beds
Penaeus japonicus	Near *Zostera* beds

Species	Comments
Diogenes brevirostris	Throughout lower estuary
Callichirus kraussi	Low numbers in sandy areas
Upogebia africana	Muddy areas – average density ca $20/m^{-2}$
Cleistostoma edwardsii	Abundant
Dotilla fenestrata	Sandbanks in lower estuary
Hymenosoma orbiculare	Common
Sesarma catenata	Abundant in saltmarsh areas
Scylla serrata	More common upstream
MOLLUSCA	
Loripes clausus	Abundant on sandbanks
Solen capensis	Abundant in channels – average density ca $1/m^{-2}$
Assiminea ovata	Abundant in lower estuary
Nassarius kraussianus	Abundant in lower estuary

D.2 RESULTS AND DISCUSSION

D.2.1 Physico-chemical data

Physico-chemical information was collected at each site (**Figure D.1**), particularly water temperature, salinity, and oxygen content of the water. Data were collected at the surface and at 0.5 m depth intervals. Physico-chemical data were collected on a strong out-going tide when sampling commenced at Station 1. A strong south-easterly wind also persisted throughout the day, particularly at the mouth. Results are shown in **Table D.3** and in **Figure D.2** for water temperature and salinity near the surface and just above the substrate. Despite being a relatively deep estuary, the water column was well mixed at the time of sampling. Water depth measured up to 5.5 m in the middle estuary where salinity remained below 1 throughout the water column. Results suggest that, like the Goukou, the Duiwenhoks was on a trajectory of recovery following floods a few weeks previously.

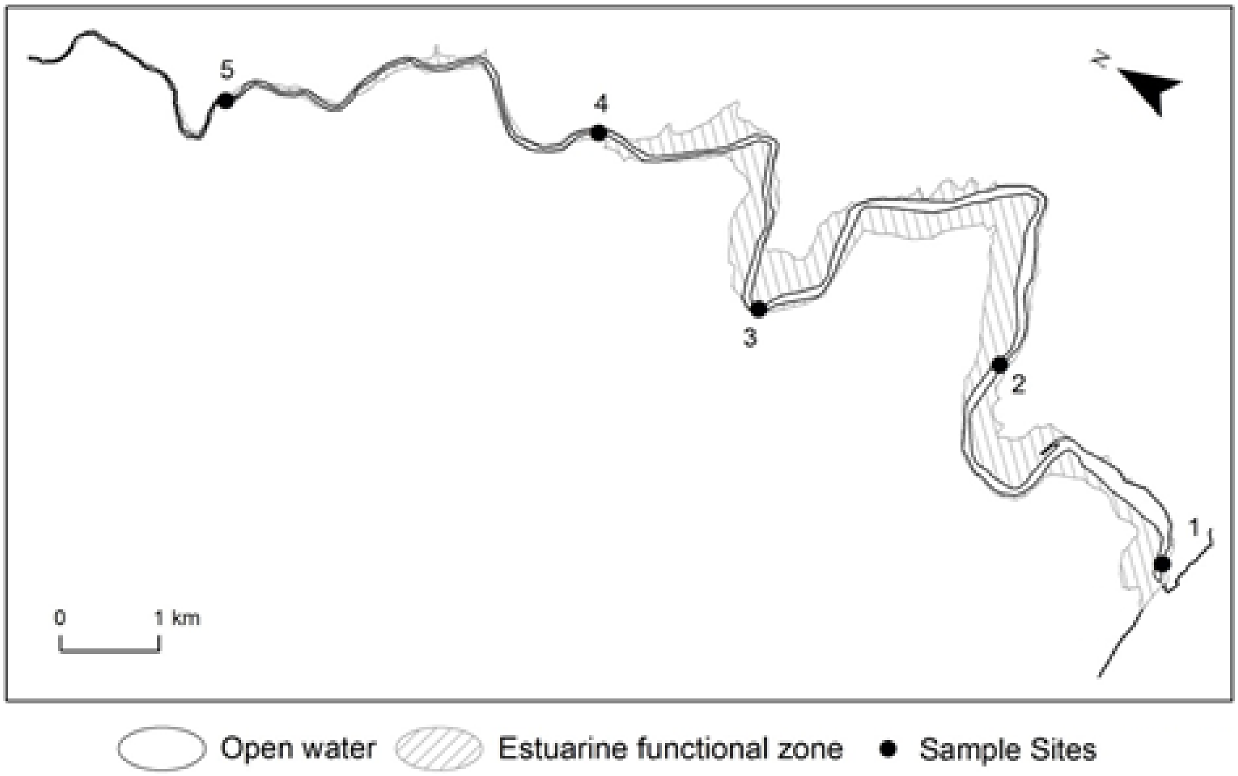


Figure D.1 **Invertebrate station positions in Duiwenhoks Estuary (see Table B.2 for distance from mouth)**

Table D.3 **Physico-chemical data collected at five stations on 4 December 2013 in the Duiwenhoks Estuary. Readings taken at 0.5 m depth intervals**

Station	Depth (m)	Temperature (°C)	Salinity	Dissolved oxygen (% saturation)	Dissolved oxygen (mg/ℓ)	pH
3	0	23.09	0.42	85.8	7.33	7.48
	0.5	23.01	0.45	86.7	7.32	7.49
	1	23.01	0.45	86.7	7.32	7.49
	1.5	22.97	0.45	84.1	7.19	7.53
	2	22.93	0.45	84.8	7.24	7.6
	2.5	22.92	0.43	85.2	7.3	7.64
	3	22.9	0.43	84.4	7.24	7.66
	3.5	22.83	0.41	83.6	7.17	7.79
	4	22.81	0.41	83.6	7.17	7.73
	4.5	22.84	0.42	83.8	7.18	7.77
	5	22.78	0.41	83.3	7.16	7.83
	5.5	22.79	0.41	82	7.05	7.86
4	0	23.39	0.4	86.7	7.37	7.14

Station	Depth (m)	Temperature (°C)	Salinity	Dissolved oxygen (% saturation)	Dissolved oxygen (mg/ℓ)	pH
	0.5	23.42	0.4	86.2	7.32	7.14
	1	23.4	0.4	85.2	7.23	7.14
	1.5	23.39	0.4	86.2	7.3	7.16
	2	23.42	0.4	87.1	7.4	7.17
	2.5	23.46	0.4	86.3	7.34	7.17
	3	23.43	0.4	85.8	7.6	7.2
5	0	22.85	0.41	96.1	8.24	7.23
	0.5	22.86	0.41	96.6	8.28	7.23
	1	22.88	0.41	95.8	8.2	7.22
	1.5	22.85	0.41	96.2	8.21	7.21
	2	22.73	0.41	94.9	8.14	7.19

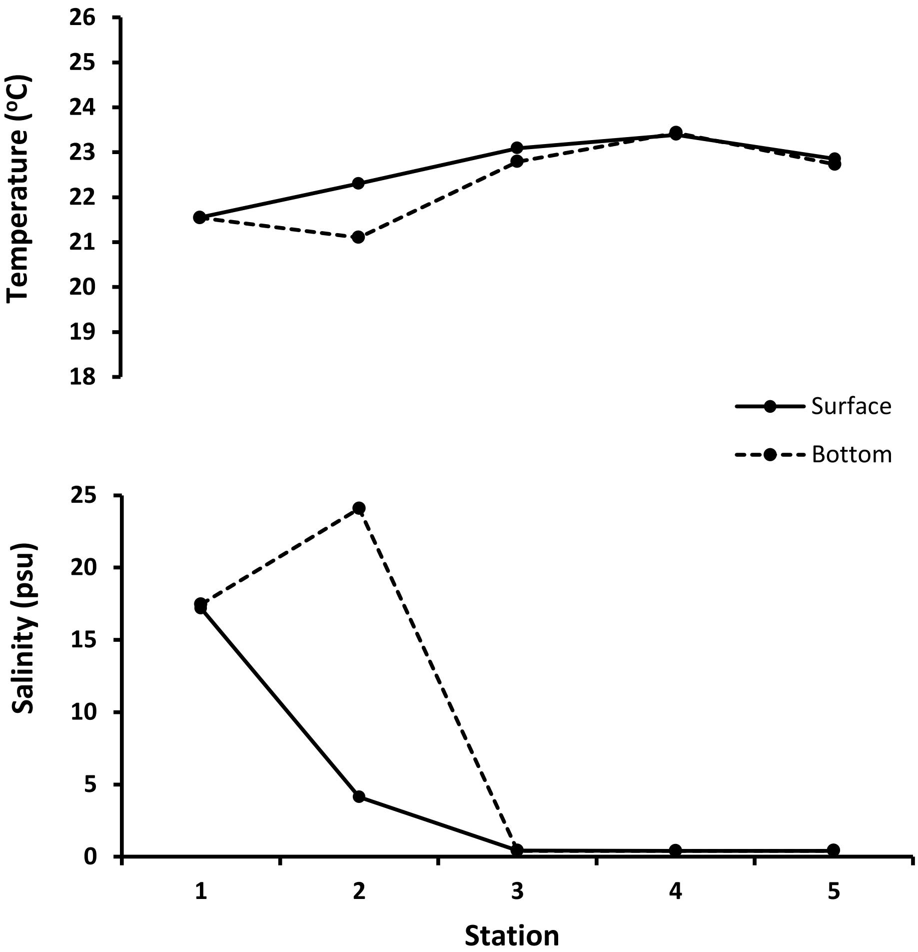


Figure D.2 Temperature and salinity readings measured just below the water surface and near the substrate at five stations in the Duiwenhoks Estuary (Station positions shown in Figure D.1)

D.2.2 Hyperbenthos

Hyperbenthic animals were sampled at five stations in the estuary (**Figure D.1**) 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 centimeters in length. 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.

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.

Seventeen taxa were recorded in the hyperbenthos (**Table D.4**). However, abundance (ind.m^3) was low and probably reflected a response to the oligohaline conditions recorded at most stations in the estuary at the time. Floods were experienced a few weeks previously and the estuary was probably in a state of recovery.

Species present were typical of estuaries along the south coast, with amphipods, mysids and carid shrimps dominating the hyperbenthic community. Of particular interest was the carid *Palaemon capensis*, females of which were carrying embryos at the time. This freshwater shrimp breeds in upper estuarine reaches where salinity values are oligohaline. **Figure D.3** provides the same information in visual format and is very similar to the composition of the hyperbenthos sampled in adjacent estuaries at the time (the Goukou is an example). The numerical dominance of amphipods is clearly visible and is mainly due to the relative abundance of *Grandidierella lignorum*.

Table D.4 Abundance of hyperbenthic organisms (ind. m^{-3}) in the Duiwenhoks Estuary. Data represent mean values of two replicates collected in December 2013 at five stations

Taxa	Station				
	1	2	3	4	5
Mysidacea					
Gastrosaccus brevifissura	0.0	16.0	2.0	0.0	0.0
Rhopalophthalmus terranatalis	0.0	10.0	0.0	0.0	0.0
Cumacea					
Iphinoe truncate	0.0	0.0	0.0	0.0	1.0
Tanaeidacea					

Taxa	Station				
	1	2	3	4	5
Apseudes digitalis	0.0	0.0	6.0	0.0	0.0
Isopoda					
Anthurid sp.	0.0	4.0	2.0	0.0	2.0
Sphaeromid juvs	0.0	0.0	2.0	0.0	1.0
Amphipoda					
Corophium triaenonyx	0.0	0.0	5.0	5.0	2.0
Grandidierella lignorum	0.0	30.0	12.0	10.0	10.0
Melita zeylanica	0.0	0.0	5.0	0.0	0.0
Caridea					
Betaeus jucundus	0.0	0.0	1.0	0.0	0.0
Carid larvae	0.0	11.0	0.0	0.0	0.0
Palaemon capensis adults with embryos	0.0	0.0	0.0	0.0	2.0
Palaemon capensis juvs	0.0	0.0	0.0	0.0	4.0
Palaemon capensis post-larvae	0.0	2.0	0.0	0.0	0.0
Brachyura					
Hymenosoma orbiculare juvs	0.0	1.0	0.0	1.0	0.0
Hymenosoma orbiculare larvae	0.0	7.0	0.0	0.0	0.0
Insecta					
Insect larvae	0.0	0.0	0.0	0.0	2.0

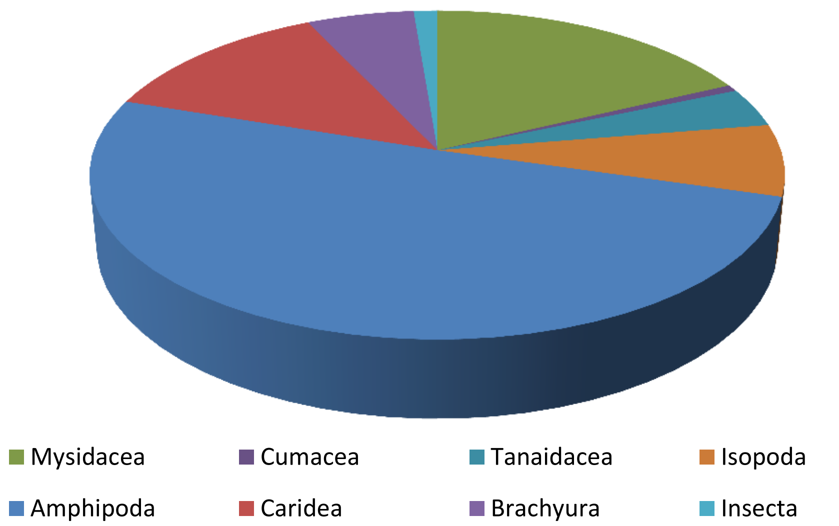


Figure D.3 Pie diagram of the most abundant hyperbenthic taxa in the Duiwenhoks Estuary. Values represent their total abundance at all sites in the estuary (see Table D.4) and expressed as percentage contribution of each group.

D.2.3 Benthos

Subtidal benthic invertebrates were collected from the deck of a flat-bottomed boat using a Van Veen type grab. Stations were the same in each estuary wrt the invertebrate group sampled. Six replicates were collected at each site and the contents of each grab sample 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 5% 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^{o}C for 48 h and then weighed) were incinerated at 550^{o}C 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^{o}C 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).

Sediment particle size distribution and organic content of the sediment is shown in **Table D.5**. Fine sand rather than mud (< 0.065 µm) dominated the sediment, with coarser sand dominating the upper two stations. At Station 5, 84.06% of the sediment particles exceeded 500 µm in diameter. Organic content of the sediment was generally low, averaging around 2% for all stations.

Table D.5 Sediment particle size distribution at five stations in the Duivenhoks Estuary. Size distribution grouped into four categories and expressed as percentage contribution of any category to the whole sample. Organic content of the sediment (expressed as percentage) shown in the last column

STN	> 0.500 µm	< 0.500 - 0.125 µm	< 0.125 - 0.065 µm	< 0.065 µm	Organic matter (%)
1	0	8.87	89.66	2.44	2.05
2	0	0.00	97.50	2.76	1.83
3	0	14.55	82.55	2.93	2.06
4	27.91	67.32	1.93	2.50	2.12
5	84.06	13.55	0.31	2.19	1.9

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.

Twelve taxa were recorded in the benthos (**Table D.6**) and must be considered low by comparison to other tidal estuaries in the temperate region. Abundance of individual species (ind.m^{-2}) was also low and may reflect a response to the oligohaline conditions recorded at most stations in the estuary at the time. No clear pattern in the distribution of the benthic community relative to sediment characteristics was discernible. Floods were experienced a few weeks previously and the estuary was in a state of recovery. By comparison to the Great Berg Estuary for example, abundance levels for the same species were orders of magnitude lower in the Duiwenhoks Estuary.

Species present were typical of estuaries along the south coast, with the community dominated by two species of amphipods (*Corophium triaenonyx* and *Grandidierella lignorum*). The polychaete worm *Ceratonereis keiskama* was the only other relatively common species. However, the intertidal zone supported very high densities of *Upogebia africana* along the banks of the estuary.

Figure D.4 summarises **Table D.6** in visual format and emphasizes the dominance of amphipods at most stations sampled. Although no quantitative data are available, a comparison of the macrobenthic species recorded in the estuary by Carter and Brownlie (1990) show little overlap with the present study. This may be partly due to the influence of flooding prior to the 2013 survey.

Table D.6 Abundance of macrozoobenthic organisms (ind. m^{-2}) in the Duiwenhoks Estuary. Data represent mean values of two replicates collected in December 2013 at five stations

Station	1	2	3	4	5
Polychaeta					
Ceratonereis keiskama	0.0	3.0	103.4	41.4	0.0
Juvenile polychaeta	3.0	0.0	0.0	0.0	0.0
Prionospio sp	0.0	0.0	0.0	5.9	0.0
Mysidacea					
Gastrosaccus brevifissura	5.9	38.4	0.0	0.0	0.0
Mysidacea sp.	0.0	0.0	0.0	11.8	0.0
Tanaidacea					
Apseudes digitalis	0.0	8.9	32.5	0.0	0.0
Isopoda					
Corallana africana	0.0	3.0	3.0	0.0	0.0
Cirolana fluviatilis	0.0	0.0	26.6	0.0	0.0
Cyathura estuaria	0.0	5.9	32.5	5.9	3.0
Amphipoda					
Corophium triaenonyx	0.0	5.9	180.3	257.1	109.3
Grandidierella lignorum	0.0	118.2	144.8	183.2	5.9
Mollusca					
Nassa kraussianus	8.9	0.0	0.0	0.0	0.0

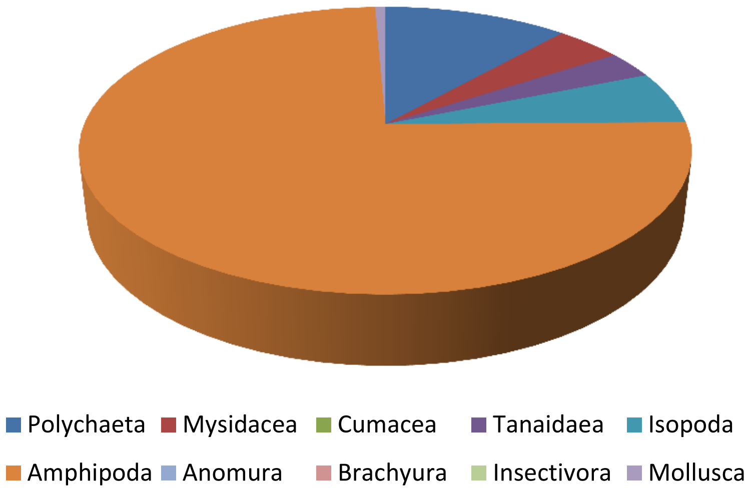


Figure D.4 Pie diagram of the most abundant macrozoobenthic taxa in the Duiwenhoks Estuary. Values represent their total abundance at all sites in the estuary (see Table D.6) and expressed as percentage contribution of each group

APPENDIX E: FISH SPECIALIST REPORT

Prepared by 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 Quarterly/twice annually in spring/summer and autumn/winter since 2000 Dec 2013	Harrison (1999); Carter and Brownlie (1990) DAFF (unpublished data) This study

Historical fish data on the Duiwenhoks is limited to once-off sampling by Harrison (1999) and anecdotal information in Carter and Brownlie (1990). Since then, the ichthyofauna of the Duiwenhoks has been sampled by DAFF Inshore Fisheries Research since 2002, the first three years quarterly and thereafter twice annually in spring/summer and autumn/winter. Until the 1990s, there was a beach-seine fishery in the Duiwenhoks with some permits issued by CapeNature (in its previous morph) but many operations illicit. Most targeting was directed at mullet species but also at aggregations of large adult dusky kob and white steenbras. Until 2001, the commercial line-fishery was allowed to launch from the slipway near the mouth but is no longer allowed to do so. However, two vessels are still regularly launched from that slipway. Illegal commercial line-fishing has been a problem in the estuary in the past and gillnetting (especially of spotted grunter and dusky kob) remains so until the present day.

E.2 ASSESSMENT OF FISH DATA

Forty-seven species of fish from 26 families have been recorded in the Duiwenhoks Estuary which is less than in the much larger Breede Estuary, but comparable to that of the adjacent Goukou and Gouritz estuaries of equivalent size. Over a 10-year sampling period (twice annually 2003-2014), 37 species were caught in the Duiwenhoks compared to 60, 38 and 37 in the Breede, Goukou and Gouritz respectively (**Table E.1**). Similarly, Harrison (1999) sampled all four systems once off yielding 16-17 species in each of the Duiwenhoks, Goukou and Gouritz Estuaries and only marginally more (22) in the Breede system.

Four estuarine residents that breed only in estuaries e.g. estuarine round herring *Gilchristella aestuaria* and checked goby *Redigobius dewaali* occur in the Duiwenhoks whereas those that breed in estuaries and the sea e.g. Cape silverside *Atherina breviceps* and Knysna sandgoby *Psammogobius knysnaensis* are represented by seven species. Obligate estuary-dependent fish such as dusky kob *Argyrosomus japonicus* and spotted grunter *Pomadasys commersonnii* comprise seven species whereas there are nine opportunistic partially estuary-dependent fish such as harder *Liza richardsonii* and Cape sole *Heteromycterus capensis*. Marine vagrants such as silver kob *Argyrosomus inodorus* and sand steenbras *Lithognathus mormyrus* comprise six species. Of the seven freshwater fish in the estuary only three, Burchell's redfin *Pseudobarbus burchelli*, Cape galaxias *Galaxias zebratus* and Cape kurper *Sandelia capensis* are Cape endemics and have not been introduced whereas the others e.g. *Oreochromis mossambicus* are alien or translocated to the system. Catadromous fish are represented by three Anguillid eels whereas freshwater mullet *Myxus capensis* may be regarded as a facultative catadromous species. Altogether, including estuarine residents and catadromous fish, 15 (32%) of the Duiwenhoks fish assemblage are completely dependent on estuaries to complete their life-cycle, 16 (34%) are partially estuary-dependent and the remainder evenly split between estuary-independent marine and freshwater species.

Numerically*, G. aestuaria* (38%), *L. richardsonii* (21%) and *Caffrogobius* spp. (15%) dominate the Duiwenhoks fish assemblage providing 74% of sampling catches. *Myxus capensis* (7%), blackhand sole *Solea turbynei* (4%), groovy mullet *Liza dumerili* (4%), *P. knysnaensis* (3%) and Cape stumpnose *Rhabdosargus holubi* (2%) are also important. The remaining species all contributed < 1% to the sampling catch. However, these species e.g. dusky kob *Argyrosomus japonicus*, spotted grunter *Pomadasys commersonnii* and leervis *Lichia amia* are large and species of natural lower abundance. G. aestuaria, Caffrogobius spp., *S. bleekeri* and *P. knysnaensis* occurred in over 50% and *L. richardsonii* and *R. holubi* in 35% of sample hauls. The larger species e.g. *A. japonicus* and *L. lithognathus* occurred in 2-15% of hauls. Superficially, the occurrence of these larger and exploited species reflected their overexploited status. The species are classified into five major categories of estuarine-dependence as suggested by Whitfield 1994.

Table E.1 A list of all 47 species and 26 families recorded in the Duiwenhoks Estuary by Carter and Brownlie (1990), Harrison (1999), DAFF (Lamberth) 2002-2015 and during this study.

Family name	Species name	Common name	Dependence
OSTEICHTHYES			
Anabantidae	*Sandelia capensis*	Cape kurper	IV
Anguillidae	*Anguilla mossambica*	Longfin eel	Va
	Anguilla bengalensis	African mottled eel	Va
	Anguilla marmorata	Madagascar mottled eel	Va
Ariidae	*Galeichthyes feliceps*	Barbel	IIb
Atherinidae	*Atherina breviceps*	Cape silverside	Ib
Blenniidae	*Omobranchus woodi*	Kappie blenny	Ia
Carangidae	*Lichia amia*	Leervis	IIa
	Trachurus capensis	Maasbunker	III
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	IV
Cichlidae	Oreochromis mossambicus	Mozambique tilapia	IV

Family name	Species name	Common name	Dependence
	Tilapia sparrmanii	Banded tilapia	IV
Clinidae	*Clinus superciliosus*	Super klipvis	Ib
Clupeidae	*Gilchristella aestuaria*	Estuarine round herring	Ia
Cyprinidae	*Cyprinus carpio*	Carp	IV
	Pseudobarbus burchelli	Burchell’s redfin	IV
Galaxiidae	*Galaxias zebratus*	Cape galaxias	IV
Gobiidae	*Caffrogobius gilchristii*	Prison goby	Ib
	Caffrogobius natalensis	Baldy	Ib
	Caffrogobius nudiceps	Barehead goby	Ib
	Psammogobius knysnaensis	Knysna sandgoby	Ib
	Redigobius dewaali	Checked goby	Ia
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa
	Pomadasys olivaceum	Piggy	III
Hemiramphidae	*Hyporhamphus capensis*	Cape halfbeak	Ia
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa
Mugilidae	*Liza dumerilii*	Groovy mullet	IIb
	Liza richardsonii	Harder	IIc
	Liza tricuspidens	Striped mullet	IIb
	Mugil cephalus	Flathead mullet	IIa
	Myxus capensis	Freshwater mullet	Vb
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc
Sciaenidae	*Argyrosomus inodorus*	Silver kob	III
	Argyrosomus japonicus	Dusky kob	IIa
Soleidae	*Heteromycterus capensis*	Cape sole	IIb
	Solea bleekeri	Blackhand sole	IIb
Sparidae	*Diplodus sargus*	Dassie	IIc
	Lithognathus lithognathus	White steenbras	IIa
	Lithognathus mormyrus	Sand steenbras	III
	Rhabdosargus globiceps	White stumpnose	IIc
	Rhabdosargus holubi	Cape Stumpnose	IIa
Syngnathidae	*Syngnathus temminckii*	Longsnout pipefish	Ib
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III
CHONDRICHTHYES			
Dasyatidae	*Gymnura natalensis*	Butterfly ray	III
Myliobatidae	*Myliobatis Aquila*	Bullray	III
	Pteromylaeus bovinus	Duckbill ray	III
Rhinobatidae	*Rhinobatos annulatus*	Lesser guitarfish	III

Along-stream distribution was largely a reflection of salinity preferences and the estuary-dependence category to which the fish belonged (**Table E.2**). Most (90%) of the facultative catadromous *Myxus capensis* occurred in the salinity < 10 REI zone whereas most (66%) of the opportunistic marine *L. richardsonii* occurred in the salinity > 30 mouth region. Most individuals (60-100%) of species that have a preference for the salinity < 10 REI zone e.g. *G.aestuaria* and moony *Monodactylus falciformis* were in Zone D, even when salinities were high throughout the system. Numerically overall, 48% of the fish assemblage was in the REI zone compared to 26% in both the middle (salinity 10-30) and lower (salinity > 30) reaches respectively. This all suggests an estuary with a greater freshwater influence historically compared to the marine dominated system of the present day. Species richness was highest (20 species) in both the lower (> 30 psu, Zone A) and upper (salinity < 10, Zone D) reaches and lowest (15 species) in both the middle reaches (salinity 10-30, Zones B and C). On the whole, fish in Zones B and C were ubiquitous in the estuary but augmented by marine vagrants and freshwater species in the lower and upper reaches respectively.

Table E.2 Duiwenhoks Estuary fish distribution (fish/haul) in four different salinity ranges

Species	> 30 psu	20-30 psu	10_20 psu	< 10 psu
Gilchristella aestuaria	6.90	3.11	7.83	84.69
Liza richardsonii	65.95	12.89	4.83	0.23
Caffrogobius	3.35	2.11	25.61	23.19
Myxus			1.36	50.77
Solea bleekeri	4.35	3.22	8.17	10.92
Liza dumerilii	7.70	6.11	2.70	3.38
Psammogobius knysnaensis	2.21	3.00	2.17	8.85
Atherina breviceps	0.95			
Mugillidae	13.85	0.33	0.87	2.31
Rhabdosargus holubi	0.70	0.67	3.04	2.77
Myxus			1.96	4.50
Galeichthyes feliceps		0.11	0.52	1.38
Heteromycterus capensis	0.90	3.00	3.09	
Monodactylus falciformis			0.74	1.12
Mugil cephalus			0.07	1.95
Lithognathus lithognathus	0.35	0.44	0.96	0.42
Omobranchus woodi		5.11		
Hyporhamphus capensis	0.75	0.33	0.48	0.19
Clinus superciliosus	1.15			
Liza tricuspidens	0.20			
Pomadasys commersonnii	0.05			0.65
Rhabdosargus globiceps				
Lichia amia	0.05	0.33	0.13	0.12
Amblyrhynchotes honckenii	0.05			

Species	> 30 psu	20-30 psu	10_20 psu	< 10 psu
Pseudobarbus burchelli				0.35
Tilapia sparrmanii				0.12
Syngnathus temminckii	0.05			
Argyrosomus japonicus				
Pomatomus saltatrix	0.05	0.11		
Redigobius dewaali				0.08
Diplodus sargus	0.05			
Pomadasys olivaceum				0.04
Trachurus capensis				
Total	**110**	**41**	**64**	**198**

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. The majority of these counts have been conducted in the summer, with exception to the 2000-2013 CWAC data[1] which also included winter surveys. Most of these counts included the full estuary and all types of birds. Dec 2013	CWAC data This study

Several counts of avifauna populations have been conducted at Duiwenhoks Estuary (**Table F.1**).

Table F.1 Summary of bird count data available for the Duiwenhoks Estuary

Date	Type of count	Number of species	Total abundance	Wader abundance	Reference
January 1976	Waders	7	Not counted		Summers *et al.* 1976
January 1981	Full	15	336	30	Underhill and Cooper 1984, Ryan *et al.* 1988
February 2000-January 2013	Full	Range 10-24	Range 20-468	Range 6-74	CWAC data
December 2013	Full	13	90	38	This study

F.2 SPECIES RICHNESS AND ABUNDANCE

A total of 41 non-passerine waterbird species have been recorded on Duiwenhoks Estuary. Across all CWAC counts 2000-2013, there were a total of 39 species recorded in summer and 31 in winter. The number of species recorded in any single count was 14 in the 1981 survey, 12 in December 2013 survey and an average of 15 in summer and 14 in winter between 2000-2013 (CWAC data). The overall abundance of birds seems to have decreased from the 1981 survey (333) until the most recent survey (87). Species and counts from Jan 1981, Dec 2013 as well as the 2000-2013 CWAC data mean and maximum counts are summarised in **Table F.2**.

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

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

Common name	Underhill and Cooper Jan 1981	2000-2013 CWAC data				Dec 2013
		Summer		Winter		
		Average	Max	Average	Max	
Cormorant, White-breasted	0	2	7	6	13	5
Cormorant, Cape	0	1	3	1	2	0
Cormorant, Bank	0	0	2	0	0	0
Cormorant, Reed	3	4	16	5	11	0
Darter, African	0	1	3	1	3	0
Heron, Grey	2	7	20	5	14	2
Heron, Black-headed	0	1	10	0	0	0
Egret, Little	2	1	3	1	2	0
Ibis, African Sacred	0	0	0	0	1	0
Ibis, Hadeda	0	0	2	2	14	3
Goose, Egyptian	0	4	16	8	14	31
Shoveler, Cape	0	0	2	0	0	0
Duck, African Black	0	0	2	0	2	0
Duck, Yellow-billed	0	1	4	2	5	3
Teal, Hottentot	0	0	2	0	2	0
Fish-Eagle, African	0	0	2	1	2	0
Osprey, Osprey	1	0	1	0	1	0
Oystercatcher, African Black	0	0	1	1	3	0
Plover, Common Ringed	0	2	19	0	0	0
Plover, White-fronted	5	4	10	6	11	4
Plover, Grey	8	3	13	0	0	3
Lapwing, Blacksmith	1	2	6	0	0	0
Sandpiper, Curlew	0	0	2	0	1	0
Stint, Little	0	0	1	0	0	0
Sanderling, Sanderling	0	1	11	0	0	0
Sandpiper, Common	1	3	7	2	6	1
Sandpiper, Marsh	0	0	1	0	3	0
Greenshank, Common	1	6	19	3	9	15
Curlew, Eurasian	0	0	4	0	3	0
Whimbrel, Common	10	3	13	0	1	10
Avocet, Pied	0	0	0	0	2	0
Thick-knee, Water	0	0	2	0	0	0
Gull, Kelp	23	15	49	15	28	2

Common name	Underhill and Cooper Jan 1981	2000-2013 CWAC data				Dec 2013
		Summer		Winter		
		Average	Max	Average	Max	
Gull, Hartlaub's	0	0	1	0	0	0
Tern, Caspian	0	2	4	1	3	0
Tern, Common	230	57	320	3	19	0
Tern, Sandwich	45	11	61	8	63	0
Tern, Swift	0	14	120	26	120	0
Kingfisher, Pied	1	3	5	2	5	8
Kingfisher, Giant	0	1	4	0	1	0
Kingfisher, Malachite	0	1	3	1	2	0
Total	**333**	**149**	**464**	**100**	**175**	**87**

F.3 BIRD GROUPS AND COMMUNITY COMPOSITION

A total of 41 non-passerine waterbird species have been recorded on the Duiwenhoks Estuary. Across all CWAC counts 2000-2013, there were a total of 39 species recorded in summer and 31 in winter. A total of 14 species were recorded in the Underhill and Cooper 1984 survey, an average of 15 in summer and 14 in winter between 2000-2013 (CWAC data) and 12 species were recorded in the December 2013 Anchor survey. While 333 birds were recorded in 1984, the summer average over 2000-2013 was 149, and 87 birds were recorded in December 2013. In December 2013, the lower estuary community was characterised by benthivorous waders, cormorants, gulls and terns. Waterfowl and piscivorous wading birds dominated towards the head of the estuary.

Over the past 13 years, the avifauna has been dominated by piscivorous gulls and terns (65%) and benthivorous waders (18%) in summer (**Figure F.1**). Most of the birds in the gulls and terns group in summer were the migratory Common Tern (38%), which was by far the most common bird overall. In winter the bird community was also dominated by the gulls and terns group (51%) and benthivorous waders (17%). The Kelp Gull (15%) and the Swift Tern (26%) were the most numerous birds seen during winter. The numbers of piscivorous cormorants and waterfowl were marginally higher in winter than in summer.

The composition of birds recorded during the summer 2000-2013 CWAC data was quite different from that recorded in the earlier Underhill and Cooper 1984 survey (**Figure F.2**). In the 1981 survey the community was dominated much more by piscivorous gulls and terns (89%), driven by high numbers of the migratory Common Tern (68%). Although the Common Tern was present from 2000-2013, high numbers were only recorded in two years (320 in 2005 and 180 in 2008). The absence of waterfowl in the 1981 survey suggests they may not have counted the full extent of the estuary. The recent December 2013 survey found a similar community composition to the summer 2000-2013 CWAC data (**Figure F.2**), with the exception of slightly higher numbers of herbivorous waterfowl (Egyptian Goose) being recorded in this study (31 vs. an average of 4).

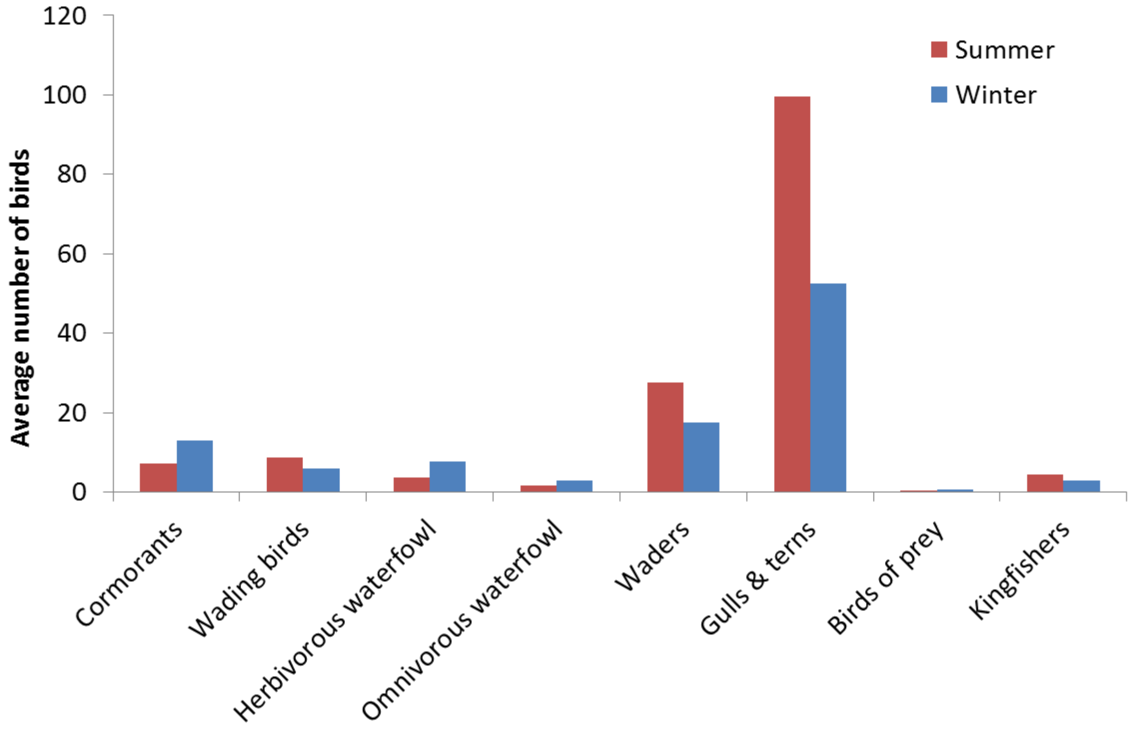


Figure F.1 Average counts of different groups of birds in summer and winter, counted from Mouth to Mazapa (2000-2013 CWAC data)

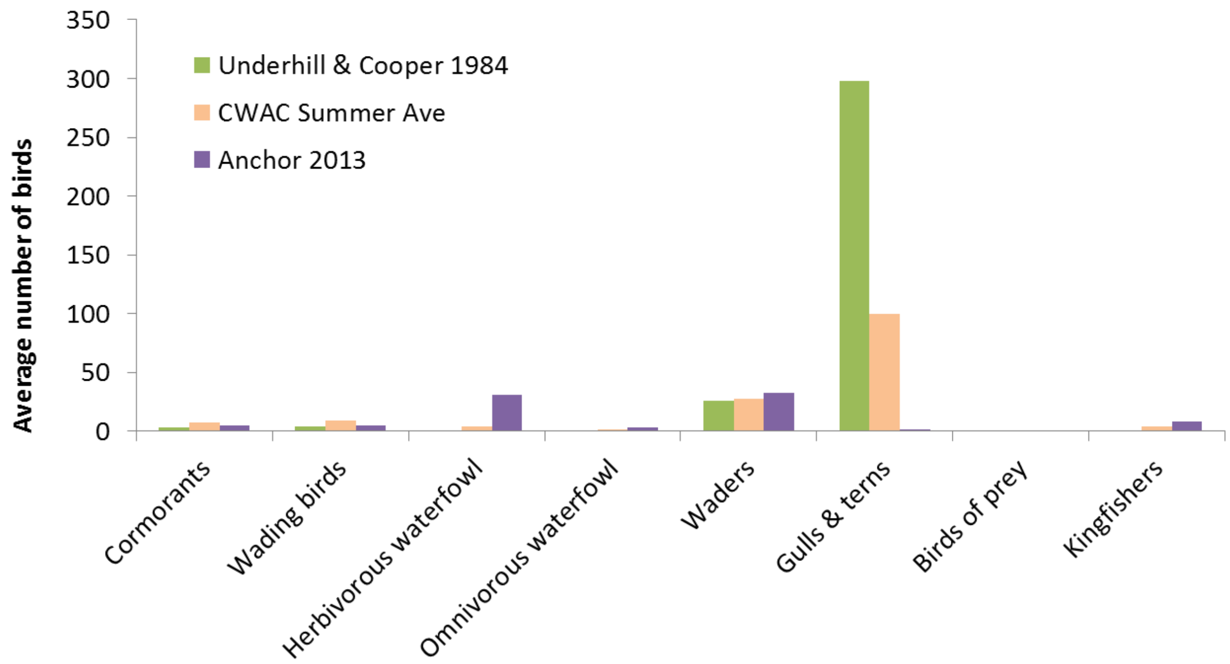


Figure F.2 Counts of different groups of birds in summer in the Dec 1981 and Jan 2013 surveys

The way in which the different groups of birds were distributed along the estuary in December 2013 is shown in **Figure F.3**. There were two main concentrations, the first closer to the mouth in the lower parts of the estuary, and the second much higher up the estuary. The lower estuary community was characterised by benthivorous waders, cormorants, gulls and terns. Waterfowl and piscivorous wading birds dominated towards the head of the estuary.

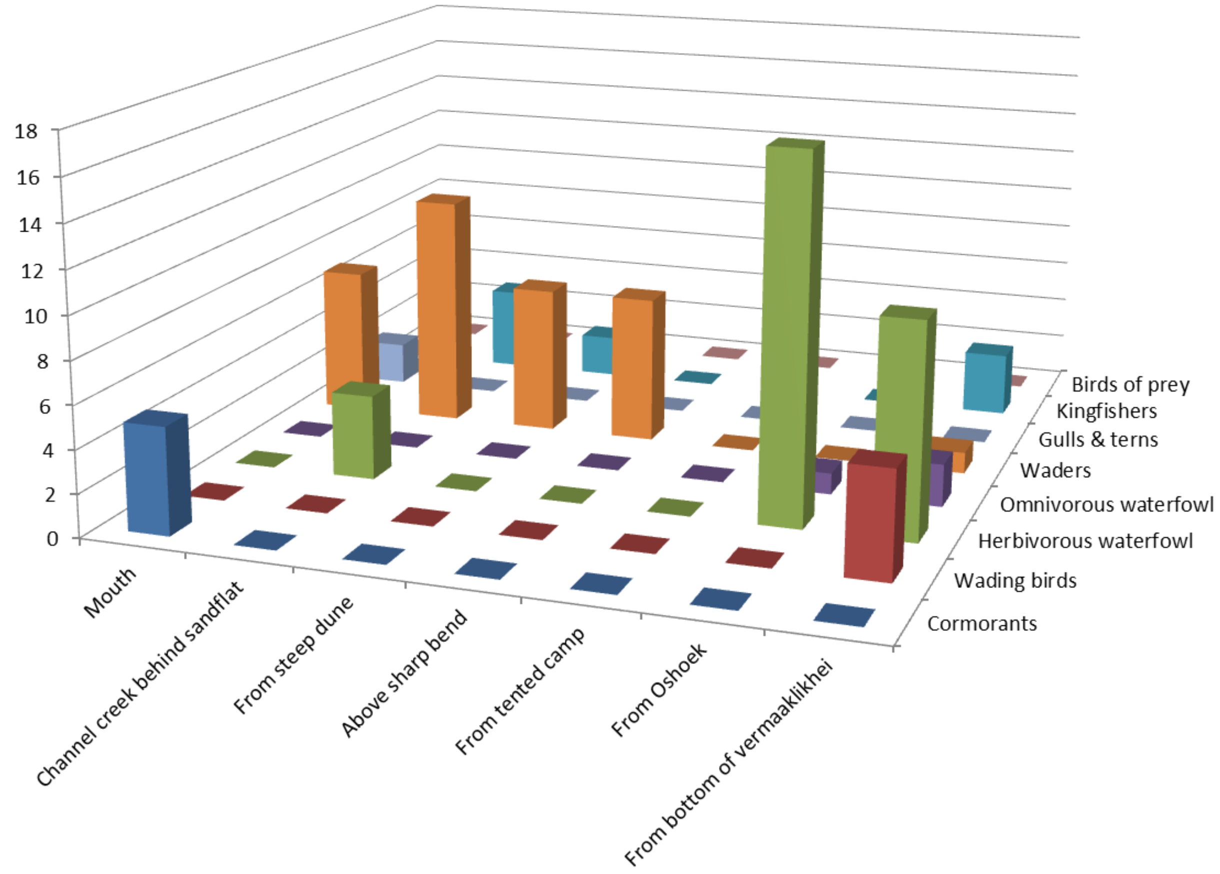


Figure F.3 Counts of different groups of birds along different stretches of the Duiwenhoks Estuary during Anchor Dec 2013 surveys

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	EcoSpecs: Fish	EcoSpecs for fish need to be more explicit	Yes	Uncertainty in EcoSpecs for fish was changed (see Section 8.2)
Comments: Simon von Witt (AECOM) dated 12 May 2015				
Entire report	Entire report	Editorial corrections made in track changes	Yes	Editorial corrections were made through out report
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 checked and consolidated (i.e. removed from individual Appendices) in the Reference section (see Section 9)

Section	Report Statement	Comments	Addressed In Report?	Author Comment
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. 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 were 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)
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.	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)

Section	Report Statement	Comments	Addressed In Report?	Author Comment
		Key missing data should be indicated in Limitations and Assumptions section of the Report.		
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.
2.1	Figure 2.1	Entirely out of focus.	Yes	Replaced figure
4.3	Table 4.9	Spelling: Well Mixed	Yes	Spelling corrected
4.6	Table 4.20	Dissolved Oxygen: Sentence not completed.	Yes	Corrected
4.8	Table 4.31 with Table 4.28	Check consistency around comment on zooplankton and benthic invertebrates in	Yes	Table 4.31 corrected to align with table 4.28
7.5	Table 7.17	Dissolved oxygen – why values in red?	Yes	Changed colour, no reason to be red
7.6	Table 7.21	Check rationale around Scenario 3 does this mean that a dam scenario scores better than scenarios 1 & 2?	No	Correct, dam reduced inflow of high nutrient water from catchment, thus "improving" conditions for microalgae
7.6	Table 7.21:	Microalgae score Min a-c: There is no a – c?	Yes	Changed wording to correct this
7.7	Table 7.22 and 7.23	The narrative in not consistent with the scoring in Table 7.23 wrt to Scenario 2.	Yes	Corrected the wording in Table 7.22 to match score in Table 7.23
7.9	Fish scoring	Section 7.9 indicates no befit in Scenario 2 from Present state yet abundances in invertebrates increase across the board between Present state and Scenario 2.	Yes	Changed fish abundance score (75) to make consistent
7	Scoring of all biotic components	The rationale of the low flow EWR having no impact on biota and the associated trophic cascading is not consistent between the trophic levels.	Yes, mostly	Where appropriate the changes in the trophic components were amended (see above), but all component are not equally sensitive to such changes, e.g. other non-flow related pressures can be stronger (see motivations in various

Section	Report Statement	Comments	Addressed In Report?	Author Comment
				components)
8	Allocation of recommended flow requirements	Section 8 Recommendations: Why deviate from the Present State and recommend Scenario 2 when it makes an almost negligible effect on the Biotic Health score?	No	Returning of base flow is a critical flow-related component necessary to elevate REC to Category B. Scenario 2 area able to improve from Category C 9present) to Category B/C, albeit incremental.
9	Reference missing	Section 9 References: Snow 2008 is missing. Check all references.	Yes	Reference included.
Appendix A	Editorial	Figure A5b in text as A5c.	Yes	Fix
Appendix A	Figure resolution	Figures A5a-e: Figures are out of focus. Check all graphs in this specialist report.	Yes	Improved
Appendix A	Figure 7a	Notes in graph are unclear	Yes	Removed note and adjusted graph accordingly to prevent confusion
Appendix C	Available data	Why is this table entirely different to that of the Goukou yet both are Intermediate studies?	Yes	Included a comprehensive table (see Section C.1)
Appendix D	Tables	Tables in Invertebrate specialist report need boarders.	Yes	Corrected
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)
Comments: Dr Aldu le Grange (AECOM) dated 26 October 2015				
Entire report	Entire report	Editorial corrections made in hard copy	Yes	Editorial corrections were made through out report