





WP 10543

RDM/WMA16/04/CON/0713, Volume 1

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

PROJECT TECHNICAL REPORT 7, VOLUME 1

ESTUARIES RDM REPORT – RAPID ASSESSMENT, VOLUME 1

KLEIN BRAK ESTUARY

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Chief Directorate: Water Ecosystems

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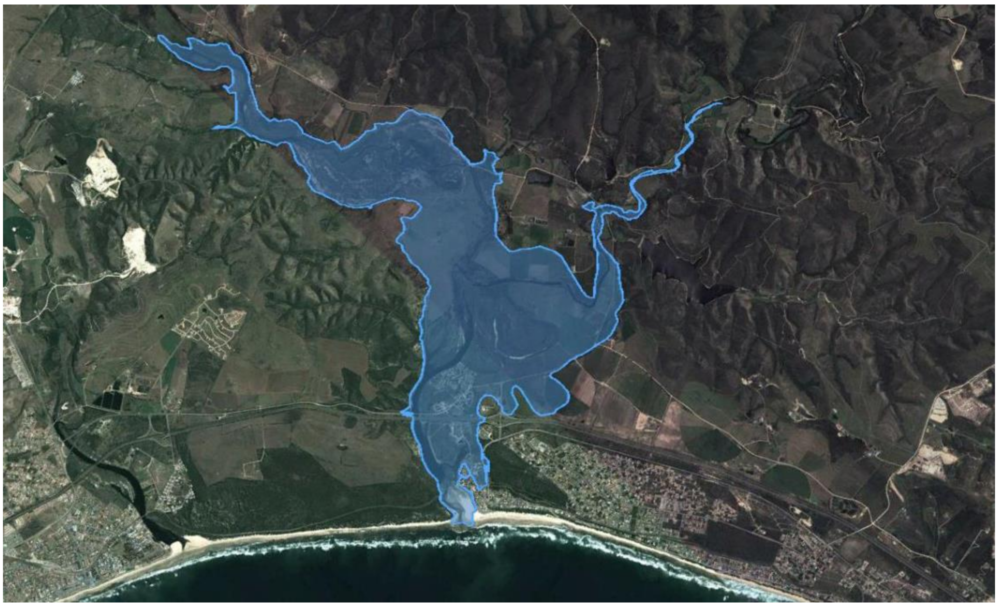
Final report	September 2015

EXECUTIVE SUMMARY

GEOGRAPHICAL BOUNDARIES

The Klein Brak Estuary is situated within the southern coastal belt, and is located approximately 12 km north of Mossel Bay. Two major tributaries, the Brandwag River and the Moordkuil River join approximately 3 km from the coast to form a well-developed flood-tidal delta.



The geographical boundaries of the estuary are defined as follows:

Downstream boundary:	*Estuary mouth 34° 5'31.98"S, 22° 8'55.43"E*
Upstream boundary:	*34° 4'36.55"S, 22° 3'57.72"E/ 34° 2'4.54"S, 22° 8'2.91"E*
Lateral boundaries:	*5 m contour above Mean Sea Level (MSL) along each bank*

PRESENT ECOLOGICAL STATUS

The Estuarine Health Score for the Klein Brak Estuary is 64, representing a Present Ecological Status (PES) of ***Category C.***

Variable	***Weight***	***Score***
Hydrology	*25*	*56*
Hydrodynamics and mouth condition	*25*	*96*
Water quality	*25*	*82*
Physical habitat alteration	*25*	*54*
Habitat health score		***72***
Microalgae	*20*	*64*
Macrophytes	*20*	*50*
Invertebrates	*20*	*70*
Fish	*20*	*60*
Birds	*20*	*31*

Variable	Weight	Score
Biotic health score		***55***
ESTUARY HEALTH SCORE Mean (Habitat health, Biological health)		***64***
PRESENT ECOLOGICAL STATUS (PES)		***C***

ECOLOGICAL IMPORTANCE

As per the national rating of estuarine importance, the Klein Brak Estuary rates as ***"Average Important"*** *albeit just below the rating of "Important". While, on a national scale, Klein Brak Estuary may be of average importance, it is certainly a large estuary in this region and plays a very important role as fish nursery for exploited and endangered fish species and providing an open estuary along a coast where a significant number of systems are seasonally closed. At a finer, regional scale the Klein Brak Estuary is, therefore, important.*

RECOMMENDED ECOLOGICAL CATEGORY

As an estuary of average importance the Klein Brak Estuary should at least be managed in a Category C (maintain PES with Category C as minimum). ***Category C*** *was therefore allocated as the* ***Recommended Ecological Category (REC)*** *for the* ***Klein Brak Estuary****. However, the estuary is on a* ***negative trajectory of change*** *and if the current (low) base flow regime, as well as certain non-flow related impacts on the system continues as at present, the estuary is likely to move into a Category C/D, even a Category D. These issues therefore need to be addressed in order to maintain the REC (Category C) in future.*

RECOMMENDED ECOLOGICAL FLOW SCENARIO

Present inflow, including the Ecological Water Requirement (EWR) for an Ecological Category C river *just upstream of the estuary (mean annual run off [MAR] 38.97 million m^3) was selected as the recommended ecological flow scenario for the Klein Brak Estuary (Category C):*

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	7.5	18.1	12.9	10.2	8.1	10.3	11.0	9.9	5.6	5.1	11.4	11.9
99	7.3	17.0	12.3	7.5	7.7	9.2	8.6	9.4	4.1	3.6	10.1	8.4
90	4.0	5.1	2.8	2.0	2.1	3.9	4.7	2.4	1.8	1.3	2.3	4.3
80	3.2	2.9	1.4	1.2	1.1	2.1	2.6	1.7	1.0	1.0	1.2	2.5
70	2.1	2.0	0.9	0.6	0.8	1.4	1.2	0.9	0.7	0.8	0.8	1.4
60	1.4	1.2	0.7	0.3	0.3	0.8	0.7	0.4	0.4	0.5	0.5	0.9
50	0.7	0.5	0.3	0.2	0.2	0.5	0.5	0.3	0.3	0.4	0.4	0.6
40	0.6	0.4	0.3	0.2	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.4
30	0.4	0.3	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3
20	0.3	0.3	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3
10	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1

Therefore to account for some of the loss in base flows as part of the mitigation to reverse the negative trajectory of change, the above scenario was selected (and not the present flow scenario). However, in order to further address the negative trajectory of change, additional interventions in terms of non-flow related impacts are essential, namely:

- *On both the Brandwag (34◦03'43.51"S; 22◦06'47.95"E) and Moordkuil arms (34◦03'15.32"S; 22◦ 07'55.24"E) there are obstructions across the estuary (i.e. roads) that prevent saline intrusion/tidal variation extending further upstream. To improve tidal connectivity these obstructions should either be removed or proper bridges should be consutructed. In doing so, the river-estuary-interface (REI) (roughly defined as the reach where salinity ranges between 10 and 0) will be introduced more readily, enhancing nursery function in the upper estuaries and thus contributing to the recovery of collapsed and endangered fish species, e.g. dusky cob and white steenbras.*
- *Further upstream in the Moordkuil arm there is also a DWS weir (34◦03'11.14"S; 22◦08'02.85" E). As this weir fulfils an important gauging function it may not have to be removed, but fish ladders should be installed on both sides of the weir to allow migrating species (e.g. eels) to move upstream.*
- *Rehabilitate degraded areas in the estuary functional zone, e.g. consolidate present access routes so as not to have a web of small roads on the salt marshes.*
- *Removal of invasive alien plant species in the estuary functional zone, focussing especially in suptratidal areas.*
- *Reduce fishing pressures and (illegal) bait collecting through increased compliance (existing DAFF initiative).*
- *Institute a ban on night fishing to reduce the pressure on breeding stock of collapsed and endangered fish species, e.g. dusky cob (proposed DAFF initiative).*

*The overall confidence of this study is **Low,** mainly because of the low confidence in the simulated hydrology and limited data availability on the abiotic components. Although measured river inflows were available for both the Brandwag and Moordkuil rivers, only limited data were available on abiotic characteristics with which to define and characterise abiotic states in this complex system (i.e. two river inflows) which is the primary mechanism by which modification in health condition from the Reference Condition to Present State determined, together with simulated river runoff scenarios. 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. Medium to low confidence in the microalgae and invertebrate is attributed to the availability of some historical data sets on this system. Extensive data on the fish component collected by DAFF as part of their long-term monitoring programmes in estuaries significantly contributed to the medium (even high) confidence in this component. Historical data on the bird component was also available from the Coordinated Waterbird Counts (CWAC) programme. Even though specialists drew on experience from their collective research on other, related estuarine systems, the complexity of this estuary, as well as the low confidence in the hydrology resulted in an overalll low confidence of this study. However, the recommended monitoring programme should focus on improving confidence for future reviews.*

ECOLOGICAL SPECIFICATIONS

The following Ecological Specifications (EcoSpecs), and associated Thresholds of Potential Concern (TPCs) are representative of a ***Category C for the Klein Brak Estuary****:*

Component	EcoSpecs	Thresholds of Potential Concern
Hydrology	*Maintain a flow regime to create the required habitat for birds, fish, macrophytes, microalgae and water quality*	*River inflow:* ▪ *Monthly river inflow < 0.4 m^3/s persists for more than 30% of the time.* ▪ *Monthly river inflow < 0.15 m^3/s persists for more than 15% of the time.* ▪ *Monthly river inflow drops to 0 m^3/s*
Hydrodynamics	*Maintain connectivity with marine environment*	▪ *Mouth closer occurs* ▪ *Upper reaches above the weirs do not contribute to tidal flow to maintain open mouth conditions* ▪ *Average tidal amplitude < 20% of present observed data from the water level recorder in the estuary near the mouth*
Sediment dynamics	▪ *Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) for biota* ▪ *No significant changes in sediment grain size 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 bathymetry along main channel change by 30% in any survey along estuary from that of the Present State (2014 baseline, to be measured) (system expected to significantly fluctuate in terms of bathymetry between flood and extended closed periods)*
Water quality	*Salinity distribution not to cause exceedence of TPCs for biota (see below)*	▪ *No salinity gradient in the upper reaches of the estuary (Zone D and F)* ▪ *No REI in the upper reaches of the estuary (Zone D and F)* ▪ *Salinity > 35*
	System variables (pH, dissolved oxygen and turbidity) not to cause exceedence of TPCs for biota (see below)	*River inflow:* ▪ *7.0 < pH > 8.5* ▪ *Dissolved oxyxgen (DO) < 5 mg/ℓ* ▪ *Suspended solids > 5 mg/ ℓ (low flow)* *Estuary:* ▪ *Average turbidity > 10 NTU (low flow)* ▪ *Average 7.0 < pH > 8.5 (increasing with increase in salinity)* ▪ *Average DO < 5 mg/ℓ*

Component	EcoSpecs	Thresholds of Potential Concern
	Inorganic nutrient concentrations (NO_3-N, NH_3-N and PO_4-P) not to cause in exceedance of TPCs for macrophytes and microalgae (see below)	River inflow: ▪ NO_x-N > 150 µg/ℓ over two consecutive months ▪ NH_3-N > 20 µg/ℓ over two consecutive months ▪ PO_4-P > 20 µg/ℓ over two consecutive months Estuary (except during upwelling or floods): ▪ Average NO_x-N > 150 µg/ℓ during survey, single concentration > 200 µg/ℓ ▪ Average NH_3-N > 20 µg/ℓ during survey, single concentration > 100 µg/ℓ ▪ Average PO_4-P > 20 µg/ℓ during survey, single concentration > 50 µg/ℓ
	Presence of toxic substances (e.g. trace metals and pesticides/herbicides) not to cause exceedence 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 medium median phytoplankton biomass ▪ Prevent median intertidal benthic microalgal biomass from exceeding 60 mg m^{-2} ▪ 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 60 mg/m^2 ▪ Site specific chlorophyll a concentration exceeds 20 µg/ℓ and cell density exceeds 10 000 cells/m ℓ
Macrophytes	▪ Maintain the distribution of sensitive macrophyte habitats (e.g. salt marsh, submerged macrophytes). ▪ Maintain the integrity of the salt marsh ▪ Rehabilitate the floodplain habitat by removing weirs, berms and invasive plants ▪ Prevent an increase in nutrient input leading to macroalgal blooms	▪ Greater than 20 % change in the area covered by submerged macrophytes and salt marsh ▪ 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 ▪ Drying of floodplain habitat. ▪ Invasive plants cover > 10% of total floodplain area ▪ Macroalgal blooms cover > 50% of the open water area during closed mouth conditions
Invertebrates	▪ Maintain rich populations of mudprawn Upogebia africana on intertidal banks in middle estuary ▪ Maintain Pseudodiaptomus hessei as the numerically dominant copepod in the zooplankton of the estuary	▪ Mudprawn populations should not deviate from average baseline valuess (as determined in first three visits) by more 25% ▪ P. hessei populations should not deviate from average baseline valuess (as determined in first three visits) by more 30%

Component	***EcoSpecs***	***Thresholds of Potential Concern***
Fish	*Fish assemblage should comprise the 5 estuarine association categories in similar proportions (diveristy and abundance) to that under the reference. Numerically assemblage should comprise:* • *Ia estuarine residents (20-60%)* • *Ib marine and estuarine breeders (10-30%)* • *IIa obligate estuarine-dependent (20-40%)* • *IIb estuarine associated species (5-20%),* • *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 four species (including G.aestuaria, Hyporamphus capensis, Omobranchus woodii).* *Category IIa obligate dependents should be well represented by large exploited species especially A. japonicus, L. lithognathus, P. commersonnii, Lichia amia.* *REI species dominated by both Myxus capensis and G. aestuaria.*	▪ *Ia estuarine residents < 20%* ▪ *Ib marine and estuarine breeders < 10%* ▪ *IIa obligate estuarine-dependent < 20%* ▪ *IIb estuarine associated species < 5%* ▪ *IIc marine opportunists < 20%* ▪ *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	*Estuary should contain a diverse avifaunal community that includes representatives of all the original groups. Saltmarsh/wetlands in the floodplain should be rich in birdlife. Intertidal areas should have a good density and diversity of both larger and smaller waders*	▪ *Numbers of waterbirds on the entire system drops below 30 species or below 250 birds for three consecutive counts* ▪ *Numbers of waterbirds in the lower estuary drops below 10 species or 50 birds (excluding terns and gulls) for three consecutive counts*

BASELINE AND LONG-TERM MONITORING PROGRAMMES

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

Component	Action	Temporal scale (frequency and when)	Spatial scale (Stations)
Sediment dynamics	*Monitoring berm height using appropriate technologies*	*Quarterly*	*Mouth*
	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals but in more detail in mouth including berm (every 100 m). Vertical accuracy at least 5 cm	*Once-off*	*Entire estuary*
	Collect sediment grab samples (at cross-section profiles) for analysis of particle size distribution and 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 in Moordkuils (station K1H5) and Brandwag (station K1H4) rivers*
	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 for two years*	*Entire estuary (10-13 stations)*
	Measure pesticides/herbicides and metal accumulation in sediments (for metals investigate establishment of distribution models – see Newman and Watling, 2007)	*Once-off*	*Entire estuary, including depositional areas (i.e. muddy areas)*
Microalgae	▪ *Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae* ▪ *Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. spectrophotometer, HPLC, fluoroprobe* ▪ *Intertidal and subtidal benthic chlorophyll-a measurements (4 replicates each) using a recognised technique, e.g. sediment corer or fluoroprobe*	*Quarterly, preferably over two years*	*Along length of estuary minimum five stations (include stations in upper reaches of Brandwag and Moordkuil arms).*
Macrophytes	• *In the field map the area covered by the different macrophyte habitats. Record boundaries and the total number of*	*Once-off*	*Entire estuary*

Component	Action	Temporal scale (frequency and when)	Spatial scale (Stations)
	macrophytes species. ▪ *Assess extent of invasive species within the 5 m contour line* ▪ *Locate the position of reed and sedge areas as indicators of future salinity changes* ▪ *Identify supratidal salt marsh areas and their condition in terms of area of bareground.* ▪ *Map sensitive submerged macrophyte habitats such as Ruppia cirrhosa and Zostera capensis beds* ▪ *Identify macroalgae present, their distribution and potential for future expansion (bloom formation) particularly under low flow conditions* ▪ *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*		
Invertebrates	▪ *Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh)* ▪ *Collect grab samples (five replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each samples to be sieved through 500 um)* ▪ *Collect sled samples (day) at same zooplankton sites for hyper benthos (190 um)* ▪ *Intertidal invertebrate hole counts using 0.25 m^2 grid (five replicates per site). Establish the species concerned using a prawn pump* ▪ *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 three sites along length of entire estuary* *For hole counts – three sites in muddy substrata on eastern shore below N2 bridge.*

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

Component	Monitoring action	Temporal acale (frequency and when)	Spatial scale (Stations)
Hydrodynamics	Record water levels	Continuous	At bridge near mouth
	Measure freshwater inflow into the estuary	Continuous	Near head of estuary in Moordkuils (station K1H5) and Brandwag (station K1H4) rivers
	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 500 m intervals but in more detail in mouth including berm (every 100 m). Vertical accuracy at least 5 cm	Every three years (and after large resetting event)	Entire estuary
	Collect sediment grab samples (at cross-section profiles) for analysis of particle size distribution and 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 in Moordkuils (station K1H5) and Brandwag (station K1H4) rivers
	Collect samples for pesticides/herbicide and metal determinations in river inflow	Every 3 – 6 years, or when contamination is expected	Near head of estuary in Moordkuils (station K1H5) and Brandwag (station K1H4) rivers
	Collect in situ continuous salinity data with mini CTD probe at a depth of about 1 m	Continuous	Four to- six sites Head of the estuary in the Brandwag and Moordkuils arms, Brandwag and moordkuil weirs/causeways, the confluence of the two arms, the lower bridge
	Record longitudinal in situ salinity and temperature pH, DO, turbidity profiles	Seasonally, every year	Entire estuary (10-13 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 water quality expected	Entire estuary (10-13 stations)

Component	Monitoring action	Temporal acale (frequency and when)	Spatial scale (Stations)
	Measure pesticides/herbicides and metal accumulation in sediments	*Every 3 – 6 years, or when contamination is expected*	*Entire estuary, including depositional areas (i.e. muddy areas)*
Microalgae	▪ *Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae* ▪ *Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. spectrophotometer, HPLC, fluoroprobe* ▪ *Intertidal and subtidal benthic chlorophyll-a measurements (four replicates each) using a recognised technique, e.g. sediment corer or fluoroprobe*	*Quarterly for first two years and then low flow surveys every three years*	*Along length of estuary minimum five stations (include stations in upper reaches of Brandwag and Moordkuil arms).*
Macrophytes	▪ *In the field map the area covered by the different macrophyte habitats. Record boundaries and the total number of macrophytes species. 2013 was a rapid field survey and did not include detailed vegetation mapping and ground truthing* ▪ *Assess extent of invasive species within the 5 m contour line* ▪ *Locate the position of reed and sedge areas as indicators of future salinity changes* ▪ *Identify supratidal salt marsh areas and their condition in terms of area of bareground* ▪ *Map sensitive submerged macrophyte habitats such as Ruppia cirrhosa and Zostera capensis beds* ▪ *Identify macroalgae present, their distribution and potential for future expansion (bloom formation) particularly under low flow conditions* ▪ *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*	*Every three years during summer*	*Entire estuary*

Component	Monitoring action	Temporal acale (frequency and when)	Spatial scale (Stations)
	laboratory for sediment moisture, organic content, electrical conductivity, pH and redox potential. In the field measure depth to water table and ground water salinity		
Invertebrates	• *Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh)* • *Collect grab samples (five replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each samples to be sieved through 500 um).* • *Collect sled samples (day) at same zooplankton sites for hyper benthos (190 um)* • *Intertidal invertebrate hole counts using 0.25 m^2 grid (five replicates per site). Establish the species concerned using a prawn pump.* • *Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton)*	*Every two years in mid-summer*	*Minimum of three sites along length of entire estuary* *For hole counts – three sites in muddy substrata on eastern shore below N2 bridge.*
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 (ten stations)*

Component	*Monitoring action*	*Temporal acale (frequency and when)*	*Spatial scale (Stations)*
Birds	*Undertake counts of all non-passerine water birds, identified to species level (as for this study)*	*Annual winter and summer surveys*	*Entire estuary including floodplain. Divide into sections: lower to N2; lower estuary adjacent marshes; middle to confluence including marshes; Moorkuils to top, Brandwag to top; upper floodplain wetlands. (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 Deaprtment of Water and Sanitation (DWS), as well as other national and provincial departments and institutions responsible for estuarine resource management such as Department of Agriculture, Forestry and Fisheries (DAFF), Department of Environmental Affairs (DEA: Oceans and Coasts), South African National Biodiversity Institute (SANBI), CapeNature, as well as relevant municipal authorities. It is recommended that the estuarine management planning process and the associated institutional structures (as required under the Integrated Coastal Management Act, 2008) be used as mechanisms through which to facilitate the implementation these interventions.

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ACRONYMS AND ABBREVIATIONS

BAS	Best Attainable State
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
EWR	Ecological Water Requirement
GPS	Global Positioning System
GRDS	Gouritz Reserve Determination Study
H	High
L	Low
M	Medium
MAR	Mean Annual Runoff
MPB	Microphytobenthos
MSL	Mean Sea Level
NMMU	Nelson Mandela Metropolitan University
NBA 2011	National Biodiversity Assessment 2011
NTU	Nephelometric Turbidity Units
NWA	National Water Act (1998)
PES	Present Ecological Status
RDM	Resource Directed Measures
REC	Recommended Ecological Category
REI	River Estuary Interface
SC&A	Scherman Colloty & Associates 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
%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 **Rapid level assessment on the Klein Brak 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 Klein Brak 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 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 very low level (< 40).

- A detailed flood analysis was not conducted as it is not a requirement for a Rapid level assessment. The simulated runoff data were used to estimate flood conditions.
- Although measured data inflow was available on both the Brandwag (station K1H4) and Moodkuil (station K1H5) rivers, data on abiotic characteristics, e.g. sediment and mouth dynamics and water quality, were not sufficient to derive abiotic states or to assess abiotic components at a medium or high confidence.
- Data availability for biotic components varied between medium to low, but as a result of the low confidence in simulated hydrology and abiotic components, as well as the complexity of this system, the overall confidence of this study remains low.
- A Rapid level assessment can only be used for individual licensing for small impacts in unstressed catchments of low importance and sensitivity. For individual licensing in important, unstressed systems, an Intermediate level assessment is required, while 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: Data summary report: Bathymetry and Hydrodynamics

B: Data summary report: Sediment dynamics

C: Data summary report: Water quality
D: Data summary report: Microalgae
E: Data summary report: Macropghytes
F: Data summary report: Invertebrates
G: Data summary report: Fish
H Data summary report: Birds
I: Comments and response register.

2 BACKGROUND INFORMATION

2.1 CATCHMENT CHARACTERISTICS AND LAND-USE

The Klein Brak catchment receives rainfall throughout the year, with peaks in autumn and spring. Two major tributaries in the catchment of the Klein Brak Estuary are the Brandwag (with a catchment size of approximately 320 km^2 arising in the Outeniqua Mountains) and the Moordkuil (with a catchment of approximately 225 km^2 arising east of the Robinson Pass in the Outeniqua Mountains). The dominant land-use types in the catchment of the two systems are (refer to **Figure 2.1**):

- 30% (green) cultivated, commercial dryland;
- 28% (light brown) scrubland and low fynbos;
- 27% (beige) thicket, bush clumps and high fynbos;
- 6% (pink) forest plantation (Pine);
- 2% (light pink) forest plantation (clearfelled);
- 1% (yellow) urban residential;
- 1% (bright green) planted grass; and
- 1% (blue) cultivated, commercial irrigated.

2.2 HUMAN ACTIVITIES AFFECTING THE ESTUARY (PRESSURES)

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

Table 2.1 Pressures related to flow modification

Activity	Present	Description of impact
Water abstraction and dams (including farm dams)	✓	Large number of farm dams and run-of river abstraction
Augmentation/Inter-basin transfer schemes		
Infestation by invasive alien plants	✓	This infestation affects base flow and threatens natural fauna and flora

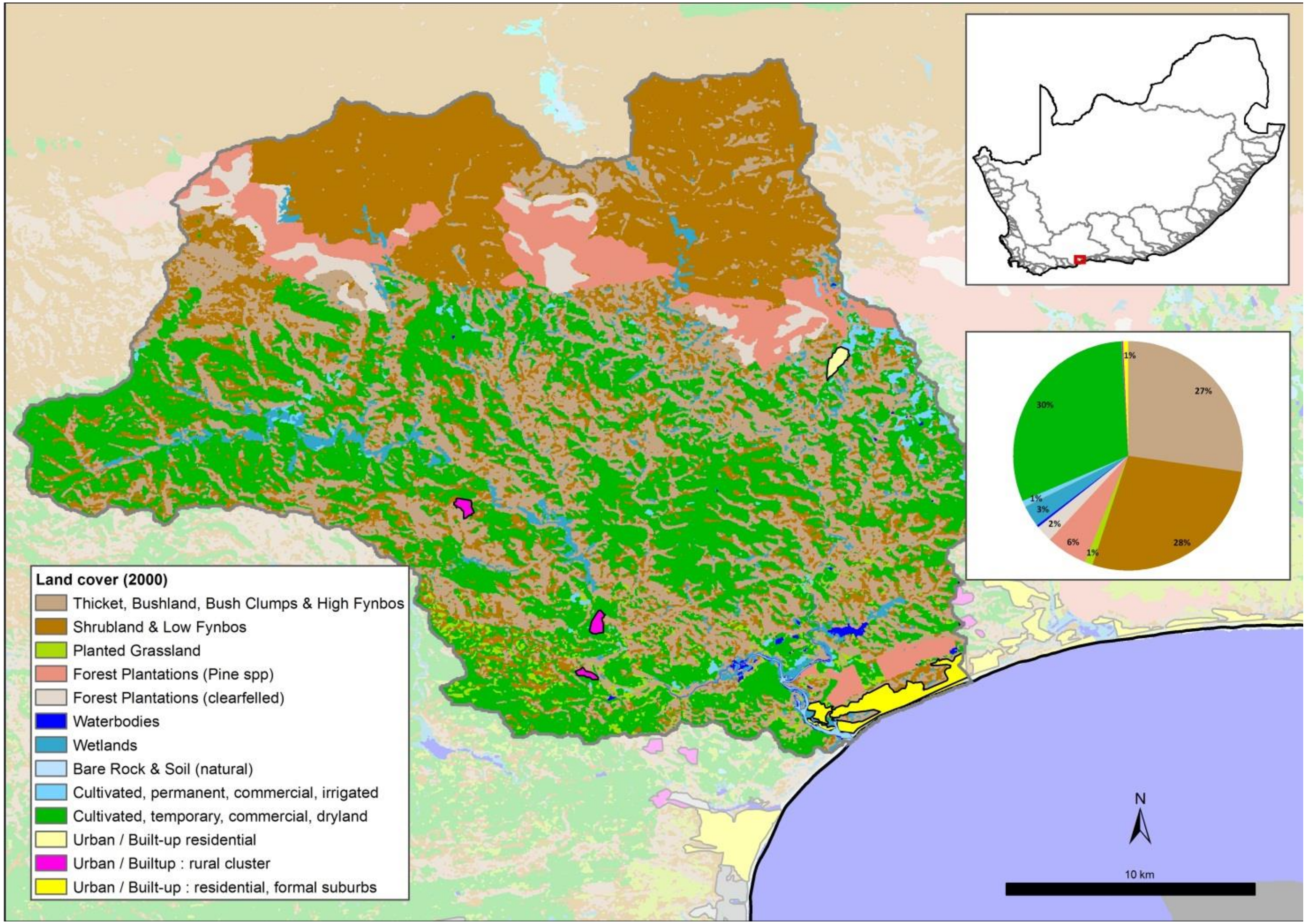


Figure 2.1 Catchment of the Klein Brak Estuary, as well as dominant land-use distribution

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	✓	Affecting water quality of river inflow
Municipal waste (including sewage disposal)/infrastructure problems	✓	Klein Brak diffuse stormwater runoff
Bridge(s)	✓	Affect sedimentation dynamics
Artificial breaching		No record of it, but breaching levels appear very low
Bank stabilisation and destabilisation	✓	In localised areas in the middle and upper reaches
Low-lying developments	✓	Along estuary banks
Migration barrier in river	✓	Causeways and weir transects both the Brandwag and Moordkuil arms in the estuary
Recreational fishing	✓	Significant pressure, e.g. targeting of large dusky cob aggregations
Commercial/Subsistence fishing (e.g. gillnet fishery)		Exploitation of fish species affecting health of fish
Illegal fishing (Poaching)	✓	
Bait collection	✓	Significant pressure
Grazing and trampling of salt mashes	✓	Exploitation of invertebrate species affecting invertebrate health
Translocated or alien fauna and flora	✓	Affect natural populations detrimentally
Recreational disturbance of waterbirds	✓	Affect roosting and feeding patterns of birds, consequently affecting health of birds

3 DELINEATION OF ESTUARY

3.1 GEOGRAPHICAL BOUNDARIES

The Klein Brak Estuary (34º05´ S; 22º08´ E) is situated within the southern coastal belt, and is located approximately 12 km north of Mossel Bay (refer to **Figure 3.1**). Two major tributaries, the Brandwag River and the Moordkuil River join approximately 3 km from the coast to form a well-developed flood-tidal delta.

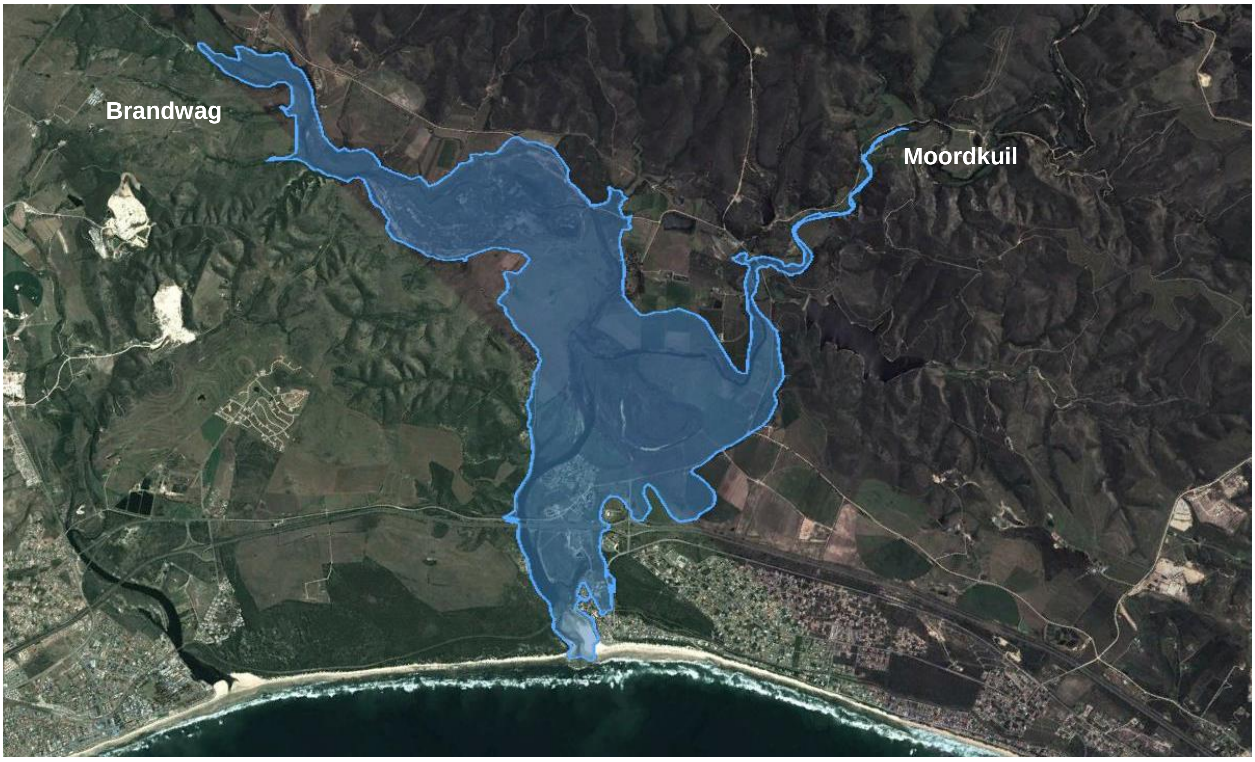


Figure 3.1 Geographical boundaries of the Klein Brak Estuary

The geographical boundaries of the estuary are defined as follows:

Downstream boundary:	Estuary mouth 34° 5'31.98"S, 22° 8'55.43"E
Upstream boundary:	34° 4'36.55"S, 22° 3'57.72"E/ 34° 2'4.54"S, 22° 8'2.91"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

3.2 ZONING OF THE KLEIN BRAK ESTUARY

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

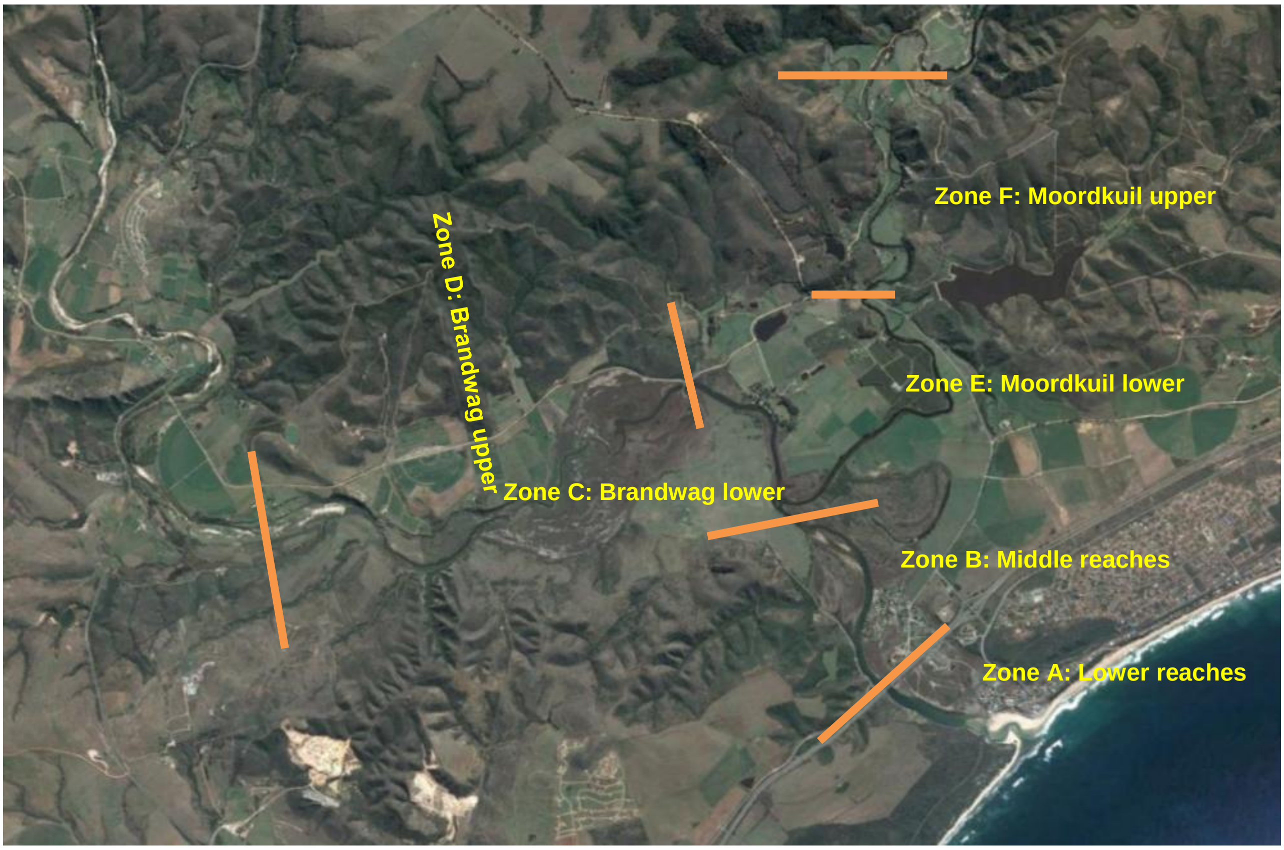


Figure 3.2 Zonation in the Klein Brak Estuary

The zoning in the Klein Brak Estuary is schematically presented as follows:

<table>
<tr><td rowspan="2">Zone A:
Lower reaches
17.8 ha
(25% of
volume)</td><td rowspan="2">Zone B:
Middle reaches
20.6 ha
(30% of volume)</td><td>Zone C: Brandwag lower
9.1 ha (15% of volume)</td><td>Zone D: Brandwag upper
5.4 ha (5% of volume)</td></tr>
<tr><td>Zone E: Moordkuil lower
14.5 ha (20% of volume)</td><td>Zone F: Moordkuil upper
4.3 ha (5% of volume)</td></tr>
</table>

Zone D (Brandwag upper) and Zone F (Moordkuil upper) historically formed part of the Klein Brak Estuary and therefore need to be acknowledged. Presently these are cut-off from the estuary by weirs to prevent saline penetration.

3.3 TYPICAL ABIOTIC STATES OF THE KLEIN BRAK ESTUARY

Based on current understanding, a number of characteristic abiotic states was identified for the Klein Brak 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 3.1.**

Table 3.1 Summary of the abiotic states that can occur in the Klein Brak Estuary

State	Flow range (m^3/s)	Description
State 1	< 0.4	Marine dominated, with intermittent periods of mouth closure
State 2	0.4 - 4.0	Full salinity gradient
State 3	4.0 – 6.0	Limited salinity penetration
State 4	> 6	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) is 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 Klein Brak Estuary is provided in **Section 4**. For more detail on the underlying data and assumptions, refer to the Abiotic Specialist Reports (**Appendices A-C**).

4 ECOLOGICAL BASELINE AND HEALTH ASSESSMENT

4.1 HYDROLOGY

4.1.1 Baseline description

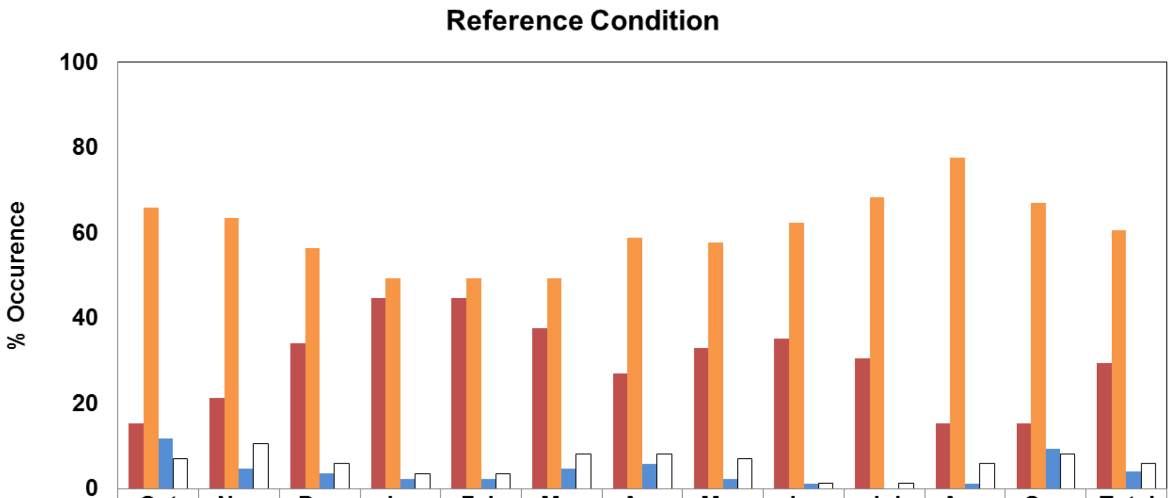
According to the hydrological data provided for the GRDS, the present mean annual runoff (MAR) into the Klein Brak Estuary is 37.66 million m^3. This is a decrease of 26% compared to the natural MAR of 50.67 million m^3. The occurrences of flow distributions (mean monthly flows in m^3/s) for the Reference Condition and Present State of the Klein Brak Estuary, derived from the 85-year simulated data set, are provided in **Tables 4.2** and **4.3**. A graphic representation of the occurrence of the various abiotic states is presented in **Figure 4.1**. The full 85-year series of simulated monthly runoff data for the Reference Condition and Present State is provided in **Tables 4.3** and **4.4**.

Table 4.1 Summary of the monthly flow distribution (in m^3/s) for the Reference Condition (refer to Table 3.1 for colour coding of abiotic states)

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	8.9	19.4	14.1	11.2	8.8	11.3	12.2	11.2	6.4	6.0	13.0	13.4
99	8.2	18.0	13.9	8.2	8.7	10.4	9.8	10.3	4.7	4.3	11.6	9.6
90	4.9	5.7	3.6	2.6	2.7	4.8	5.3	2.8	2.3	1.8	3.3	5.0
80	3.8	3.6	2.0	1.6	1.6	2.5	3.2	2.2	1.4	1.5	1.9	3.0
70	2.7	2.6	1.5	1.0	1.1	1.8	1.8	1.4	1.1	1.2	1.4	1.8
60	2.0	1.7	1.2	0.7	0.6	1.2	1.1	0.8	0.8	0.9	1.0	1.4
50	1.2	0.9	0.8	0.5	0.4	0.9	0.9	0.6	0.6	0.6	0.8	0.9
40	1.0	0.6	0.5	0.3	0.3	0.5	0.7	0.5	0.5	0.5	0.7	0.7
30	0.8	0.5	0.3	0.2	0.2	0.4	0.5	0.4	0.4	0.4	0.5	0.6
20	0.5	0.4	0.2	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4
15	0.4	0.3	0.2	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4
10	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3
1	0.2	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2

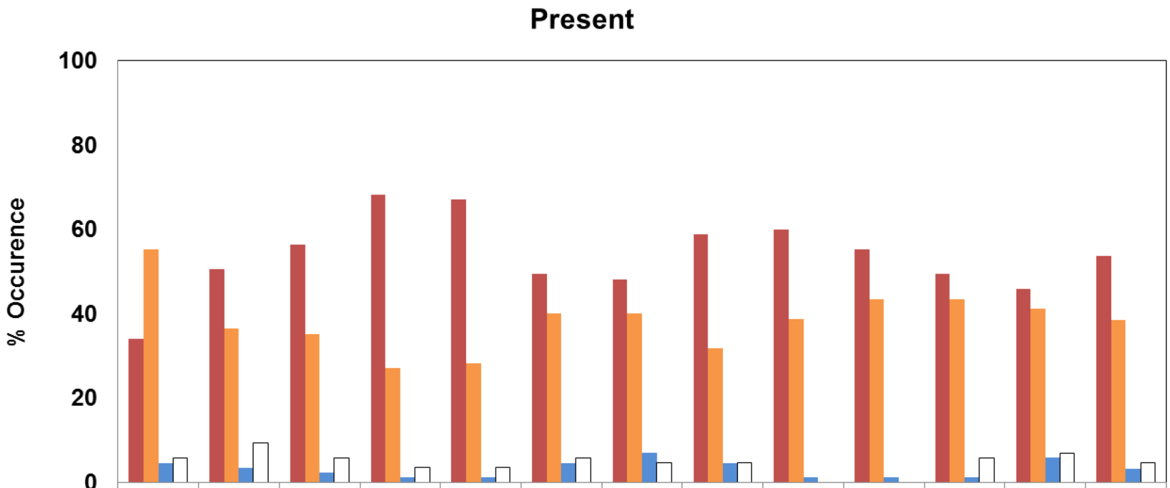
Table 4.2 Summary of the monthly flow distribution (in m^3/s) for the Present State (refer to Table 3.1 for colour coding of abiotic states)

%iles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	7.6	18.1	12.9	10.8	8.2	10.2	11.4	10.7	5.8	5.3	11.7	12.2
99	7.4	16.9	12.4	7.8	7.7	9.2	9.0	9.8	4.2	3.5	10.8	9.0
90	4.1	5.3	2.9	1.8	2.1	4.3	4.6	2.4	1.5	1.2	2.5	4.2
80	3.0	2.9	1.2	1.0	0.9	2.0	2.4	1.8	0.9	0.9	1.3	2.6
70	2.0	1.9	0.8	0.5	0.6	1.3	1.2	0.9	0.7	0.7	0.8	1.4
60	1.3	1.1	0.6	0.2	0.2	0.7	0.6	0.5	0.4	0.5	0.5	0.8
50	0.7	0.4	0.3	0.1	0.1	0.4	0.5	0.3	0.2	0.3	0.4	0.5
40	0.5	0.3	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3
30	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
20	0.2	0.2	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
10	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	15	21	34	45	45	38	27	33	35	31	15	15	30
State 2	66	64	56	49	49	49	59	58	62	68	78	67	60
State 3	12	5	4	2	2	5	6	2	1	0	1	9	4
State 4	7	11	6	4	4	8	8	7	1	1	6	8	6

Figure 4.1 Graphic presentation of the occurrence of the various abiotic states under the Reference Condition (refer to Table 3.1 for colour coding of abiotic states)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	34	51	56	68	67	49	48	59	60	55	49	46	54
State 2	55	36	35	27	28	40	40	32	39	44	44	41	38
State 3	5	4	2	1	1	5	7	5	1	1	1	6	3
State 4	6	9	6	4	4	6	5	5	0	0	6	7	5

Figure 4.2 Graphic presentation of the occurrence of the various abiotic states under the Present State (refer to Table 3.1 for colour coding of abiotic states)

Table 4.3 Summary of the monthly flow distribution (in m^3/s) for the Reference Condition (refer to Table 3.1 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.4	0.2	1.5	0.9	3.9	2.3	3.5	2.2	1.1	1.1	1.9	1.5
1921	0.6	0.3	3.3	2.2	1.1	2.3	1.3	0.7	0.5	1.8	1.0	0.5
1922	0.4	4.3	1.5	0.2	0.1	0.2	1.1	0.8	1.4	0.9	0.6	0.4
1923	0.3	0.6	0.3	0.2	0.3	0.1	0.2	0.2	0.3	0.3	1.4	1.2
1924	0.5	0.3	0.3	0.3	0.1	0.2	0.2	0.1	0.3	0.4	0.7	5.6
1925	2.4	0.5	1.4	0.5	0.1	0.4	0.3	0.2	0.3	0.5	0.5	0.4
1926	2.7	3.6	0.9	0.1	0.3	0.9	0.5	0.3	0.3	0.2	0.4	0.4
1927	0.2	0.2	0.1	0.0	0.1	4.6	2.5	0.2	0.2	0.1	0.4	1.1
1928	0.7	19.6	14.1	1.6	0.3	0.3	0.2	0.3	0.6	1.7	1.9	3.0
1929	1.5	0.4	2.0	0.8	0.7	0.7	0.3	1.0	0.9	0.5	0.8	0.9
1930	1.0	0.5	0.1	1.3	0.5	0.4	1.3	0.7	0.2	0.5	0.4	0.4
1931	0.9	0.5	13.8	7.3	1.3	0.6	0.2	0.2	0.4	0.4	0.4	13.8
1932	8.0	1.1	0.4	0.1	0.3	0.3	0.2	0.6	0.6	0.4	3.1	1.8
1933	0.3	2.9	1.4	1.5	1.2	1.6	0.7	0.1	0.1	1.5	2.4	1.5
1934	4.1	5.1	1.3	0.1	0.1	0.1	0.7	6.0	4.0	1.2	0.9	4.1
1935	2.3	0.6	0.4	0.1	0.2	0.3	0.1	0.4	0.3	1.6	1.0	0.6
1936	1.6	3.0	2.4	0.6	0.1	3.0	1.5	0.1	0.2	0.3	0.2	1.1
1937	1.1	0.4	1.7	0.8	0.1	0.9	0.9	0.4	0.2	0.2	0.2	0.3
1938	1.2	1.1	0.7	0.2	3.5	11.4	5.4	0.3	0.2	1.3	3.5	2.6
1939	1.0	0.4	0.1	0.4	8.8	5.3	1.0	0.4	0.3	0.3	0.2	0.4
1940	0.3	0.9	0.5	0.7	0.4	0.2	5.0	2.6	0.7	0.6	0.6	0.8
1941	4.6	2.3	0.3	1.7	0.8	0.6	0.5	0.8	0.6	0.3	0.2	0.2
1942	0.5	0.3	1.0	2.2	1.3	0.9	1.0	0.4	0.2	0.1	0.5	4.1
1943	3.0	6.7	3.7	0.3	0.1	1.6	0.8	1.4	1.0	2.6	1.6	2.9
1944	1.9	0.5	0.1	0.1	0.1	0.1	0.1	1.5	2.3	1.2	0.7	0.9
1945	2.6	1.2	0.1	0.1	0.3	7.0	3.9	0.2	0.1	0.2	0.2	0.3
1946	0.2	0.1	0.0	0.0	0.3	10.3	6.0	0.6	0.7	1.2	0.9	1.4
1947	1.0	0.6	0.2	2.3	1.3	1.1	2.5	1.1	0.3	0.3	0.2	0.6
1948	4.0	2.3	0.2	0.2	0.2	0.1	0.5	2.8	1.5	0.3	0.2	1.4
1949	0.8	10.5	5.5	0.1	0.1	0.0	0.1	0.2	0.1	0.9	0.9	0.6
1950	4.2	9.3	4.4	7.5	4.2	0.4	0.2	0.2	0.4	1.9	1.6	1.8
1951	1.0	0.2	0.1	1.6	1.6	0.6	0.3	0.3	0.3	0.2	0.7	5.2
1952	2.9	0.8	0.5	0.3	0.2	0.1	0.6	0.4	0.7	2.7	2.6	2.2
1953	5.2	3.2	0.6	0.1	0.0	0.9	1.2	6.5	4.3	1.4	11.2	6.9
1954	0.9	2.9	1.5	3.8	6.7	2.6	0.4	0.4	0.6	0.6	0.6	1.0
1955	1.2	1.7	0.6	0.3	0.4	2.1	1.4	1.3	1.0	0.6	0.5	0.5
1956	2.0	1.1	2.0	0.9	2.4	2.9	1.0	0.6	1.8	1.3	1.4	4.2
1957	2.3	0.5	0.1	0.1	0.0	1.9	1.2	5.7	3.7	0.6	0.9	0.7
1958	0.7	0.4	0.9	2.9	1.7	5.0	6.0	2.7	0.6	1.7	2.6	1.5
1959	6.4	3.6	0.7	1.0	0.4	2.4	1.9	1.4	1.1	0.7	0.5	0.6
1960	0.6	2.2	2.3	0.9	1.2	6.2	7.0	2.6	0.8	0.5	0.6	0.7
1961	0.9	0.5	0.2	0.4	0.5	1.8	1.4	0.5	0.3	0.3	13.1	8.4
1962	4.4	4.0	1.1	0.8	0.5	8.6	5.2	0.5	0.4	0.9	0.7	0.3
1963	0.3	0.3	1.3	2.0	0.7	0.4	0.3	0.2	2.2	1.3	1.4	8.8
1964	4.3	0.7	0.2	0.1	0.6	1.5	1.1	2.6	1.5	0.7	0.6	0.4
1965	5.1	8.6	3.3	1.6	0.7	0.1	0.4	1.0	0.7	0.3	3.4	2.4
1966	0.6	0.2	0.2	0.1	2.3	3.9	12.4	10.1	2.7	1.5	1.1	2.2
1967	1.1	0.8	0.3	0.0	0.0	0.8	0.7	0.5	2.6	1.5	0.8	0.8
1968	0.5	2.8	1.2	0.1	0.2	0.3	0.3	0.2	1.5	1.1	0.5	0.5
1969	0.5	0.3	0.1	0.4	1.0	0.4	0.1	0.1	0.1	0.1	1.5	1.0
1970	1.3	0.7	0.8	0.3	2.0	1.2	1.9	2.4	1.5	6.2	7.8	3.1
1971	0.6	2.0	0.9	0.2	2.1	1.4	0.6	0.6	0.9	1.0	1.1	0.8
1972	0.4	0.2	0.1	0.7	0.3	0.3	0.9	0.6	1.9	1.2	0.6	0.5
1973	0.3	0.9	0.8	1.7	2.8	1.8	0.6	1.7	1.1	0.3	0.5	0.7
1974	0.5	0.5	0.2	0.6	0.3	0.1	0.1	0.3	0.6	0.9	2.3	4.6
1975	2.4	1.5	1.2	0.6	0.7	2.1	1.1	0.6	0.8	0.9	0.7	0.6
1976	4.2	2.9	0.6	0.1	5.3	2.5	0.5	11.3	6.6	0.6	0.7	1.6
1977	1.1	1.8	1.5	0.5	0.1	0.4	0.9	0.6	0.5	0.5	0.6	0.5
1978	1.6	2.7	1.3	0.5	0.4	0.2	0.1	0.7	0.8	3.2	2.7	2.5
1979	1.2	0.3	0.2	0.4	0.2	0.1	0.6	0.4	0.6	0.5	0.6	1.3
1980	2.8	3.9	1.8	11.5	8.7	4.3	8.2	9.1	3.6	1.2	10.4	6.3
1981	1.3	0.6	0.6	0.6	0.6	1.0	9.3	5.3	1.2	1.2	0.9	4.5
1982	2.7	0.6	0.2	0.1	0.1	0.1	0.2	0.7	1.7	4.0	2.1	1.8
1983	2.8	1.8	0.6	0.2	0.2	1.5	0.9	0.3	0.3	1.9	1.2	0.4
1984	1.0	0.7	0.3	2.5	3.9	1.1	1.8	1.1	0.7	1.5	1.1	0.4
1985	3.8	3.5	3.2	1.4	0.3	0.3	0.2	0.1	0.1	0.3	11.3	7.3
1986	4.0	2.1	0.4	0.2	0.2	0.1	3.4	1.8	0.4	0.3	0.4	3.4
1987	1.7	0.2	0.6	0.3	0.2	0.3	0.6	0.5	0.4	0.4	1.0	0.9
1988	0.4	0.2	0.4	0.3	0.2	0.4	3.7	1.9	0.4	0.3	0.4	0.3
1989	7.3	8.1	1.8	0.1	1.9	1.1	1.9	1.6	1.3	0.9	0.5	0.4
1990	0.8	0.6	0.2	0.4	0.4	0.2	0.1	0.2	0.3	0.5	0.4	0.3
1991	8.9	4.9	1.2	0.9	1.2	1.1	0.7	0.5	1.1	1.9	1.5	0.8
1992	5.9	6.1	1.6	0.2	0.5	0.5	3.2	2.9	1.0	0.5	0.5	7.1
1993	3.7	0.4	2.6	1.4	0.5	0.8	1.0	0.6	0.5	0.9	3.5	2.2
1994	0.9	0.4	8.3	4.4	1.0	2.8	3.3	2.3	1.1	0.4	0.4	0.3
1995	0.3	10.8	8.1	1.9	0.6	0.2	0.1	0.1	0.1	0.2	0.2	0.2
1996	7.3	17.7	7.7	0.2	0.1	1.1	1.1	1.6	1.4	1.3	1.4	0.9
1997	2.7	1.4	0.2	1.3	0.8	3.0	2.1	0.8	0.4	0.6	0.8	0.5
1998	0.2	0.7	3.0	3.6	2.5	1.7	0.9	0.5	0.3	0.3	0.4	0.7
1999	3.6	1.8	0.3	2.7	1.4	7.5	4.5	0.3	0.3	0.3	0.2	0.3
2000	0.3	1.2	1.8	0.7	0.2	2.0	6.0	2.6	0.4	0.4	1.0	1.0
2001	2.3	4.8	1.8	0.4	0.3	0.1	0.1	0.8	0.8	1.5	5.2	4.6
2002	1.5	0.3	0.2	0.4	0.4	9.1	6.4	7.0	4.0	0.8	0.9	0.7
2003	1.0	0.6	0.2	0.4	0.4	0.5	2.3	1.4	0.6	0.6	2.6	1.5
2004	7.0	2.9	4.6	5.1	2.1	0.9	0.8	0.7	1.1	1.8	1.2	0.6

Table 4.4 Summary of the monthly flow distribution (in m³/s) for the Present State (refer to Table 3.1 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.2	0.1	0.7	0.3	3.2	2.0	3.1	1.7	0.8	0.8	1.4	1.1
1921	0.2	0.1	2.3	1.8	0.7	1.9	0.9	0.5	0.2	1.5	0.5	0.1
1922	0.1	3.7	0.7	0.0	0.0	0.0	0.5	0.3	0.8	0.4	0.2	0.1
1923	0.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.8	0.7
1924	0.2	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.3	4.5
1925	1.6	0.2	0.6	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2
1926	1.9	2.9	0.2	0.0	0.0	0.3	0.1	0.1	0.1	0.1	0.2	0.2
1927	0.1	0.1	0.1	0.0	0.0	3.6	1.7	0.1	0.1	0.1	0.1	0.5
1928	0.2	18.2	12.9	0.8	0.1	0.1	0.1	0.1	0.2	1.1	1.2	2.6
1929	0.9	0.2	1.1	0.3	0.5	0.5	0.1	0.5	0.4	0.2	0.5	0.6
1930	0.5	0.2	0.1	0.5	0.1	0.3	0.8	0.4	0.1	0.1	0.1	0.1
1931	0.4	0.2	12.3	6.7	0.9	0.3	0.1	0.0	0.1	0.1	0.1	12.5
1932	7.4	0.6	0.1	0.0	0.0	0.1	0.1	0.2	0.2	0.1	2.2	1.1
1933	0.1	1.9	0.8	0.9	0.8	1.2	0.3	0.1	0.0	0.8	1.8	1.0
1934	3.7	4.8	0.7	0.1	0.0	0.0	0.2	5.1	3.5	0.8	0.6	3.7
1935	1.6	0.3	0.2	0.1	0.1	0.0	0.0	0.1	0.1	1.0	0.4	0.2
1936	0.9	2.3	1.6	0.3	0.1	2.2	0.9	0.1	0.0	0.1	0.1	0.5
1937	0.4	0.1	0.9	0.2	0.0	0.4	0.4	0.2	0.1	0.1	0.1	0.1
1938	0.5	0.5	0.3	0.1	2.6	10.3	4.7	0.2	0.1	0.7	2.8	2.3
1939	0.5	0.2	0.1	0.1	7.6	4.9	0.6	0.2	0.2	0.1	0.1	0.1
1940	0.1	0.4	0.3	0.1	0.1	0.0	4.0	1.8	0.3	0.2	0.3	0.3
1941	3.6	1.4	0.1	1.0	0.3	0.2	0.2	0.5	0.2	0.1	0.1	0.1
1942	0.1	0.1	0.4	1.5	0.7	0.3	0.6	0.1	0.1	0.0	0.1	3.2
1943	2.5	6.4	3.0	0.1	0.0	0.8	0.2	0.9	0.6	2.2	1.1	2.6
1944	1.4	0.3	0.1	0.0	0.0	0.0	0.0	0.9	1.7	0.6	0.3	0.4
1945	1.8	0.5	0.1	0.0	0.0	5.9	3.0	0.1	0.1	0.1	0.1	0.1
1946	0.1	0.1	0.0	0.0	0.0	9.0	5.1	0.2	0.3	0.7	0.4	0.8
1947	0.4	0.2	0.1	1.5	0.7	0.7	1.9	0.6	0.1	0.1	0.1	0.2
1948	3.1	1.5	0.1	0.0	0.0	0.0	0.1	2.0	0.8	0.1	0.1	0.7
1949	0.2	9.6	4.5	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.2
1950	3.2	8.6	3.7	7.2	3.4	0.1	0.1	0.1	0.1	1.2	1.0	1.4
1951	0.5	0.1	0.1	0.8	0.8	0.2	0.1	0.1	0.1	0.1	0.4	4.3
1952	2.2	0.4	0.2	0.1	0.1	0.1	0.2	0.1	0.3	1.9	2.0	1.8
1953	4.7	2.7	0.2	0.1	0.0	0.3	0.6	5.7	3.9	1.1	10.6	6.4
1954	0.4	2.4	0.9	3.4	6.3	2.0	0.1	0.1	0.2	0.3	0.2	0.6
1955	0.7	1.1	0.2	0.1	0.1	1.3	0.8	1.0	0.6	0.3	0.3	0.2
1956	1.3	0.6	1.4	0.4	1.8	2.5	0.5	0.3	1.4	0.9	1.0	3.9
1957	1.7	0.3	0.1	0.0	0.0	1.1	0.6	5.0	3.2	0.3	0.5	0.3
1958	0.3	0.1	0.3	2.3	1.2	4.6	5.6	2.3	0.3	1.2	2.3	1.0
1959	5.8	2.8	0.2	0.6	0.1	1.7	1.6	1.2	0.7	0.4	0.2	0.2
1960	0.2	1.5	1.6	0.5	0.8	5.5	6.6	2.2	0.4	0.2	0.2	0.3
1961	0.5	0.2	0.1	0.1	0.1	1.1	0.8	0.2	0.1	0.1	11.8	7.8
1962	4.0	3.6	0.5	0.3	0.1	7.9	4.6	0.2	0.2	0.5	0.3	0.1
1963	0.1	0.1	0.6	1.2	0.2	0.1	0.1	0.1	1.4	0.7	0.8	8.3
1964	3.6	0.3	0.1	0.0	0.1	0.8	0.5	2.2	1.0	0.4	0.3	0.2
1965	4.2	8.4	2.6	1.0	0.2	0.1	0.1	0.5	0.3	0.1	2.6	1.9
1966	0.3	0.1	0.0	0.0	1.3	3.2	11.6	9.6	2.2	1.2	0.7	1.9
1967	0.6	0.4	0.1	0.0	0.0	0.2	0.2	0.1	1.7	0.9	0.5	0.4
1968	0.2	2.1	0.6	0.0	0.0	0.0	0.1	0.1	0.9	0.5	0.2	0.1
1969	0.1	0.1	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.8	0.4
1970	0.7	0.3	0.2	0.1	1.2	0.6	1.3	1.9	1.0	5.4	7.3	2.5
1971	0.4	1.3	0.4	0.1	1.3	1.0	0.3	0.3	0.5	0.6	0.7	0.4
1972	0.2	0.1	0.0	0.1	0.1	0.0	0.3	0.2	1.2	0.6	0.2	0.2
1973	0.1	0.3	0.2	1.0	2.2	1.4	0.2	1.3	0.7	0.1	0.2	0.3
1974	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.1	0.2	0.4	1.5	4.0
1975	1.6	1.0	0.7	0.1	0.3	1.5	0.6	0.3	0.5	0.6	0.3	0.3
1976	3.5	2.3	0.3	0.1	4.2	1.9	0.2	10.8	6.0	0.3	0.3	1.2
1977	0.6	1.2	0.9	0.1	0.0	0.1	0.4	0.2	0.2	0.2	0.2	0.2
1978	1.1	2.1	0.7	0.1	0.1	0.1	0.0	0.3	0.4	2.3	2.1	2.2
1979	0.6	0.2	0.1	0.1	0.1	0.0	0.1	0.1	0.2	0.2	0.2	0.8
1980	2.0	3.1	1.1	11.1	8.3	3.9	7.8	8.7	3.1	0.8	9.8	5.7
1981	0.8	0.3	0.1	0.1	0.2	0.6	8.6	4.7	0.9	0.9	0.5	4.0
1982	2.1	0.3	0.1	0.0	0.0	0.0	0.0	0.2	1.0	3.2	1.3	1.3
1983	2.4	1.2	0.2	0.1	0.1	0.7	0.3	0.1	0.1	1.2	0.6	0.1
1984	0.4	0.2	0.1	1.7	3.3	0.6	1.4	0.7	0.4	1.2	0.6	0.2
1985	3.0	3.0	2.7	0.8	0.1	0.1	0.1	0.1	0.1	0.1	9.9	6.4
1986	3.4	1.5	0.1	0.1	0.0	0.0	2.5	1.0	0.1	0.1	0.1	2.6
1987	1.0	0.1	0.1	0.1	0.0	0.1	0.2	0.2	0.1	0.1	0.5	0.3
1988	0.1	0.1	0.1	0.1	0.0	0.1	2.8	1.1	0.1	0.1	0.1	0.1
1989	6.1	7.4	0.9	0.1	1.0	0.5	1.5	1.3	1.0	0.5	0.2	0.2
1990	0.3	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1
1991	7.6	3.8	0.5	0.3	0.6	0.6	0.3	0.2	0.7	1.5	1.0	0.4
1992	5.3	5.6	1.0	0.1	0.1	0.1	2.4	2.5	0.6	0.2	0.2	6.3
1993	3.0	0.2	1.7	0.8	0.2	0.4	0.6	0.3	0.2	0.5	2.9	1.7
1994	0.4	0.2	7.2	3.7	0.5	2.4	3.0	2.0	0.7	0.2	0.2	0.1
1995	0.1	9.7	7.3	1.3	0.2	0.1	0.1	0.0	0.0	0.1	0.1	0.1
1996	6.1	16.7	6.6	0.1	0.1	0.5	0.5	1.2	1.0	0.8	1.0	0.5
1997	2.2	0.9	0.1	0.5	0.3	2.4	1.7	0.5	0.2	0.3	0.4	0.2
1998	0.1	0.3	2.0	3.3	2.0	1.4	0.5	0.2	0.1	0.1	0.1	0.2
1999	2.7	1.2	0.1	1.8	0.8	6.9	3.8	0.1	0.1	0.1	0.1	0.1
2000	0.1	0.6	1.0	0.2	0.1	1.3	5.2	2.1	0.2	0.1	0.5	0.6
2001	1.7	4.5	1.1	0.1	0.1	0.0	0.0	0.3	0.4	0.9	4.3	4.2
2002	0.9	0.2	0.1	0.1	0.2	7.9	5.6	6.6	3.4	0.4	0.5	0.4
2003	0.6	0.3	0.1	0.1	0.1	0.1	1.5	0.8	0.2	0.2	1.9	1.0
2004	6.3	2.0	4.3	4.9	1.5	0.5	0.5	0.4	0.7	1.2	0.8	0.2

4.1.2 Hydrological health

4.1.2.1 Low flows

River inflows only decreased below 0.3 m^3/s for 20% and below 0.1 m^3/s for 5 % of the time under the Reference Condition. Under the Present State, flows below 0.3 m^3/s and 0.1 m^3/s occur for about 50% and 30% of the time respectively (refer to **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%	0.4	0.1	32.3
20%	0.3	0.1	32.2
10%	0.2	0.1	31.9
% Similarity in low flows			32.2

Confidence: Low

4.1.2.2 Flood regime

There are no large dams in the catchment of the Klein Brak Estuary. Freshwater abstraction from the Moordkuil River is transferred to the Klipheuwel Dam to supply the town of Mossel Bay. In addition, there are numerous relatively small farm dams in the catchment capturing first flushes and freshettes, as well as run-of-river abstraction. Thus, it is estimated that there is a significant reduction in river inflow to the estuary mainly in relation to low flows.

To provide an indication of the change in flood regime from the Reference Condition to the Present State the ten highest simulated monthly flow volumes were compared for the 85-year period (summarised in **Table 4.6**). The analysis of the simulated monthly flow data indicate that under Reference Conditions floods were about 10 % higher than at present, depending on the size class.

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

Date	Monthly volume (million m^3/month)		% remaining
	Natural	Present	
Nov 1928	50.7	47.2	93.0
Nov 1996	45.9	43.3	94.3
Dec 1928	37.8	34.6	91.6
Dec 1931	37.0	32.9	89.0
Sep 1932	35.7	32.4	90.9

Date	Monthly volume (million m^3/month)		% remaining
	Natural	Present	
Aug 1962	35.2	31.6	89.9
Apr 1967	32.2	30.2	93.8
Jan 1981	30.8	29.7	96.6
Mar 1939	30.6	27.7	90.5
Aug 1986	30.3	26.5	87.4
% Similarity in floods			**92**

Confidence: Medium

4.1.3 Hydrological health

Table 4.7 provides a summary of the hydrological health of the Klein Brak Estuary.

Table 4.7 Present hydrological health scores

Variable	Summary of change	Weight	Score	Confidence
a. % Similarity in period of low flows	Significant increase in the low flow period and reduction in flow rate.	60	32	L
b. % Similarity in mean annual frequency of floods	The simulated monthly flow data indicate that under Reference Conditions floods were about 10 % higher than at present, depending on the size class.	40	92	L
Hydrology score weighted mean (a,b)			**56**	**L**

4.2 PHYSICAL HABITAT

4.2.1 Baseline description

Physical habitat in the Klein Brak Estuary has been transformed as a result of development and activities in and around the estuary. These include bridges and roads, as well as inappropriate access routes, bank protection farming practices. Large floods are important in flushing out sediment accumulations within the estuary (both from riverine and marine origin), and preventing the encroachment of reeds and sedges into the main estuary channel. In this cathment flood events have not been affected significantly from the Reference Condition to Present State. The small dams will preferentially trap a larger proportion of the coarser sediments, but have very low sediment trapping efficiency and capacity. With the Klipheuwel Dam as an off-channel impoundment there is also little effect on sediment yield from the catchment.

4.2.2 Physical habitat health

Table 4.8 provides the present physical habitat health scores of the Klein Brak Estuary based on the interpretation of available information and expert opinion.

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	Score	Confidence
a	% similarity in supratidal area	1. Direct habitat destruction as a result of extensive formal and informal settlements on the floodplain of the esutuary has occured. Stormwater runoff from these settlements is likely to comprise higher suspended solids. 2. Grazing and trampling associated with cattle farming in the floodplain increased potential for land erosion and sediment inputs (also higher suspended solids) into the estuary. Agricultural activities in the catchment (e.g. cultivation and fruit orchards) lead to increased land erosion and thus sediment yield to the estuary. 3. Bank protection is impacting on estuarine habitat and morphology in the upper reaches. Besides the direct impacts within the footprint of the structure, such works often lead to increased erosion of adjacent areas (erosion hot spots). 4. Rubble revetments, bank protection and slipways are impacting on estuarine habitat and morphology near Klein Brak River town (in middle reaches). 5. Multiple road bridges and abutments are impacting on estuary banks and supratidal area. Due to large open spans the impacts on tidal flows are not expected to be large. 6. Invasive alien plant species have colonized some channel banks and floodplain areas. These may significantly hinder “natural” bank erosion during floods, allowing for compaction/consolidation of sediments and further establishment of “permanent” vegetation, with associated dampening of natural channel variability. 7. Significant modification of the banks for recreational activities and access at a camping site. Besides direct physical habitat destruction, the removal of vegetation such as reeds, sedges, etc., can also potentially lead to higher erosion during large river floods.	60	L
b	% similarity in area of intertidal sand- and mudflats	1. As for (a) Points 3 to 7 of the above. 2. Flood events are expected to occur relatively untransformed from Reference Condition to Present State, i.e. in the order of 10% change from Reference. Thus slightly reduced mobility and flushing of sediments in the estuary, and potentially increased penetration of marine sediments. 3. “Low-water drifts” and culverts are impeding tidal flow into the upper reaches of the estuary and flushing of sediments out of these areas. Such channel modifications and flow impediments are found on both of the main arms of the estuary along the upper reaches. 4. Multiple road bridges and abutments are impacting on estuary banks and supratidal area. Due to large open spans the impacts on tidal flows are not expected to be large. 5. The railway bridge near the mouth has a significant effect on the hydrodynamics as well as on the sediment dynamics in the area.	54	L
c	% similarity in area of subtidal/submerged sand and mud substrates	As for (a) (3 to 5) and (b) (2 to 5)	75	L

Variable		Summary of change	Score	Confidence
d	% similarity in bathymetry/ estuary water volume	1. Volume probably very similar to reference except reductions at present head; also slightly more marine water with associated marine sediment ingress. 2. Also slightly higher sediment load in the water column during and just after floods, due to catchment cultivation and transformed estuarine floodplain.	95	L
Physical habitat score min (a to d)			**54**	**L**
% of impact due to non-flow factors			90	
Adjusted score			95	L

4.3 HYDRODYNAMICS

4.3.1 Baseline description

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

Table 4.9 Summary of the abiotic states and associated hydrodynamic characteristics

Parameter	Abiotic state			
	1	**2**	**3**	**5**
Flow range (m^3/s)	< 0.4	0.4- 4.0	4.0 – 6.0	> 6.0
Mouth condition	Open, but can close intermediately	Open	Open	Open
Water level (m to MSL)	1.5	1.5	1.5	3.0 – 4.0 during Floods
Inundation	During mouth closure	-	-	During floods
Tidal range	**Ref/Pres/Scn 1 & 2** 0.5 when open **Scn 3** 0.45 when open **Scn 4** 0.4 when open	1.0	1.5	1.75, but suppressed during floods
Dominant circulation process	Tide	Tide	River & Tide	River
Salinity Structure	Well mixed	Well mixed	Strong stratification in deeper areas, e.g. Moordkuil	Stratification, Zone A

4.3.2 Hydrodynamic health

An evaluation of the mouth closure event indicates that three main factors contribute to inlet closure, namely:

- River inflow below 0.4 m^3/s;
- The occurrence of high waves (generally associated with winter); and
- The development of a "sand plug" in the lower reaches of the estuary. The removal of this ingress of marine sediment is strongly dependant on the regular occurrence of resetting floods.

Table 4.10 presents the hydrodynamic helath scores for the Klein Brak Estuary based on available information and epert opinion.

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	Confidence
a.	% similarity in abiotic states and mouth condition	It is a nearly 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)	As a result of the increase in low flow conditions (State 1) the average tidal amplitude is likely to have decreased from between 0.9 – 1.0 m under the Reference State to 0.8 m under the Present State.	50	92	L
Hydrodynamic score weighted mean (a to d)				96	L
% of impact due to non-flow factors				10	
Adjusted score				96	L

4.4 WATER QUALITY

4.4.1 Baseline description

A summary of the water quality characteristics for the various states, in each of the six 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 (refer to **Appendix C**). 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: Marine	State 2: Full gradient	State 3: Limited gradient	State 4: Fresh
Salinity	Reference 35, 35, 30/30, 20/20 Present/Future 1 & 2 35, 35, 30/30, 0/0 Future 3 35, 35, 40/40, 0/0 Future 4 35, 35, 45/45, 0/0	30, 20, 5/10, 0/0	25, 15, 0/0, 0/0	5, 0, 0/0, 0/0
Temperature (^{o}C)	Summer 17- 25, lower temperature in saline areas reaches (i.e. States 1-3) when colder upwelled waters intrude during summer Winter 10 - 20			
pH	6.9 – 8.5 (usually lower in fresher waters compared with more saline waters)			
DO (mgl/ℓ)	Reference 6, 6, 6/5, 6/6 Present/Future 6, 6, 2/2, 4/4	Reference 6, 6, 6/6, 6/6 Present/Future 6, 6, 5/4, 6/6	Reference 6, 6, 6/6, 6/6 Present/Future 6, 6, 6/5, 6/6	6, 6, 6/6, 6/6

Parameter	State 1: Marine	State 2: Full gradient	State 3: Limited gradient	State 4: Fresh
Turbidity (NTU)	10, 10, 15/10, 20/10	Reference: 10, 10, 20/10, 30/10 Present/Future: 10, 10, 40/10, 60/10	Reference: 10, 15, 30/10, 30/10 Present/Future: 10, 30, 60/10, 60/10	Reference: 20, 30, 50/20, 50/20 Present/Future: 50, 60, 100/20, 100/20

Parameter	State 1: Marine	State 2: Full gradient	State 3: Limited gradient	State 4: Fresh
Dissolved inorganic nitrogen (DIN) (µg/ℓ)	Reference: 100, 100, 80/50, 80/50 Present/Future: 100, 100, 100/100, 200/100	Reference: 100, 100, 80/50, 80/50 Present/Future: 100, 150, 200/100, 200/100	Reference: 100, 80, 80/50, 80/50 Present/Future: 100, 150, 200/100, 200/100	Reference: 100, 100, 100/100, 100/100 Present/Future: 100, 150, 200/100, 200/100
Dissolved inorganic phosphate (DIP) (µg/ℓ)	Reference: 10, 10, 10/10, 10/10 Present/Future: 10, 10, 10/10, 15/20	Reference: 10, 10, 10/10, 10/10 Present/Future: 10, 10, 10/15, 15/20	Reference: 10, 10, 10/10, 10/10 Present/Future: 10, 20, 15/20, 15/20	Reference: 10, 10, 10/10, 10/10 Present/Future: 20, 30, 20/30, 20/30
Dissolved reactive silicate (DRS) (µg/ℓ)	100, 100, 200/200, 800/800	200, 800, 2000/900, 2500/2500	500, 1000, 2500/2500, 2500/2500	2000, 2500, 2500/2500, 2500/2500

Table 4.12 Summary of average changes in water quality parameters from Reference Condition to Present State within each of the zones in the Klein Brak 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	A: Lower	30	31
		B: Middle	23	27
		C: Brandwag lower	12	18
		D: Brandwag upper	7	1
		E: Moordkuil lower	18	22
		F: Moordkuil upper	7	1
DIN (µg/ℓ)	⇧ due to agricultural activities in the catchment, highest dissolved inorganic nitrogen (DIN) coming from Brandwag catchment	A: Lower	100	100
		B: Middle	100	123
		C: Brandwag lower	81	146
		D: Brandwag upper	81	200
		E: Moordkuil lower	53	100
		F: Moordkuil upper	53	100
DIP (µg/ℓ)	⇧ due to agricultural activities in the catchment, highest dissolved inorganic phosphate (DIP) coming from Moordkuil catchment	A: Lower	10	11
		B: Middle	10	11
		C: Brandwag lower	10	11
		D: Brandwag upper	10	15
		E: Moordkuil lower	10	13
		F: Moordkuil upper	10	21
Turbidity (NTU)	⇧ due to agricultural activities in the catchment, especially from the Brandwag catchment	A: Lower	11	12
		B: Middle	11	13
		C: Brandwag lower	21	30
		D: Brandwag upper	28	40
		E: Moordkuil lower	11	11
		F: Moordkuil upper	11	11
DO (mg/ℓ)	⇩due to organic enrichment associated with agricultural activities catchment and along the banks, especially in the deeper Moordkuil arm where stratification prevents re-aeration of bottom waters at times	A: Lower	6	6
		B: Middle	6	6
		C: Brandwag lower	6	4
		D: Brandwag upper	6	5
		E: Moordkuil lower	6	3
		F: Moordkuil upper	6	5
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 and C)
- **Volume fraction** of each zone **(V)** (i.e. Lower = 0.43; Middle = 0.32; Upper = 0.32)
- Different **abiotic states (S)** (i.e. States 1 to 4)
- Define the **flow scenarios** (i.e. Reference, Present, Future scenarios)
- Determine the **% occurrence** of abiotic states for each scenario
- 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 final scores, a weighted average of the similarity scores of different zones was computed using the volume fractions (refer to **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	Confidence
1	**Similarity in salinity**	⇧ due to increase in low flow conditions	40	85	M
2	**General water quality in estuary**				
a	DIN/DIP concentrations	⇧ due to agricultural activities in catchment		82	M/L
b	Turbidity	⇧ due to agricultural activities in catchment		93	M/L
c	Dissolved oxygen	⇩due to organic enrichment associated with agricultural activities		90	M/L
d	Toxic substances	⇧ due to agricultural activities in catchment		80	L
General water quality in estuary (min (a to d)			60	80	
Water quality health score weighted mean (1,2)				**82**	**L/M**
% of impact non-flow related				50	
Adjusted score				**91**	**L/M**

4.5 MICROALGAE

4.5.1 Overview

4.5.1.1 Main grouping and baseline description

Lemley (2015) sampled the estuary when river flow was approx. 0.7 – 1.2 m^3/s (State 2) with a full longitudinal salinity gradient and strong vertical stratification. Phytoplankton biomass was generally low, ranging from 0 µg/ℓ in the lower reach to 8.4 ± 3.5 µg/ℓ in the Brandwag tributary (4.5 km from the mouth). The phytoplankton was dominated by flagellates (72 - 91%), and diatoms (3 – 18%), dinoflagellates (1 – 12%) and blue-greens (cyanobacteria; 0 – 2%) were present. No chlorophyte cells were recorded. This community structure suggests that the river water is not nutrient-rich (this would usually support chlorophyte growth), the estuary itself contains 'old' oxygen-poor water as a result of long flushing times (this supports blue-green growth), and the water column is stratified with elevated nutrients (supporting dinoflagellate growth). The Reference Condition most probably had a high diatom:flagellate ratio and this has decreased as a result of reduced river flow and elevated nutrients. However, the low phytoplankton biomass suggests that these effects were minor.

In contrast to the water column, the benthic microalgal biomass was high upstream of the marine dominated mouth region; average 39.6 ± 4.7 mg/m^2. Secchi depth was generally to the bottom or > 1.0 m, and the organic content of the sediment was relatively high (> 3%) at most sites suggesting that the microalgae were largely dependent on the mineralisation of nutrients in the sediments and growth was not light limited. The diversity and the evenness of dominant (> 10% of relative abundance) benthic diatoms in the Klein Brak Estuary were considerably higher than other estuaries in this WMA. The Shannon Diversity Index and Species Evenness scores were 3.07 and 0.84 respectively.

Ten benthic diatoms were dominant in the Klein Brak Estuary during the April 2013 survey (Lemley, 2015); *Amphora coffeaeformis, A. exigua, A. micrometra, Cocconeis placentula var. euglypta, Entomoneis paludosa, Navicula gregaria, Nitzschia laevis, N. paleaformis, Parlibellus* sp. and *Tryblionella constricta*. Most of the taxa are typically found in brackish water and are cosmopolitan. There is very little information available information about their respective pollution tolerances except for *Navicula gregaria* and *Cocconeis placentula* that can tolerate eutrophic conditions.

In December 2013 the river flow was approx. 2 – 4 m^3/s, just 2 – 4 weeks after a resetting event. There was a full longitudinal salinity gradient and the water column was strongly vertically stratified. Phytoplankton biomass was relatively low and ranged from 0.3 µg/ℓ to 6.3 µg/ℓ, averaging 3.3 ± 0.5 µg/ℓ. The phytoplankton were dominated by flagellates (67 – 94%), and the diatoms (1 – 27%), dinoflagellates (0 – 27%) and blue-greens (0 – 2%) were present in the estuary. No chlorophytes were present in the estuary. Average cell density was low, ranging from 118 cells/ml to 457 cells/ml (phytoplankton blooms typically have cell densities exceeding 10 000 cells/ml).

Benthic biomass was high sites in the middle and upper reaches of the estuary, ranging from 13.9 mg/m^2 to 75.2 mg/m^2. Biomass was low in the well flushed marine-dominated site at the mouth of the estuary (< 7 mg/m^2). In total there were 68 diatom species identified and 11 species were dominant (> 10% relative abundance); *Navicula rajmundii*, *Hantzschia* sp., *Stauroneis* sp., *N. gregaria*, *Achnanthes oblongella*, *Navicula* sp., *A. delicatula*, *H. distinctipunctata*, *A. engelbrechtii*, *N. microcari* and *Fallacia scaldensis*.

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 (refer to **Table 3.1**).

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 & P)	↑	↑	↓ (diatom:flag.)	↑	-
Herbicides	↓	↓	↓	↓	↓
Tidal flushing	↓	↓	↓	↓	↓
Turbidity	↓	↓	↓	↓	↓
Dissolved oxygen	-	-	-	-	↑

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

Table 4.15 Summary of microalgal biotic responses to different abiotic states

Abiotic state	Response
State 1: Marine dominant, some mouth closure	Marine dominated (< 0.4 m^3/s) and intermittently closed (mouth closure similar to reference), negligible nutrient and suspended solid input. When open there is a likely decrease in phytoplankton and intertidal microalgal biomass and an increase in subtidal benthic microalgal biomass (favoured by increased residence time and water clarity, and benthic mineralisation). Strong tidal flushing limits microalgal biomass in the marine sand dominated lower reaches (phytoplankton and benthic microalgae). When closed the intertidal zone will become flooded and benthic microalgae will dominate within the first few weeks of closure.

Phytoplankton					Mpb			
		6.0 µg/l	3.0 µg/l				60 mg/m^2	60 mg/m^2
1.0 µg/l	4.0 µg/l				5 mg/m^2	60 mg/m^2	60 mg/m^2	60 mg/m^2
		1.0 µg/l	1.0 µg/l		10 mg/m^2	60 mg/m^2	40 mg/m^2	40 mg/m^2
							30 mg/m^2	20 mg/m^2

<table>
<tr><th>Abiotic state</th><th>Response</th></tr>
<tr><td>State 2: Full salinity gradient</td><td>Flow 0.4 – 4.0 m^3/s (strong salinity stratification, both vertical & longitudinal) April and December 2013 results fell within this flow range. Phytoplankton growth appears to be largely dependent on nutrient release from the sediment through mineralisation within the Brandwag arm where sediment is fine, organic content is high (> 3%), dissolved oxygen is relatively low, and residence time is high. Similarly, benthic microalgae is high (40 – 60 mg.l^{-1}), particularly in the middle reaches of the estuary and Brandwag arm, as a result of the organic-rich sediment and available light.
<table>
<tr><td colspan="2">Phytoplankton</td><td>8.0 µg/l</td><td>3.0 µg/l</td></tr>
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<table>
<tr><td colspan="2">Mpb</td><td>60 mg/m^2</td><td>60 mg/m^2</td></tr>
<tr><td>5 mg/m^2</td><td>60 mg/m^2</td><td>60 mg/m^2</td><td>40 mg/m^2</td></tr>
<tr><td>10 mg/m^2</td><td>60 mg/m^2</td><td>40 mg/m^2</td><td>40 mg/m^2</td></tr>
<tr><td></td><td></td><td>30 mg/m^2</td><td>20 mg/m^2</td></tr>
</table></td></tr>
<tr><td>State 3: Limited salinity penetration</td><td>Flow 4.0 – 6.0 m^3/s river flow with limited longitudinal salinity gradient and 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 a slight decrease in benthic microalgal biomass). Herbicides and suspended solids may limit primary production further.
<table>
<tr><td colspan="2">Phytoplankton</td><td>5.0 µg/l</td><td>2.0 µg/l</td></tr>
<tr><td>2.0 µg/l</td><td>5.0 µg/l</td><td>1.0 µg/l</td><td>1.0 µg/l</td></tr>
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<table>
<tr><td colspan="2">Mpb</td><td>60 mg/m^2</td><td>50 mg/m^2</td></tr>
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<tr><td>10 mg/m^2</td><td>50 mg/m^2</td><td>40 mg/m^2</td><td>30 mg/m^2</td></tr>
<tr><td></td><td></td><td>20 mg/m^2</td><td>10 mg/m^2</td></tr>
</table></td></tr>
<tr><td>State 4: Freshwater dominant</td><td>High river flow (> 6 m^3/s) introducing nutrients and suspended solids to entire estuary. Residence time is too short to support microalgal growth (low phytoplankton and reduced benthic microalgal biomass throughout). Herbicides and suspended solids may limit primary production further.
<table>
<tr><td colspan="2">Phytoplankton</td><td>3.0 µg/l</td><td>1.0 µg/l</td></tr>
<tr><td>2.0 µg/l</td><td>3.0 µg/l</td><td>1.0 µg/l</td><td>1.0 µg/l</td></tr>
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<table>
<tr><td colspan="2">Mpb</td><td>40 mg/m^2</td><td>40 mg/m^2</td></tr>
<tr><td>5 mg/m^2</td><td>40 mg/m^2</td><td>30 mg/m^2</td><td>20 mg/m^2</td></tr>
<tr><td>5 mg/m^2</td><td>30 mg/m^2</td><td>30 mg/m^2</td><td>20 mg/m^2</td></tr>
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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
Nutrient input – Brandwag and Moordkuil tributaries	Supports microalgal growth
Residence time – Particularly Brandwag arm	Supports deposition and subsequent mineralisation of nutrients supporting microalgal growth
Elevated suspended solids – Particularly Brandwag arm	Limits light penetration through water column, limiting microalgal growth
Tidal flushing of marine-dominated lower reaches	Effective tidal flushing limits microalgal growth in the lower reaches

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	Confidence
Phytoplankton			
a. Species richness	There has been a slight increase in nutrients and a reduction in river flow, which could result in a slight loss of nutrient-sensitive species (~10%).	90	L/M
b. Abundance	The reduction in river flow (increased residence time), increase in nutrients (river flow + mineralisation), increase in suspended solids, and increase in herbicides result in a gross increase in phytoplankton biomass (13%).	87	L/M
c. Community composition	The diatom:flagellate ratio is likely to have occurred in response to decreased river flow and elevated nutrients. The Present State supports more dinoflagellates (vertical stratification + nutrients) and blue-greens (long residence time + nutrients). Flagellates (+20%), diatoms (-20%), dinos (+20%), blue-greens (+10%), chloros (0%) = 70/5 = 14% change.	86	L/M
Benthic microalgae			
a. Species richness	There has been a slight increase in nutrients and a reduction in river flow. In addition, suspended solids would contribute to fines and organic matter accumulation in sediments (organic loading and mineralisation). This is likely to result in the loss of nutrient-sensitive and saprophobic species (~20%).	80	L/M

Variable	Summary of change	Score	Confidence
b. Abundance	The reduction in river flow, increased deposition of fines (mud/silt and organics), increase in suspended solids, and increase in herbicides result in a gross increase in microphytobenthos biomass (36%).	64	L/M
c. Community composition	Reference condition would have had slightly lower nutrients (oligotrophic) and coarser sediments (sandier with lower organic content) supporting fewer cyanobacteria species, and more episammic species than epipelics. However, estuary still has sandy and muddy areas so unlikely to have lost many, if any, species. Assume slight (~10%) change related to loss of nutrient-sensitive species.	90	L/M
Microalgae health score min (a to c)		**64**	**L/M**
% of impact non-flow related		60	
Adjusted score		86	L/M

4.6 MACROPHYTES

4.6.1 Overview

4.6.1.1 Main grouping and baseline description

The Klein Brak Estuary has a large supratidal and floodplain habitat compared with area covered by intertidal salt marsh and reeds and sedges (refer to **Table 4.18**). The intertidal salt marsh in the lower reaches of the Klein Brak Estuary (1 ha) consisted of a mosaic of *Triglochin striata*, *Sarcocornia decumbens* and *Spartina maritima*; all typical intertidal species (Adams *et al*., 2010). These species require frequent tidal inundation and were dominant areas closest to the water channel and within the creeks. *Spartina maritima* is common in large permanently open Cape estuaries and can grow to heights of 80 cm (Adams *et al*., 1999). Further upstream in the middle reaches of the estuary the salt marsh area (16 ha) had *Sarcocornia decumbens* and sharp rush *Juncus kraussii*. Throughout the estuary at higher elevations supratidal salt marsh was the dominant macrophyte habitat.

Only two species of reeds and sedges were dominant namely *Juncus kraussii* and *Phragmites australis*. These species were found in the lower reaches of the estuary in areas of freshwater seepage as salinity is the main controlling factor for these macrophytes (Adams *et al*., 1999). A single species of submerged macrophyte was observed by Adams *et al.* (2010), i.e. *Zostera capensis*, in the lower reaches of the estuary where salinity was favourable for growth. Day (1981) however, also observed *Ruppia* sp. in the upper reaches of the estuary; however, strong freshwater flow may be responsible for the removal of this macrophyte from the system as they are highly susceptible to mechanical damage and uprooting.

Table 4.18 Macrophyte habitat areas for the Klein Brak Estuary

Habitat type	Defining features, typical/dominant species	2014 area (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	98
Sand and mud banks	Intertidal zone consists of sand/mud banks that provide a possible area for microphytobenthos to inhabit.	48
Macroalgae	Filamentous green algae could establish during low flow, closed mouth conditions and in response to an increase in nutrients.	2
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. *Zostera capensis* as well as *Ruppia* spp. have been found in the estuary.	3
Salt marsh	The following species have been recorded: *Disphyma crassifolium, Salicornia meyeriana, Sarcocornia decumbens, Sarcocornia pillansii, Stenotaphrum secundatum, Sporobolus virginicus* and *Triglochin striata*	494
Reeds and sedges	*Juncus kraussii* (sharp rush) and *Phragmites australis* (common reed) are dominant.	18
Floodplain	This is a mostly grassy area which occurs within the 5 m contour line. Agriculture takes place in 507 ha. Invasive plants are present.	565
Total Estuarine Area (ha)		1224

4.6.1.2 Description of factors influencing macrophytes

Table 4.19 summarises the key responses of estuarine macrophytes to changes in abiotic and other biotic components, while **Table 4.20** translates these into expected responses within each of the abiotic states (refer to **Table 3.1**).

Table 4.19 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various macrophyte groupings

Process	Macrophytes
Mouth condition	Open mouth conditions create intertidal habitat. There are areas of intertidal salt marsh within the lower reaches, with supratidal salt marsh occurring in the middle to upper reaches of the estuary.
Retention times of water masses	Closed mouth conditions and longer water retention times promote macroalgal growth.
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.
Total volume and/or	The longitudinal salinity gradient promotes species richness, different macrophyte

Process	Macrophytes
estimated volume of different salinity ranges	habitats are distributed along the length of the estuary, for example salt marsh in the lower reaches and reeds and sedges in the upper reaches.
Floods	Large floods are important in flushing out salts from the salt marsh area. Hypersaline sediments caused by evaporation and infrequent flooding will result in dry bare patches in the supratidal salt marsh areas. High groundwater level and freshwater flooding maintains suitable moisture conditions for plant growth in the marsh.
Salinity	Base flow is sufficient to maintain longitudinal salinity gradients from the mouth to head of the estuary which promotes macrophyte diversity.
Turbidity	Increase sediment load within the water column results in a reduction in the photic zone and will limit submerged macrophyte establishment.
Dissolved oxygen	The estuary is well oxygenated.
Nutrients	Increased nutrient inputs would increase macrophyte growth particularly in areas of freshwater seepage (i.e. reeds and sedges).
Sediment characteristics (including sedimentation)	There has been some marine sedimentation in the lower reaches of the estuary. This area is very dynamic with few macrophytes establishing except for dune vegetation further up the elevation gradient.
Other biotic components	Grazing and trampling has occurred in certain sections of salt marsh. Invasive plants are common.

Table 4.20 Summary of macrophyte responses to different abiotic states

Abiotic state	Response
State 1: Marine dominant, some mouth closure	Macroalgae would increase in cover during closed mouth conditions.
State 2: Full salinity gradient	Favourable for salt marsh growth.
State 3: Limited salinity penetration	Favourable for growth of reeds and sedges.
State 4: Freshwater dominant	Submerged macrophytes and macroalgae lost due to high flow.

4.6.1.3 Reference Condition

A summary of the relative changes in macrophytes in the Klein Brak Estuary from Reference Condition to Present State is summarised in **Table 4.21**.

Table 4.21 Summary of relative changes in macrophytes from Reference Condition to Present State

Key drivers	Change
⇩ river flow ⇧ salinity	⇩ Reed & sedge growth in upper reaches and salt marsh productivity
⇩ floods ⇧ salinity	⇩ Salt marsh due to salinization and formation of bare areas
⇧ nutrients	⇧ Macroalgae particularly during closed mouth conditions ⇧ reeds and sedges as sites of stormwater input

Key drivers	Change
⇧ agriculture, disturbance & invasive plants	⇩ 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 4.22**). 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 and development has disturbed 526 ha of habitat which is now a degraded state; there is currently 30 ha of undisturbed floodplain within the 5 m contour line. Supratidal salt marsh in 2014 covers 278 whereas intertidal salt marsh covers 17 ha. There has been an increase in reeds and sedges from 12 to 18 ha due to an increase in nutrient rich run-off and sediment stability. Invasive plants and macroalgae would not have been present in the reference state but both habitats now cover approximately 2 ha. In total macrophytes covered 586 ha but now cover 350 ha with a 60% similarity in abundance compared to reference conditions. Approximately 20 % of the changes are due to flow related impacts and 80% 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 4.22 Area covered by macrophyte habitats and calculation of the similarity in community composition for the Klein Brak Estuary

Macrophyte habitat	Reference area cover (ha)	Present area cover (ha)	Minimum
Floodplain	278	30	30
Intertidal salt marsh	17	17	17
Supratidal salt marsh*	278	278	278
Reeds & sedges	12	18	12
Submerged macrophytes	1	3	1
Invasive plants	0	2	0
Macroalgae	0	2	0
SUM	586	350	338
% similarity	**Sum min /(sum ref+present)/2**	**338/([586+350 /2] = 72%**	

consists of degraded areas

The macrophyte health scores for the Present State are presented in **Table 4.23**.

Table 4.23 Present macrophyte health score, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

Variable	Summary of change	Score	Confidence
a. Species richness	Low baseflow and increase in salinity has reduced macrophyte species richness. Development, disturbance and loss of salt marsh and floodplain habitat would also result in loss of species.	80	M
b. Abundance	There has been substantial loss of floodplain and supratidal salt marsh area due to agriculture and development. Loss of habitat due to invasive plants.	50	M
c. Community composition	Degraded floodplain has replaced supratidal salt marsh and floodplain areas. Macroalgae and reeds grow in response to nutrient input and invasive plants are common in the floodplain areas.	72	M
Macrophyte health score min (a to c)		**50**	**M**
% of impact non-flow related		80	
Adjusted score		90	M

4.7 INVERTEBRATES

4.7.1 Overview

4.7.1.1 Main grouping and baseline description

Previous information on invertebrates from the Klein Brak Estuary is limited. Day (1981) recorded 11 invertebrate species and concluded that the Klein Brak supported a "*poor fauna"*. Mudprawn *Upogebia africana* was sparse and *Eumarcia paupercula* was the only bivalve found. However, at the time of the survey, oil pollution from the Venpet-Venoil collision extended two kilometres up the estuary. By contrast to Day's findings, Wooldridge & Loubser (1996) recorded prawn-hole densities of *Upogebia africana* that ranged between 500 and 700 holes/m^2 immediately below the N2 road bridge and on the eastern bank. These values are relatively high by comparison to other temperate estuaries in the region.

Four major invertebrate groups (mesozooplankton, hyperbenthos, subtidal macrozoobenthos and intertidal macrozoobenthos) are identified for the purposes of reserve determination studies in estuaries. During the 2013 survey, twenty-one taxa were recorded in the Klein Brak zooplankton. Abundance (ind.m^{-3}) was relatively low for most species, although the copepod *Pseudodiaptomus hessei* followed a more typical pattern of abundance for temperate estuaries. This species is often the numerically dominant taxon in the zooplankton of South African estuaries and the Klein Brak therefore follows this broader pattern. However, abundance was still an order of magnitude lower relative to many other temperate systems.

The zooplankton species present were typical of estuaries along the south coast, with amphipods, mysids, cumaceans and unidentified copepods also being numerically important. No distinct difference was observed in species composition and abundance between the two arms of the estuary, although *Pseudodiaptomus hesei* was more abundant in the Moordkuil arm. Amphipods dominated the zooplankton community numerically, with *Grandidierella lignorum* being the most important. It was more common in the middle section and in both tributaries of the estuary.

Seventeen hyperbenthic taxa were recorded 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 two of the seventeen species exceeded 50 $ind.m^{-3}$. Of these, the mysid *Mesopodopsis wooldridgei* and larvae of the Crown crab (*Hymenosoma orbiculare*) dominated in the lower estuary particularly.

Sixteen taxa were recorded in the benthos and must be considered low by comparison to other tidal estuaries in the temperate region. This is particularly due to the scarcity of Polychaete species. Abundance of individual species ($ind.m^{-2}$) was also low and averaged at least an order of magnitude lower compared to many other tidal estuaries.

Species present were typical of estuaries along the south and west coast, with the community dominated by two species of amphipods (*Corophium triaenonyx* and *Grandidierella lignorum*). The polychaete worm *Prionospio* sp. and the Tanaid *Apseudes digitalis* were the only other relatively common species. In terms of biomass, the community was dominated by gastropods and bivalve molluscs. Along the intertidal zone, very high densities of *Upogebia africana* were present along the eastern bank of the lower estuary. Along much of the estuary, the modified shoreline as well as vegetated and steep banks along the two tributaries has reduced habitat available to intertidal organisms typical of unvegetated shorelines.

4.7.1.2 Description of factors influencing invertebrates

The effect of abiotic characteristics and processes, as well as other biotic components (variables) on various invertebrate groupings are provided in **Table 4.24**.

Table 4.24 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. Occasional mouth closure in the Klein Brak will also reduce biomass of the mudprawn *Upogebia africana*, particularly if mouth closure persists (months).
Turbidity	Increasing turbidity reduces predation pressure from visual-hunters, particularly the zooplankton. Other species s such as the mysid *Rhopalophthalmus terranatalis* prefer deeper waters for the same reason (predator avoidance).
Salinity	A full salinity gradient will increase species richness and enable zonation patterns to develop within the zooplankton community. Biomass increases, particularly in the REI.

Variable	Response of the zooplankton and hyperbenthos
Floods	Floods will flush populations from the estuary – recovery in some cases will be relatively slow. Sediment characteristics change locally and this impacts community structure.
Tidal currents	Strong tidal currents flush populations from the estuary, particularly near the mouth.
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 – recruitment to the population ceases should the mouth close during the breeding season. After about three to four years of mouth closure, mudprawn populations become locally extinct.
Salinity	A full salinity gradient will increase species richness and enable zonation patterns to develop within the benthic community. Low salinity zones are particularly favourable for amphipod species such as *Corophium triaenonyx* and *Grandidierella lignorum*.
Oxygen	A decrease in oxygen concentration (below 50% of surface values) will result in the disappearance of many of the benthic species.
Floods	Some populations, particularly in unconsolidated sediments will be flushed from the estuary.
Estuary becomes shallower	Likely increase in the intertidal area leading to new habitat becoming available to intertial organisms.
Organic content of the sediment	High organic content of the sediment favours species that are associated with the surface layers particularly.
Changes in sediment characteristics	Benthic species distribution will change in accordance with the shift of habitat preference.
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.

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

Table 4.25 Summary of invertebrate responses to different abiotic states

Abiotic state	Response
State 1: Marine dominant, some mouth closure	Marine dominance will lead to a significant change in zooplankton species distribution and biomass. In the lower and middle estuary species richness will increase, but biomass will decrease. Variability will also decease since freshwater inflow is persistently low. Community composition will also change, with species favouring higher salinity values extending up-estuary. An oligohaline community will only persist in the extreme upper reaches of the two tributaries, but biomass will be low because of high variability in salinity particularly. Fringing vegetation in the tributaries will also decrease, leading to loss of habitat for hyperbenthic species such as carid shrimps. Because of the expansion of submerged macrophyte beds under higher salinity

Abiotic state	Response
	conditions, the benthic community will change in composition as the habitat changes. Benthic species that favour submerged plants as a colonising 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). In the deeper upper reaches of the estuary (particularly the Moordkuil tributary) low oxygen concentrations (below 50% surface saturation) in bottom waters will impact the benthic community particularly in a negative way – species will disappear. Higher salinity values in the upper estuary will also lead to a decrease in the habitat available to amphipod species (particularly *Corophium triaenonyx and Grandidierella lignorum*) that dominate habitats influenced by low salinity conditions. Other species are likely to begin dominating the estuarine benthic community and this change will impact higher trophic levels.
State 2: Full salinity gradient	A full salinity gradient will maximize for species richness and biomass – the latter also supported by an increase in primary production. The presence of the REI will favour zooplankton biomass. Submerged macrophyte cover will decrease relative to State 1 and this will favour burrowing forms in the benthos.
State 3: Limited salinity penetration and State 4: Freshwater dominant	As salinity penetration decreases progressively from States 3 to 4, there will be a concomitant decrease in species richness as species favouring higher salinity values (> 28) disappear from the estuary. Populations will shift downstream in accordance with salinity tolerance levels. Euryhaline zooplankton communities will be more at risk from flushing effects and as populations are forced nearer the mouth. Flushing will be exacerbated as tidal current increase in velocity nearer the mouth. Because of decreasing residence time of water in the estuary, some populations (zooplankton particularly) will not be able to complete their respective life cycles as larvae or eggs are flushed to sea. The net result is that oligohaline forms will dominate the whole estuary under State 4.

4.7.1.3 Reference Condition

Table 4.26 summarised the relative changes from Reference Condition to Present State in the invertebrate component.

Table 4.26 Summary of relative changes in invertebrates from Reference Condition to Present State

Key drivers	Change
Increased marine dominance upstream	Twenty-six percent reduction in MAR has resulted in marine dominance increasing during all months of the year, particularly during winter. A marine dominated state now persists for longer. In terms of the zooplankton and variability over time will decrease as higher salinity values persist. Although a salinity gradient is present under the Present State, average salinity in the middle-upper reaches has increased (from ca 18 to 23). The range in salinity in the middle-upper estuary has decreased - under the natural state the range was 12 – 23 and under Present State from 18 – 27. The salinity gradient in this sector of the estuary has therefore weakened. The net result for the zooplankton is reduced biomass (also lower phytoplankton biomass) and weaker zonation of species along the estuary. Under Present State, a REI community has also developed, but the biomass of invertebrates associated with this REI will be very low because of the very small habitat available (relative to the estuary). 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. The intertidal area inhabited by the mudprawn *Upogebia africana* has decreased, mostly due to modification of the intertidal zone (e.g. bank stabilisation). 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 colonise low salinity estuarine areas very successfully. The repeated pattern of high amphipod biomass in low salinity estuarine areas indicates a preference for his zone.
Increased macrophyte biomass	Increased coverage by submerged macrophytes will favour those invertebrate species that utilize such habitats. Examples are bivalve molluscs - *Exosphaeroma hylocoetes* and Anthurid isopods. Species mix in the benthic community will therefore include a greater proportion of invertebrate that attach themselves to the macrophytes.
Oxygen concentration	The development of low oxygen concentrations in the deeper parts of the estuary (e.g. in the Moordkuil tributary) will lead to the disappearance of benthic populations particularly as concentrations decrease below 50%.
TOTAL CHANGE	Overall, about a 35% change

4.7.2 Invertebrate health

The invertebrate health scores for the Present State are presented in **Table 4.27**.

Table 4.27 Present invertebrate health score, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

Variable	Summary of change	Score	Confidence
Zooplankton			
a. Species richness	Species richness has not changed, based on a time frame of one year	100	H
b. Abundance	Abundance has decreased, particularly due to the persistence of State 1 (increased marine dominance). Although relative, high abundance is linked to the euryhaline community that decreases as average salinity increases and phytoplankton production decreases.	80	M
c. Community composition	There has been a shift towards less variability in community composition within the annual cycle. The mix of species in along the estuary has also changed, because of increasing average salinity values upstream. Under present conditions, the REI appears in the uppermost reaches of the estuary.	70	M
Hyperbenthos			
a. Species richness	Species richness has not changed, based on a time frame of one year.	100	H
b. Abundance	Abundance has decreased, particularly due to the persistence of State 1 (increased marine dominance). Although relative, high abundance is linked to the euryhaline community that decreases as average salinity increases and phytoplankton production decreases. Because of reduced reed coverage, carid shrimps have also declined in abundance.	80	M
c. Community composition	There has been a shift towards less variability in community composition within the annual cycle. The mix of species in along the estuary has also changed, because of increasing average salinity values upstream. Under present conditions, the REI appears in the uppermost reaches of the estuary.	70	L
Benthos			
a. Species richness	Species richness has not changed, based on a time frame of one year.	100	H

Variable	Summary of change	Score	Confidence
b. Abundance	Subtidal abundance has decreased, particularly in the low salinity zones (5-15) under the natural state that now experiences increased salinity values on average. Key groups in the low salinity zone are the tanaeids and amphipods that favour low salinity conditions (*Apseudes digitalis*, *Corophium triaenonyx* and *Grandidierella lignorum*). The aperiodic development of reduced oxygen concentrations in deeper sections of the estuary will lead to a decline in benthic abundance particularly. Intertidal invertebrates have decreased because of loss of habitat (Bank stabilisation, modified intertidal marsh areas etc.)	70	M
c. Community composition	There has been a shift towards reduced variability within benthic populations. Species that favour submerged macrophytes as a substrate have increased as macophyte coverage increased. Species mix will also change as abiotic drivers such as low oxygen concentrations develop, particularly in deeper areas.	70	M
Invertebrate score min (a to c)		**70**	M
% of impact non-flow related factors (bank stabilisation, trampling of saltmarsh habitats etc.)		5	
Adjusted score		72	M

4.8 FISH

4.8.1 Overview

4.8.1.1 Main grouping and baseline description

South African estuarine fish species may be categorised according to their dependence on estuaries using the five-category classification scheme as refined by Whitfield (1994), based on life-history characteristics (**Table 4.28**).

Thirty-five species of fish from 19 families have been recorded in the Klein Brak Estuary which is comparable to that of the adjacent Groot Brak and Gouritz estuaries of equivalent size. Over a 4-year sampling period (twice annually 2010-2014), 32 species were caught in the Klein Brak compared to 26 and 37 in the Groot Brak and Gouritz respectively. Of these, 12 (38%) are entirely dependent on estuaries to complete their life-cycle (Categories Ia and IIa), of which 4 are estuarine breeders; estuarine round-herring *G. aestuaria*, Cape halfbeak *Hyporhamphus capensis* and river goby *Glossogobius callidus* (Category Ia). Eight species, including Cape stumpnose *Rhabdosargus holubi*, dusky kob *Argyrosomus japonicus*, white steenbras *L. lithognathus*, leervis *Lichia amia* and spotted grunter *Pomadasys commersonnii* are dependent on estuaries as nursery areas for at least their first year (Category IIa). Another 10 species (31%) are at least partially dependent on estuaries, e.g. southern mullet *L. richardsonii*, groovy mullet *Liza dumerilii*, elf *P. saltatrix,* dassie *Diplodus capensis,* white stumpnose *Rhabdosargus globiceps* (Categories IIb and IIc). In all, 69% of the fish species recorded from the Klein Brak Estuary are either partially or completely dependent on estuaries for their survival. Most of the remaining species were marine species (22%), e.g. evil-eye puffer / blaasop *Amblyrhynchotes honckenii*, white-spotted puffer *Arothron hispidus* and Piggy *Pomadasys olivaceum* which occur in estuaries, but are not dependent on estuaries (Category III); three (9%) are alien euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance, namely Carp *Cyprinus carpio,* Banded tilapia *Tilapia sparmanii and* Mozambique tilapia *Oreochromis mossambicus* (Category IV).

Table 4.28 The five major categories of fish that utilise South African estuaries (after Whitfield 1994)

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

Numerically*, G. aestuaria* (39%), *Caffrogobius* spp. (12%), *L. richardsonii* (11%) and *R. holubi* (9%) dominate the Klein Brak fish assemblage providing 71% of sampling catches. *Mugilidae* spp (6%), *P. knysnaensis* (6%), groovy mullet *Liza dumerili* (4%), piggy *P. olivaceum* (4%) and two sole species namely blackhand sole *Solea turbynei* (3%) and Cape sole *Heteromycteris capensis* (3%) are also important. The remaining species all contributed < 1% to the sampling catch. However, some of these species, e.g. dusky kob *Argyrosomus japonicus*, spotted grunter *Pomadasys commersonnii*, elf *Pomatomus saltatrix* and leervis *Lichia amia* are large and species of natural lower abundance. *Caffrogobius* spp. and *P. knysnaensis* occurred in over 70% and *S. bleekeri* , *L. richardsonii* and *R. holubi* in around 50% of sample hauls.

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 & V. Freshwater species
Mouth condition	Klein Brak predominantly open, seldom closes 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 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 & V. Freshwater species
		high turbidity often occur immediately adjacent to estuary mouths during floods. Estuarine connectivity driven by flood events.				
Salinities	Resident and estuary associated marine species very tolerant of salinities in the range 1-35.				Tend to stay as close to 35 as possible. Stressed less than 20.	Highly variable and most prefer salinity < 10.
Turbidity	Tolerant of a wide range of turbidity.	Turbidity preferences and tolerances vary among species. High turbidity tolerance (physiological adaptation) among some species affords them refuge and access to a specialist ecological niche.			Generally prefer low turbidity	Tolerant of a wide range of turbidity.
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 & 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 more in temporarily open/closed than permanently open estuaries.					

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 & V. Freshwater species
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 distributed according to their burrowing ability and sediment characteristics.					
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 & 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, some mouth closure	*L. richardsonii* become dominant in the lower, middle and upper reaches. Reaches. REI species e.g. *Myxus capensis* and *Monodactylus falciformis* are in low abundance due to the almost complete absence of the REI zone. The few individuals in the estuary are concentrated in the upper reaches and in the 10-20 psu zones. . One advantage is that the more turbid 10-30 psu area expands increasing available habitat for juvenile *A. japonicus, P. commersonnii* and other important exploited species. However, most (53%) of the fish in the estuary marine opportunists and obligate estuarine-dependent species, are concentrated in the limited REI zone. These numbers half with each of the four salinity zones (< 10, 11-20, 21-30, > 30) mouth wards. Marine species e.g. *P. olivaceum* occur in relatively high numbers 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 and middle reaches but prey species may burrow down or

Abiotic state	Response
	move elsewhere specifically for this reason.
State 2 Full salinity gradient	Fish will be distributed according to their salinity preferences and overall recruitment into the estuary along the salinity gradient should be at a maximum. Increases in phytoplankton and zooplankton production translate into more food for juvenile and larval fish of most species. Again, elevated benthic algal biomass will benefit all mullet species. REI presence will favour zooplankton biomass and juvenile fish that prey upon it. However, REI zone still limited to a narrow headwater stretch and REI species largely absent due to absence of REI or most of the time.
State 3 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 4 Freshwater dominant	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. However, REI absence for most of the time in the present day will result in REI fish assemblage not recovering until freshwater dominated conditions persist for a few years or more. Catadromous glass eels will recruit into the catchment or adult silver eels migrate back via the estuary into the sea (freshwater catchment habitat degraded though). Elevated silt loads will replenish specialist habitat for young-of-the-year *A. japonicus* 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 from Reference Condition to Present State.

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

Key drivers	Change
⇧⇩Floods	Floods still occur during peak recruitment periods in spring and early summer. Ten percent reduction in flood volume may reduce level of connectivity with adjacent systems. Slightly shorter duration of high flow events may shorten recruitment window.

Key drivers	Change
⇧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 suggests that the REI zone is absent for most of the present day. REI species now either absent or in very low abundance whereas estuary dependent marine species e.g. *R. holubi* abundant throughout most of the estuary. This said, both obligate estuarine-dependent (e.g. *L. lithognathus)* and marine opportunistic species (e.g. *L. richardsonii*) are concentrated against the anthropogenic barriers in both arms of the estuary. 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 have been adversely affected by a decline in zooplankton biomass.
⇩Benthic invertebrate biomass	A decrease in invertebrate biomass (specifically *Upogebia africana*) should see declines in invertebrate feeders e.g. *P. commersonnii, R. holubi*. However, this needs to be compared to a possible increase in sand-prawn *C. kraussi*. The availability of invertebrate burrows, especially the latter two species) should also be reflected within 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.
TOTAL CHANGE	An increase in abundance and diversity of small bodied species and juvenile fish but a drastic decline in abundance of large exploited species.

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	Confidence
a. Species richness	Loss of many REI and large estuarine-dependent species. Three, alien/translocated freshwater species in the estuary (carp *Cyprinus carpio,* banded tilapia *Tilapia sparrmanii* Mozambique tilapia *Oreochromis mossambicus*and possibly smallmouth-bass *M. dolomieu*.)	80	M
b. Abundance	An almost complete loss of REI species e.g. *Myxus capensis*. Even though there should be an increase in abundance and diversity of small bodied species and juvenile fish, especially marine opportunists, upstream barriers have excluded these fish from much of the estuary. There has also been a drastic (nationwide) decline (60%-95 %) in abundance of large exploited species.	70	M
c. Community composition	REI fish component functionally extinct. Increase in abundance of small-bodied detrital & benthic diatom feeders but a drastic decline in the influence of large piscivorous predators – upper trophic levels depleted by overfishing throughout the coast. Three alien freshwater species in the estuary.	60	M
Fish health score: min (a to c)		**60**	**M**
% of impact non-flow related		60	
Adjusted score		84	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 (refer to **Table 4.33**).

Table 4.33 Major bird groups found in the Klein Brak 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.

Bird groups	Defining features, typical/dominant species
Piscivorous wading birds	This group comprises the egrets, herons, ibises and spoonbill. Loosely termed piscivores, their diet varies in plasticity, with fish usually dominating, but often also includes other vertebrates, such as frogs, and invertebrates. The ibises were included in this group, though their diet mainly comprises invertebrates and is fairly plastic. They tend to be tolerant of a wide range of salinities. Wading piscivores prefer shallow water up to a certain species dependant wading depth.
Herbivorous waterfowl	This group is dominated by species that tend to occur in lower salinity or freshwater habitats and are associated with the presence of aquatic plants such as *Potamageton* and *Phragmites*. The group includes some of the ducks (e.g. Southern Pochard), and all the rallids (e.g. Redknobbed Coot). Some herbivorous waterfowl such as Egyptian Goose probably feed in terrestrial areas away from the estuary and floodplain as well as in the estuary.
Omnivorous waterfowl	This group comprises ducks which eat a mixture of plant material and invertebrate food such as small crustaceans - Yellow-billed Duck, Cape Teal, Red-billed Teal and Cape Shoveller. Although varying in tolerance, these species are fairly tolerant of more saline conditions.
Benthivorous waders	This group includes all the waders in the order Charadriiformes (e.g. Greenshank, Curlew Sandpiper). They are the smallest species on the estuary, and feed on benthic macroinvertebrates in exposed and shallow intertidal areas. Invertebrate-feeding waders forage mainly on exposed sandbanks, mudflats and in the inter-tidal zone.
Piscivorous gulls & 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 the 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 (refer to **Table 4.34**). These relationships may vary seasonally, from estuary to estuary, or between biogeographical zones. Certain groups or species are liable to be more responsive to changes in system variables than others, depending on their ability to adapt to a range of circumstances (e.g. Turpie and Hockey, 1997). Very few quantitative studies have been made of the influence of abiotic and biotic factors on bird community structure and abundance in South African estuaries. Because numerous factors affect avifaunal community structure and abundance, it is difficult to demonstrate these effects empirically (Evans, 1997, Hockey and Turpie, 1999). Thus predictions regarding the reference state and future scenarios have to be made on the basis of expert understanding of the relationships between elements of estuarine bird communities and their main drivers.

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

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

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

Variable	Cormorants & wading piscivores	Kingfishers & 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	

Variable	Cormorants & wading piscivores	Kingfishers & fish-eagle	Waterfowl	Waders, gulls and terns
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, some mouth closure	System is marine salinity throughout. Under lower flow scenarios the system is hypersaline. Would support very few waterfowl. Floodplain wetlands become more dry and hypersaline leading to changed community composition.
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: Limited salinity penetration	As above, but the particularly favourable conditions for fish could attract more piscivores to the system.
State 4: Freshwater dominant	Waterfowl will be more common 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; floodplain wetlands will be more functional.

4.9.1.3 Reference Condition

Estimation of the Reference Condition takes into account the expected response to flow-related and non-flow related drivers into account, in conjunction with any evidence from existing data. Key flow-related changes and their expected effect are summarised in **Table 4.36**.

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

Key drivers	Change
⇧Salinities	Reduced suitable habitat for waterfowl. Changing nature of floodplain wetlands.
⇧Sediment , ∆ characteristics	Changed mouth dynamics leads to poorer conditions for terns in mouth area. Change in suitability for sandy beach and mudflat waders.
⇧ Turbidity	Unlikely to have had significant effect.
⇩Salt marsh in lower estuary and saltmarsh/wetland habitats in upper floodplain	Negative impact on waders in lower estuary; major impact on waders and wading birds and water fowl in upper floodplain.
⇩Emergent veg/reed marsh	Decreased habitat and food source for skulking rallids and waterfowl. Relates to the increased salinity.
⇩Benthic invertebrate biomass	Reduction in benthic invert abundance leads to reduced number of waders in lower estuary
⇩Fish biomass	Even though there should be an increase in abundance and diversity of small bodied species and juvenile fish upstream barriers have excluded these fish from much of the estuary. Decrease in biomass of fish species reduces food for piscivorous species. Supported by observation – slight decrease (~20%) in piscivorous cormorants and wading birds

Comparison of the two comprehensive counts in 1981 and 2013 suggests that there have been major changes in the avifauna of this system. These changes are described below. However it should be borne in mind that comparison of two one-off counts is difficult, since this does not take into account the potential variability in the system, or the conditions under which the counts were undertaken. The conclusions that can be drawn from this are therefore of a low confidence, but do err on the side of caution, since count conditions in Dec 2013 were unfavourable due to high winds.

Waterfowl have declined markedly in diversity and abundance, from several hundred birds of ten species, to just a few birds of two species in 2013. This is indicative of a major loss of freshwater and backwater/floodplain wetland habitats.

While Reed Cormorant and African Darter were fairly numerous and Whitebreasted Cormorant was rare in the 1981 count, the opposite was true in the recent count. These changes are indicative of a system that has become far more saline. The slight decline in overall numbers is also consistent with the suggestion that fish biomass has decreased.

Six species of herons, egrets, ibis and spoonbill were recorded in 1981, dominated by African Spoonbill and Little Egret. The recent count found seven species, dominated by Sacred Ibis, Hadeda Ibis and Cattle Egret. These are all species whose population numbers have increased regionally.

Numbers of other piscivorous birds, the birds of prey and kingfishers, appear to have been relatively stable, with a possibly slight decrease in numbers. While only Osprey was recorded in early counts and African Fish Eagle was not recorded, its presence on the system has been confirmed by others.

Kelp Gull numbers have increased steadily over time, from seven to 40. Several terns have been recorded in small numbers, and larger roosts of up to 430 Swift Terns have been recorded on the system several times during the Coordinated Waterbird Counts (CWAC) surveys. They were not recorded during either of the 1981 or 2013 surveys. The changed mouth dynamics of the estuary, as well as the decrease in fish populations, would have made it less attractive for terns over time.

Eighteen wader species amounting to 725 birds were recorded in 1981, including species associated with beach, dry pan, mudflat and marshy habitats. In comparison, only 244 waders were counted in the 2013 survey. Species that were not counted again or that have only been seen since in much smaller numbers include Ruddy Turnstone, Kittlitz's Plover, Grey Plover, Threebanded Plover, Curlew Sandpiper, Sanderling, Common Sandpiper, Ruff, Wood Sandpiper, Marsh Sandpiper, African Snipe and Eurasian Curlew. Many of these are species that would be found in floodplain habitats, and indicate a loss of habitat. The absence of others, such as Grey Plover and Eurasian Curlew, suggests that there has also been a loss of productive mudflat areas.

4.9.2 Bird health

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

Table 4.37 Present bird health score, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

Variable	Summary of change	Score	Confidence
a. Species richness	Big reduction in average instantaneous species richness	70	L
b. Abundance	Numbers of most groups expected to have declined, with overall decrease in numbers.	31	L
c. Community composition	Reduced numbers of some of the more numerous groups – waders, gulls and terns, influx of some wading birds, gulls etc., overall major change in community composition	47	L
Bird health score: min (a to c)		**31**	**L**
% of impact non-flow related		40	
Adjusted score		59	L

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 Klein Brak, in accordance with the EHI as presented in **Table 5.1**.

Table 5.1 Present Ecological Status of the Klein Brak Estuary

Variable	Weight	Score
Hydrology	25	56
Hydrodynamics and mouth condition	25	96
Water quality	25	82
Physical habitat alteration	25	54
Habitat health score		**72**
Microalgae	20	64
Macrophytes	20	50
Invertebrates	20	70
Fish	20	60
Birds	20	31
Biotic health score		**55**
ESTUARY HEALTH SCORE Mean (Habitat health, Biological health)		**64**
PRESENT ECOLOGICAL STATUS (PES)		**C**
OVERALL CONFIDENCE		**Low**

The Estuarine Health Score for the Klein Brak Estuary is 64; thus a PES of **Category C.**

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

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

Specialist concluded that non-flow related factors contributed significantly to ecological modifications in the Klein Brak Estuary from Reference Condition to the Present State as summarised in **Table 5.2**.

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

Component	% of modification in health (non-flow related factors)	Key non-flow related factors
Hydrology	N/A	Flow related factor
Hydrodynamics and mouth condition	10	Weirs in Brandwag and Moordkuil arms reducing tidal amplitude and flows
Water quality	60	Weirs in Brandwag and Moordkuil arms Nutrient input mainly from agricultural activities
Physical habitat alteration	90	Bank developments
Microalgae	40	Weirs in Brandwag and Moordkuil arms Nutrient input mainly from agricultural activities Changes in physical habitat
Macrophytes	80	Degradation of estuarine habitat development) Weirs in Brandwag and Moordkuil arms Aliens in riparian zone Nutrient input mainly from agricultural activities
Invertebrates	5	Limited bait collection pressures
Fish	60	Fishing pressures
Birds	40	Human disturbance Presence of alien species (e.g. Egyptian geese)

Specialists estimated that by removing non-flow related factors (**Table 5.2**) the present state of the Klein Brak Estuary could improve to a Category B. This demonstrates that the modification in river inflow patterns only partly contributed to the present ecological health status in the Klein Brak Estuary (i.e. Category C). The key flow related factor contributing to the modification in health condition is the loss of base flows in order to create a more permanent REI zone in the estuary.

5.3 OVERALL CONFIDENCE

The overall confidence of this study is **Low (40-60% certainty),** mainly because of the low confidence in the simulated hydrology and limited data availability on the abiotic components. Although measured river inflows were available for both the Brandwag and Moordkuil tributaries, only limited data were available on abiotic characteristics with which to define and characterise abiotic states in this complex system (i.e. two river inflows) which is the primary mechanism by which modification in health condition from the Reference Condition to Present State determined, together with simulated river runoff scenarios.

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. Medium to low confidence in the microalgae and invertebrate is attributed to the availability of some historical data sets on this system. Extensive data on the fish component collected by DAFF as part of their long-term monitoring programmes in estuaries significantly contributed to the medium (even high) confidence in this component. Historical data on the bird component was also available from the CWAC programme. Even though specialists drew on experience from their collective research on other, related estuarine systems, the complexity of this estuary, as well as the low confidence in the hydrology resulted in an overalll confidence of this study. However, the recommended monitoring programme should focus on to improving 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. These importance scores ideally refer to the system in its **Present State**. The scores have been determined for all South African estuaries (Turpie and Clark, 2007), apart from functional importance, which is scored by the specialists in the workshop (refer to **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 Klein Brak Estuary

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

Table 6.2 Estuarine Importance scores (EIS) for the Klein Brak Estuary

Criterion	Weight	Score
Estuary Size	15	80
Zonal Rarity Type	10	10
Habitat Diversity	25	10
Biodiversity Importance	25	69
Functional Importance	25	100
Weighted Estuary Importance Score		**58**

Referring to the estuarine importance rating system (DWAF, 2008), the importance score of the Klein Brak Estuary – a score of **58** - translates into an importance rating of **"Average Important"** albeit just below the rating of "Important" (refer to **Table 6.3**). While, on a national scale, Klein Brak Estuary may be of average importance, it is certainly a large estuary in this region and plays a very important role as a fish nursery for exploited and endangered fish species and provides an open estuary along a coast where a significant number of systems are seasonally closed. At a finer, regional scale the Klein Brak Estuary is, therefore, important.

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 (refer to **Table 6.4**) the Klein Brak Estuary should at least be managed in a **Category C**. The motivation being that the estuary is important, requiring a minimum REC of a C.

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 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

While the PES of the Klein Brak Estuary is currently in a Category C, specialists concluded that the system was on a **negative trajectory of change**, that is if the current (low) base flow regime, as well as certain non-flow related impacts on the system continue as at present, the estuary is likely to move into a Category C/D, or even a Category D. According to DWAF (2008) guidelines for the REC, an REC equivalent to the PES was allocated to the Klein Brak Estuary, namely a **Category C.**

7 CONSEQUENCES OF ALTERNATIVE SCENARIOS

7.1 DESCRIPTION OF SCENARIOS

The proposed scenarios for the Klein Brak system are summarised in **Table 7.1**.

Table 7.1 Summary of flow scenarios

Scenario	Description	MAR (10^6 m^3)	Percentage remaining
Reference	Natural	50.67	100
Present	Present day	37.66	74
Scenario 1	River class C EWR	38.97	77
Scenario 2	A dam of 10 million m^3 on the Moordkuil tributary and an abstraction of 12.5 million m^3/a from the dam	30.11	59
Scenario 3	A dam of 10 million m^3 on the Moordkuil tributary and an abstraction of 16 million m^3/a from the dam	25.24	50
Scenario 4	Increase the dam to 20 million m^3 and the abstraction to 20 million m^3/a. Add a run-of-river abstraction of 3 million m^3/a from k10D.	20.24	40

7.2 Variability in river inflow

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

Table 7.2 Summary of the monthly flow distribution (in m^3/s) for Scenario 1 (refer to Table 3.1 for colour coding of abiotic states)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	7.5	18.1	12.9	10.2	8.1	10.3	11.0	9.9	5.6	5.1	11.4	11.9
99	7.3	17.0	12.3	7.5	7.7	9.2	8.6	9.4	4.1	3.6	10.1	8.4
90	4.0	5.1	2.8	2.0	2.1	3.9	4.7	2.4	1.8	1.3	2.3	4.3
80	3.2	2.9	1.4	1.2	1.1	2.1	2.6	1.7	1.0	1.0	1.2	2.5
70	2.1	2.0	0.9	0.6	0.8	1.4	1.2	0.9	0.7	0.8	0.8	1.4
60	1.4	1.2	0.7	0.3	0.3	0.8	0.7	0.4	0.4	0.5	0.5	0.9
50	0.7	0.5	0.3	0.2	0.2	0.5	0.5	0.3	0.3	0.4	0.4	0.6
40	0.6	0.4	0.3	0.2	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.4
30	0.4	0.3	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3
20	0.3	0.3	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3
10	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1

Table 7.3 Summary of the monthly flow distribution (in m^3/s) for Scenario 2 (refer to Table 3.1 for colour coding of abiotic states)

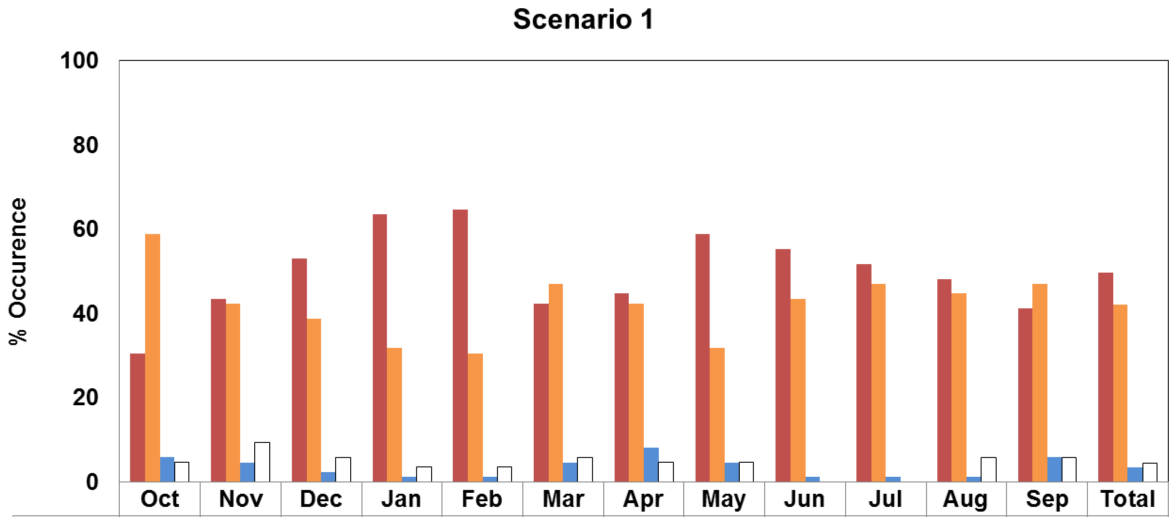
%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	6.9	16.7	12.6	10.3	7.8	8.3	11.0	10.0	5.5	4.3	10.1	10.4
99	6.0	16.5	9.6	7.4	6.5	7.2	8.1	9.4	4.0	2.3	9.8	7.9
90	3.4	5.0	2.6	1.2	1.2	4.0	4.3	2.2	0.9	0.8	2.0	3.7
80	2.3	2.1	0.9	0.6	0.5	1.7	1.3	1.0	0.5	0.6	0.8	1.8
70	1.5	1.3	0.5	0.3	0.3	0.8	0.7	0.6	0.4	0.4	0.5	0.9
60	0.7	0.7	0.3	0.1	0.1	0.4	0.4	0.3	0.2	0.3	0.3	0.6
50	0.4	0.3	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3
40	0.3	0.3	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.2
30	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
20	0.2	0.2	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
10	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1

Table 7.4 Summary of the monthly flow distribution (in m^3/s) for Scenario 3 (refer to Table 3.1 for colour coding of abiotic states)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	6.7	16.5	12.3	9.3	7.6	6.6	11.1	10.1	5.3	1.7	10.1	10.1
99	5.6	13.1	8.2	7.2	6.2	6.6	8.0	9.4	3.8	1.4	9.5	7.7
90	3.1	4.8	2.4	0.8	0.9	3.3	3.8	1.9	0.8	0.7	1.6	3.6
80	1.9	2.0	0.6	0.4	0.3	1.3	1.2	0.8	0.4	0.5	0.7	1.5
70	1.1	0.8	0.3	0.2	0.2	0.3	0.5	0.3	0.2	0.3	0.3	0.7
60	0.6	0.3	0.2	0.0	0.1	0.2	0.3	0.2	0.2	0.2	0.2	0.3
50	0.3	0.2	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
40	0.2	0.2	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
30	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
20	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	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
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

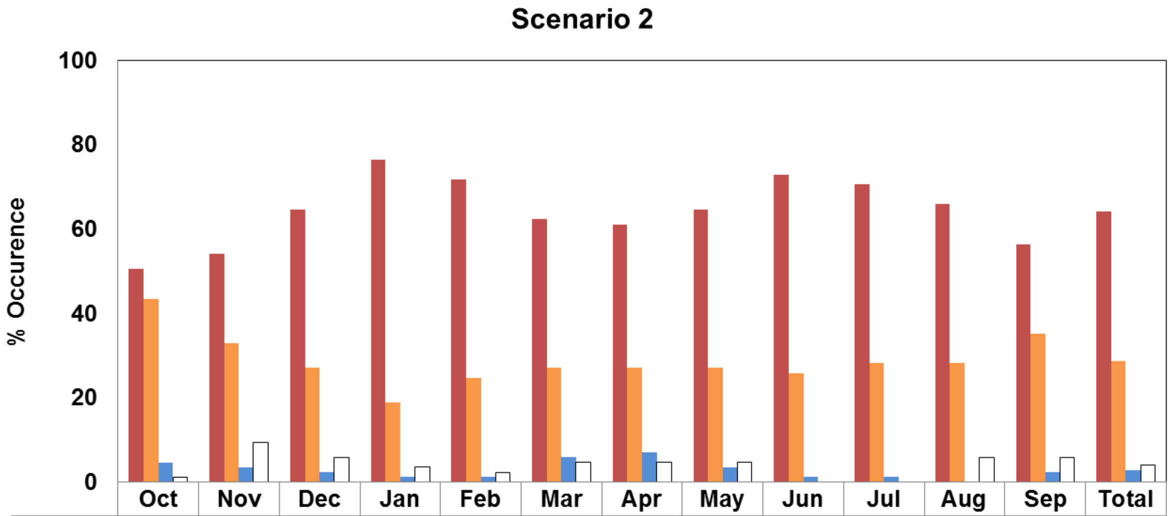
Table 7.5 Summary of the monthly flow distribution (in m^3/s) for Scenario 4 (refer to Table 3.1 for colour coding of abiotic states)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	6.5	15.0	12.1	6.5	7.4	5.7	10.4	9.0	5.1	1.3	9.9	8.7
99	5.3	11.0	7.6	6.0	6.0	5.2	7.7	8.8	3.6	0.8	9.2	7.3
90	2.1	3.1	1.8	0.6	0.6	2.5	3.2	1.7	0.6	0.5	0.8	2.8
80	1.1	1.3	0.5	0.3	0.3	0.7	0.9	0.7	0.4	0.3	0.4	0.9
70	0.8	0.7	0.3	0.2	0.1	0.3	0.4	0.3	0.2	0.3	0.3	0.5
60	0.4	0.3	0.2	0.0	0.1	0.2	0.3	0.2	0.2	0.2	0.2	0.2
50	0.3	0.2	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2
40	0.2	0.2	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
30	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
20	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	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
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



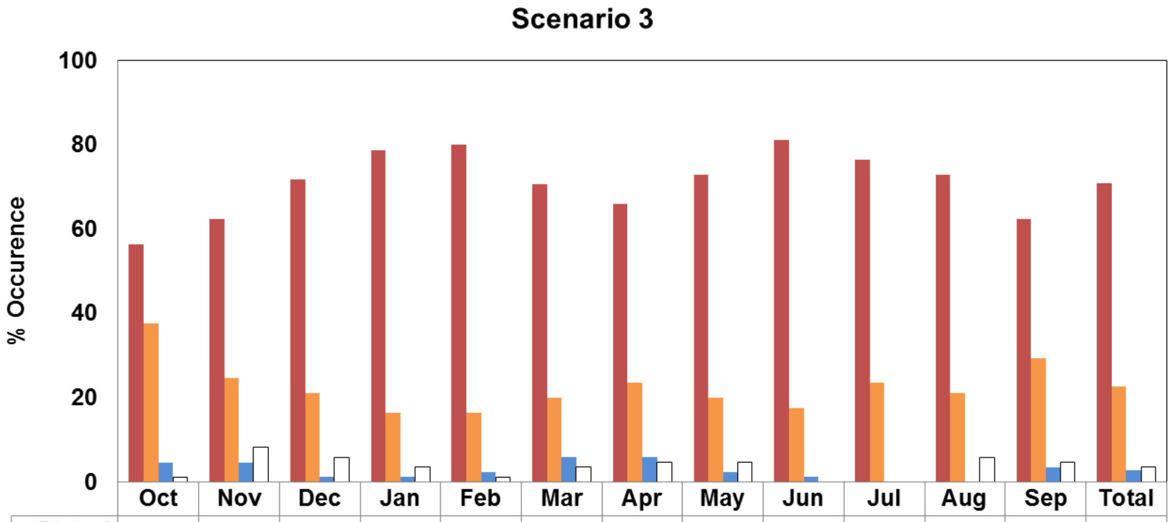
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	31	44	53	64	65	42	45	59	55	52	48	41	50
State 2	59	42	39	32	31	47	42	32	44	47	45	47	42
State 3	6	5	2	1	1	5	8	5	1	1	1	6	4
State 4	5	9	6	4	4	6	5	5	0	0	6	6	5

Figure 7.1 **Occurrence of abiotic states under the Scenario 1 (refer to Table 3.1 for colour coding of abiotic states)**



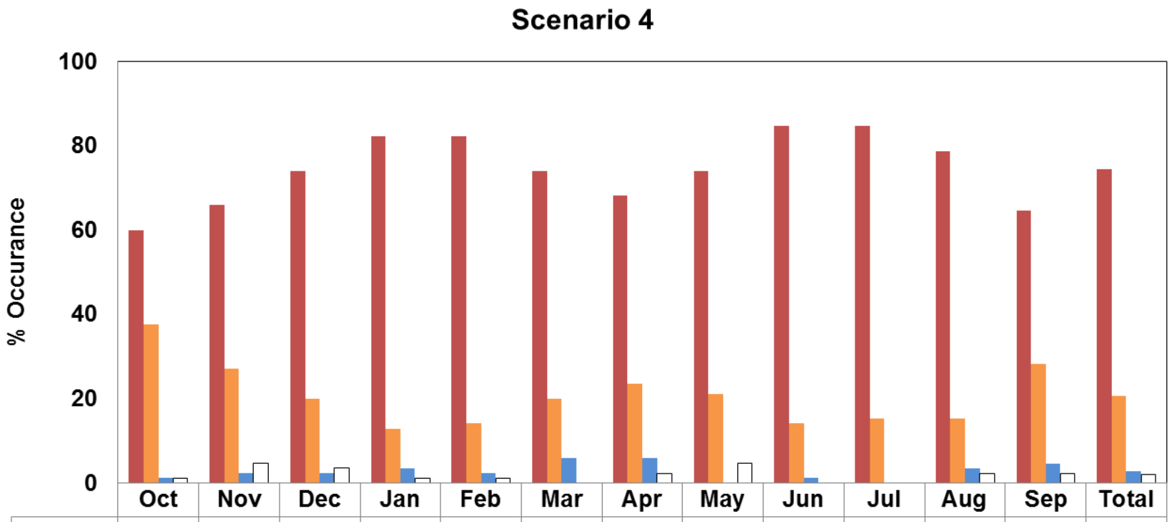
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	51	54	65	76	72	62	61	65	73	71	66	56	64
State 2	44	33	27	19	25	27	27	27	26	28	28	35	29
State 3	5	4	2	1	1	6	7	4	1	1	0	2	3
State 4	1	9	6	4	2	5	5	5	0	0	6	6	4

Figure 7.2 **Occurrence of abiotic states under the Scenario 2 (refer to Table 3.1 for colour coding of abiotic states)**



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	56	62	72	79	80	71	66	73	81	76	73	62	71
State 2	38	25	21	16	16	20	24	20	18	24	21	29	23
State 3	5	5	1	1	2	6	6	2	1	0	0	4	3
State 4	1	8	6	4	1	4	5	5	0	0	6	5	4

Figure 7.3 Occurrence of abiotic states under the Scenario 3 (refer to Table 3.1 for colour coding of abiotic states)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	60	66	74	82	82	74	68	74	85	85	79	65	75
State 2	38	27	20	13	14	20	24	21	14	15	15	28	21
State 3	1	2	2	4	2	6	6	0	1	0	4	5	3
State 4	1	5	4	1	1	0	2	5	0	0	2	2	2

Figure 7.4 Occurrence of abiotic states under the Scenario 4 (refer to Table 3.1 for colour coding of abiotic states)

Table 7.6 Simulated monthly flows (in m³/s) for Scenario 1 (refer to Table 3.1 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.3	0.2	0.9	0.4	3.2	2.0	2.9	1.7	0.8	0.8	1.1	1.1
1921	0.3	0.2	2.3	1.7	0.8	1.8	0.8	0.4	0.2	1.3	0.5	0.2
1922	0.2	3.7	0.8	0.1	0.1	0.1	0.6	0.4	0.9	0.4	0.3	0.2
1923	0.2	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.8	0.8
1924	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	4.5
1925	2.0	0.3	0.9	0.1	0.0	0.1	0.2	0.2	0.2	0.3	0.3	0.3
1926	2.1	3.0	0.4	0.1	0.1	0.5	0.2	0.2	0.2	0.2	0.3	0.3
1927	0.1	0.1	0.1	0.0	0.0	3.8	2.1	0.1	0.1	0.1	0.2	0.7
1928	0.4	18.2	13.0	1.1	0.1	0.1	0.1	0.2	0.3	1.3	1.2	2.5
1929	1.0	0.3	1.4	0.3	0.5	0.5	0.2	0.6	0.5	0.3	0.4	0.5
1930	0.5	0.3	0.1	0.8	0.2	0.3	0.9	0.4	0.1	0.2	0.2	0.2
1931	0.5	0.3	12.2	6.5	1.0	0.4	0.1	0.1	0.2	0.2	0.2	12.3
1932	7.2	0.7	0.2	0.1	0.1	0.1	0.1	0.3	0.3	0.2	2.2	1.3
1933	0.2	2.2	0.9	1.0	0.8	1.2	0.3	0.1	0.0	1.0	1.6	1.0
1934	3.5	4.5	0.8	0.1	0.1	0.1	0.4	5.0	3.4	1.0	0.5	3.5
1935	1.7	0.4	0.2	0.1	0.1	0.1	0.1	0.2	0.2	1.2	0.5	0.3
1936	1.1	2.4	1.8	0.4	0.1	2.5	1.0	0.1	0.1	0.2	0.1	0.7
1937	0.6	0.3	1.1	0.3	0.1	0.5	0.5	0.3	0.2	0.2	0.1	0.2
1938	0.7	0.7	0.4	0.1	2.8	10.4	4.7	0.3	0.1	0.9	2.6	2.2
1939	0.6	0.3	0.1	0.2	7.7	4.6	0.9	0.3	0.2	0.2	0.1	0.2
1940	0.2	0.5	0.3	0.2	0.2	0.1	4.1	2.2	0.4	0.4	0.3	0.4
1941	3.8	1.7	0.2	1.3	0.4	0.3	0.2	0.4	0.3	0.2	0.1	0.1
1942	0.2	0.2	0.6	1.8	0.9	0.5	0.6	0.2	0.1	0.1	0.2	3.5
1943	2.4	6.0	3.0	0.2	0.1	1.1	0.4	0.9	0.6	2.1	0.9	2.4
1944	1.4	0.4	0.1	0.0	0.1	0.1	0.1	1.0	1.9	0.8	0.4	0.5
1945	2.0	0.7	0.1	0.1	0.1	5.9	3.4	0.1	0.1	0.1	0.1	0.1
1946	0.2	0.1	0.0	0.0	0.1	9.0	5.3	0.4	0.3	0.8	0.5	1.0
1947	0.6	0.3	0.2	1.8	0.9	0.7	1.9	0.6	0.2	0.2	0.1	0.3
1948	3.3	1.7	0.1	0.1	0.1	0.0	0.2	2.2	1.0	0.2	0.2	0.9
1949	0.4	9.5	4.5	0.1	0.0	0.0	0.1	0.1	0.1	0.5	0.4	0.3
1950	3.4	8.4	3.6	6.9	3.4	0.3	0.2	0.1	0.2	1.4	0.9	1.4
1951	0.6	0.2	0.1	1.1	1.1	0.2	0.2	0.2	0.2	0.1	0.3	4.5
1952	2.3	0.5	0.3	0.1	0.1	0.1	0.3	0.2	0.4	2.2	1.8	1.8
1953	4.3	2.5	0.3	0.1	0.0	0.5	0.8	5.5	3.7	1.2	9.7	6.2
1954	0.5	2.3	0.9	3.1	6.1	2.3	0.2	0.2	0.3	0.3	0.3	0.6
1955	0.7	1.2	0.3	0.1	0.2	1.6	0.9	0.9	0.6	0.4	0.3	0.3
1956	1.5	0.6	1.5	0.5	1.8	2.4	0.5	0.3	1.3	0.9	0.8	3.6
1957	1.7	0.4	0.1	0.1	0.0	1.4	0.7	4.9	3.3	0.4	0.4	0.4
1958	0.3	0.2	0.4	2.3	1.3	4.1	5.3	2.4	0.4	1.2	1.8	1.0
1959	5.4	3.1	0.3	0.6	0.2	1.9	1.4	1.0	0.7	0.4	0.2	0.3
1960	0.3	1.6	1.7	0.5	0.8	5.2	6.2	2.3	0.5	0.3	0.3	0.4
1961	0.5	0.3	0.1	0.2	0.3	1.3	0.9	0.3	0.2	0.2	11.5	7.7
1962	3.6	3.4	0.6	0.4	0.2	7.5	4.6	0.3	0.3	0.5	0.4	0.2
1963	0.2	0.2	0.8	1.5	0.3	0.2	0.2	0.1	1.7	0.8	0.8	7.6
1964	3.7	0.4	0.2	0.1	0.2	1.1	0.6	2.1	1.0	0.4	0.3	0.2
1965	4.2	7.8	2.6	1.1	0.2	0.1	0.2	0.6	0.4	0.2	2.4	1.9
1966	0.3	0.1	0.1	0.1	1.7	3.2	11.2	9.3	2.3	1.1	0.6	1.7
1967	0.6	0.4	0.2	0.0	0.0	0.4	0.3	0.2	2.0	1.0	0.4	0.4
1968	0.3	2.2	0.6	0.1	0.1	0.1	0.2	0.1	1.1	0.6	0.3	0.2
1969	0.3	0.2	0.1	0.1	0.6	0.2	0.0	0.0	0.1	0.1	0.7	0.6
1970	0.9	0.4	0.3	0.2	1.5	0.8	1.4	2.0	1.1	5.2	6.8	2.5
1971	0.5	1.5	0.5	0.1	1.6	1.1	0.3	0.3	0.5	0.6	0.6	0.5
1972	0.3	0.1	0.1	0.3	0.1	0.1	0.4	0.3	1.4	0.8	0.3	0.3
1973	0.2	0.5	0.3	1.3	2.2	1.4	0.3	1.2	0.7	0.2	0.2	0.4
1974	0.3	0.3	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.5	1.5	4.0
1975	1.8	1.1	0.7	0.2	0.3	1.6	0.6	0.3	0.4	0.5	0.3	0.3
1976	3.4	2.2	0.3	0.1	4.4	2.1	0.2	10.0	5.8	0.5	0.3	1.2
1977	0.6	1.3	0.9	0.2	0.1	0.1	0.5	0.3	0.2	0.3	0.2	0.3
1978	1.1	2.1	0.8	0.2	0.2	0.1	0.1	0.3	0.4	2.6	1.8	2.0
1979	0.6	0.3	0.2	0.2	0.1	0.0	0.3	0.2	0.3	0.3	0.3	0.9
1980	2.2	3.3	1.3	10.5	8.1	3.7	7.4	8.3	3.0	0.9	9.0	5.6
1981	0.8	0.4	0.3	0.2	0.3	0.6	8.1	4.8	0.8	0.8	0.5	3.8
1982	2.1	0.4	0.1	0.1	0.1	0.1	0.1	0.3	1.2	3.2	1.5	1.4
1983	2.2	1.3	0.3	0.1	0.1	1.0	0.5	0.2	0.2	1.4	0.6	0.2
1984	0.5	0.4	0.2	2.0	3.2	0.7	1.3	0.6	0.3	1.1	0.6	0.3
1985	3.1	2.9	2.5	0.9	0.1	0.1	0.1	0.1	0.1	0.2	9.8	6.6
1986	3.3	1.6	0.2	0.1	0.1	0.1	2.8	1.2	0.2	0.2	0.2	2.9
1987	1.1	0.2	0.2	0.1	0.1	0.1	0.3	0.3	0.2	0.2	0.5	0.5
1988	0.2	0.1	0.2	0.1	0.1	0.2	3.1	1.3	0.2	0.2	0.2	0.2
1989	6.0	7.6	1.2	0.1	1.4	0.7	1.4	1.1	0.9	0.5	0.3	0.2
1990	0.4	0.3	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2
1991	7.5	4.4	0.7	0.5	0.8	0.7	0.3	0.2	0.6	1.5	0.8	0.4
1992	4.9	5.5	1.0	0.1	0.2	0.2	2.6	2.4	0.6	0.3	0.2	6.0
1993	3.2	0.3	2.0	0.9	0.2	0.4	0.6	0.3	0.3	0.5	2.6	1.7
1994	0.4	0.3	7.0	3.6	0.7	2.3	2.7	1.8	0.7	0.3	0.2	0.2
1995	0.2	9.6	7.1	1.4	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1996	6.0	16.7	6.6	0.1	0.1	0.6	0.7	1.1	0.9	0.8	0.8	0.6
1997	2.1	0.9	0.2	0.8	0.4	2.5	1.6	0.5	0.3	0.4	0.4	0.3
1998	0.2	0.4	2.3	3.1	2.0	1.5	0.5	0.2	0.2	0.2	0.2	0.4
1999	2.9	1.3	0.2	2.0	0.9	6.5	4.0	0.2	0.2	0.2	0.1	0.2
2000	0.2	0.8	1.2	0.3	0.1	1.6	5.0	2.3	0.2	0.2	0.5	0.6
2001	1.7	4.2	1.2	0.2	0.2	0.1	0.1	0.4	0.4	1.1	4.1	4.0
2002	0.9	0.3	0.1	0.2	0.2	8.0	5.8	6.1	3.4	0.6	0.4	0.4
2003	0.6	0.4	0.1	0.2	0.2	0.2	1.7	0.9	0.3	0.3	1.7	1.0
2004	5.5	2.4	4.1	4.8	1.5	0.5	0.5	0.4	0.7	1.3	0.6	0.3

Table 7.7 Simulated monthly flows (in m^3/s) for Scenario 2 (refer to Table 3.1 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.3	0.2	0.9	0.4	3.2	2.0	2.9	1.7	0.8	0.8	1.1	1.1
1921	0.3	0.2	2.3	1.7	0.8	1.8	0.8	0.4	0.2	1.3	0.5	0.2
1922	0.2	3.7	0.8	0.1	0.1	0.1	0.6	0.4	0.9	0.4	0.3	0.2
1923	0.2	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.8	0.8
1924	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	4.5
1925	2.0	0.3	0.9	0.1	0.0	0.1	0.2	0.2	0.2	0.3	0.3	0.3
1926	2.1	3.0	0.4	0.1	0.1	0.5	0.2	0.2	0.2	0.2	0.3	0.3
1927	0.1	0.1	0.1	0.0	0.0	3.8	2.1	0.1	0.1	0.1	0.2	0.7
1928	0.4	18.2	13.0	1.1	0.1	0.1	0.1	0.2	0.3	1.3	1.2	2.5
1929	1.0	0.3	1.4	0.3	0.5	0.5	0.2	0.6	0.5	0.3	0.4	0.5
1930	0.5	0.3	0.1	0.8	0.2	0.3	0.9	0.4	0.1	0.2	0.2	0.2
1931	0.5	0.3	12.2	6.5	1.0	0.4	0.1	0.1	0.2	0.2	0.2	12.3
1932	7.2	0.7	0.2	0.1	0.1	0.1	0.1	0.3	0.3	0.2	2.2	1.3
1933	0.2	2.2	0.9	1.0	0.8	1.2	0.3	0.1	0.0	1.0	1.6	1.0
1934	3.5	4.5	0.8	0.1	0.1	0.1	0.4	5.0	3.4	1.0	0.5	3.5
1935	1.7	0.4	0.2	0.1	0.1	0.1	0.1	0.2	0.2	1.2	0.5	0.3
1936	1.1	2.4	1.8	0.4	0.1	2.5	1.0	0.1	0.1	0.2	0.1	0.7
1937	0.6	0.3	1.1	0.3	0.1	0.5	0.5	0.3	0.2	0.2	0.1	0.2
1938	0.7	0.7	0.4	0.1	2.8	10.4	4.7	0.3	0.1	0.9	2.6	2.2
1939	0.6	0.3	0.1	0.2	7.7	4.6	0.9	0.3	0.2	0.2	0.1	0.2
1940	0.2	0.5	0.3	0.2	0.2	0.1	4.1	2.2	0.4	0.4	0.3	0.4
1941	3.8	1.7	0.2	1.3	0.4	0.3	0.2	0.4	0.3	0.2	0.1	0.1
1942	0.2	0.2	0.6	1.8	0.9	0.5	0.6	0.2	0.1	0.1	0.2	3.5
1943	2.4	6.0	3.0	0.2	0.1	1.1	0.4	0.9	0.6	2.1	0.9	2.4
1944	1.4	0.4	0.1	0.0	0.1	0.1	0.1	1.0	1.9	0.8	0.4	0.5
1945	2.0	0.7	0.1	0.1	0.1	5.9	3.4	0.1	0.1	0.1	0.1	0.1
1946	0.2	0.1	0.0	0.0	0.1	9.0	5.3	0.4	0.3	0.8	0.5	1.0
1947	0.6	0.3	0.2	1.8	0.9	0.7	1.9	0.6	0.2	0.2	0.1	0.3
1948	3.3	1.7	0.1	0.1	0.1	0.0	0.2	2.2	1.0	0.2	0.2	0.9
1949	0.4	9.5	4.5	0.1	0.0	0.0	0.1	0.1	0.1	0.5	0.4	0.3
1950	3.4	8.4	3.6	6.9	3.4	0.3	0.2	0.1	0.2	1.4	0.9	1.4
1951	0.6	0.2	0.1	1.1	1.1	0.2	0.2	0.2	0.2	0.1	0.3	4.5
1952	2.3	0.5	0.3	0.1	0.1	0.1	0.3	0.2	0.4	2.2	1.8	1.8
1953	4.3	2.5	0.3	0.1	0.0	0.5	0.8	5.5	3.7	1.2	9.7	6.2
1954	0.5	2.3	0.9	3.1	6.1	2.3	0.2	0.2	0.3	0.3	0.3	0.6
1955	0.7	1.2	0.3	0.1	0.2	1.6	0.9	0.9	0.6	0.4	0.3	0.3
1956	1.5	0.6	1.5	0.5	1.8	2.4	0.5	0.3	1.3	0.9	0.8	3.6
1957	1.7	0.4	0.1	0.1	0.0	1.4	0.7	4.9	3.3	0.4	0.4	0.4
1958	0.3	0.2	0.4	2.3	1.3	4.1	5.3	2.4	0.4	1.2	1.8	1.0
1959	5.4	3.1	0.3	0.6	0.2	1.9	1.4	1.0	0.7	0.4	0.2	0.3
1960	0.3	1.6	1.7	0.5	0.8	5.2	6.2	2.3	0.5	0.3	0.3	0.4
1961	0.5	0.3	0.1	0.2	0.3	1.3	0.9	0.3	0.2	0.2	11.5	7.7
1962	3.6	3.4	0.6	0.4	0.2	7.5	4.6	0.3	0.3	0.5	0.4	0.2
1963	0.2	0.2	0.8	1.5	0.3	0.2	0.2	0.1	1.7	0.8	0.8	7.6
1964	3.7	0.4	0.2	0.1	0.2	1.1	0.6	2.1	1.0	0.4	0.3	0.2
1965	4.2	7.8	2.6	1.1	0.2	0.1	0.2	0.6	0.4	0.2	2.4	1.9
1966	0.3	0.1	0.1	0.1	1.7	3.2	11.2	9.3	2.3	1.1	0.6	1.7
1967	0.6	0.4	0.2	0.0	0.0	0.4	0.3	0.2	2.0	1.0	0.4	0.4
1968	0.3	2.2	0.6	0.1	0.1	0.1	0.2	0.1	1.1	0.6	0.3	0.2
1969	0.3	0.2	0.1	0.1	0.6	0.2	0.0	0.0	0.1	0.1	0.7	0.6
1970	0.9	0.4	0.3	0.2	1.5	0.8	1.4	2.0	1.1	5.2	6.8	2.5
1971	0.5	1.5	0.5	0.1	1.6	1.1	0.3	0.3	0.5	0.6	0.6	0.5
1972	0.3	0.1	0.1	0.3	0.1	0.1	0.4	0.3	1.4	0.8	0.3	0.3
1973	0.2	0.5	0.3	1.3	2.2	1.4	0.3	1.2	0.7	0.2	0.2	0.4
1974	0.3	0.3	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.5	1.5	4.0
1975	1.8	1.1	0.7	0.2	0.3	1.6	0.6	0.3	0.4	0.5	0.3	0.3
1976	3.4	2.2	0.3	0.1	4.4	2.1	0.2	10.0	5.8	0.5	0.3	1.2
1977	0.6	1.3	0.9	0.2	0.1	0.1	0.5	0.3	0.2	0.3	0.2	0.3
1978	1.1	2.1	0.8	0.2	0.2	0.1	0.1	0.3	0.4	2.6	1.8	2.0
1979	0.6	0.3	0.2	0.2	0.1	0.0	0.3	0.2	0.3	0.3	0.3	0.9
1980	2.2	3.3	1.3	10.5	8.1	3.7	7.4	8.3	3.0	0.9	9.0	5.6
1981	0.8	0.4	0.3	0.2	0.3	0.6	8.1	4.8	0.8	0.8	0.5	3.8
1982	2.1	0.4	0.1	0.1	0.1	0.1	0.1	0.3	1.2	3.2	1.5	1.4
1983	2.2	1.3	0.3	0.1	0.1	1.0	0.5	0.2	0.2	1.4	0.6	0.2
1984	0.5	0.4	0.2	2.0	3.2	0.7	1.3	0.6	0.3	1.1	0.6	0.3
1985	3.1	2.9	2.5	0.9	0.1	0.1	0.1	0.1	0.1	0.2	9.8	6.6
1986	3.3	1.6	0.2	0.1	0.1	0.1	2.8	1.2	0.2	0.2	0.2	2.9
1987	1.1	0.2	0.2	0.1	0.1	0.1	0.3	0.3	0.2	0.2	0.5	0.5
1988	0.2	0.1	0.2	0.1	0.1	0.2	3.1	1.3	0.2	0.2	0.2	0.2
1989	6.0	7.6	1.2	0.1	1.4	0.7	1.4	1.1	0.9	0.5	0.3	0.2
1990	0.4	0.3	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2
1991	7.5	4.4	0.7	0.5	0.8	0.7	0.3	0.2	0.6	1.5	0.8	0.4
1992	4.9	5.5	1.0	0.1	0.2	0.2	2.6	2.4	0.6	0.3	0.2	6.0
1993	3.2	0.3	2.0	0.9	0.2	0.4	0.6	0.3	0.3	0.5	2.6	1.7
1994	0.4	0.3	7.0	3.6	0.7	2.3	2.7	1.8	0.7	0.3	0.2	0.2
1995	0.2	9.6	7.1	1.4	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1996	6.0	16.7	6.6	0.1	0.1	0.6	0.7	1.1	0.9	0.8	0.8	0.6
1997	2.1	0.9	0.2	0.8	0.4	2.5	1.6	0.5	0.3	0.4	0.4	0.3
1998	0.2	0.4	2.3	3.1	2.0	1.5	0.5	0.2	0.2	0.2	0.2	0.4
1999	2.9	1.3	0.2	2.0	0.9	6.5	4.0	0.2	0.2	0.2	0.1	0.2
2000	0.2	0.8	1.2	0.3	0.1	1.6	5.0	2.3	0.2	0.2	0.5	0.6
2001	1.7	4.2	1.2	0.2	0.2	0.1	0.1	0.4	0.4	1.1	4.1	4.0
2002	0.9	0.3	0.1	0.2	0.2	8.0	5.8	6.1	3.4	0.6	0.4	0.4
2003	0.6	0.4	0.1	0.2	0.2	0.2	1.7	0.9	0.3	0.3	1.7	1.0
2004	5.5	2.4	4.1	4.8	1.5	0.5	0.5	0.4	0.7	1.3	0.6	0.3

Table 7.8 Simulated monthly flows (in m^3/s) for Scenario 3 (refer to Table 3.1 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.1	0.0	0.2	0.2	1.7	1.5	2.8	1.4	0.6	0.6	0.7	0.7
1921	0.1	0.0	1.2	1.3	0.3	1.6	0.5	0.2	0.0	0.9	0.1	0.0
1922	0.0	2.7	0.1	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.1	0.0
1923	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.5
1924	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1925	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
1926	0.6	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1
1927	0.0	0.0	0.0	0.0	0.0	0.9	1.0	0.0	0.0	0.0	0.0	0.1
1928	0.1	12.3	12.8	0.6	0.0	0.0	0.0	0.0	0.1	0.3	0.5	1.6
1929	0.5	0.1	0.4	0.1	0.4	0.4	0.0	0.2	0.2	0.1	0.1	0.1
1930	0.2	0.1	0.0	0.0	0.0	0.2	0.5	0.3	0.0	0.0	0.0	0.0
1931	0.1	0.1	7.4	6.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0	10.4
1932	6.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.5	0.6
1933	0.1	0.6	0.6	0.2	0.3	0.7	0.1	0.0	0.0	0.2	0.9	0.7
1934	3.4	4.4	0.4	0.0	0.0	0.0	0.0	3.2	3.2	0.5	0.2	3.3
1935	1.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
1936	0.2	1.0	1.0	0.2	0.0	0.4	0.5	0.0	0.0	0.0	0.0	0.1
1937	0.1	0.0	0.1	0.1	0.0	0.1	0.3	0.1	0.0	0.0	0.0	0.0
1938	0.1	0.3	0.2	0.0	0.7	6.5	4.3	0.1	0.0	0.2	2.0	1.9
1939	0.3	0.1	0.0	0.0	5.8	4.4	0.3	0.1	0.1	0.0	0.0	0.0
1940	0.0	0.2	0.2	0.0	0.0	0.0	0.9	1.0	0.2	0.2	0.2	0.2
1941	1.8	1.0	0.0	0.3	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0
1942	0.0	0.0	0.1	0.6	0.6	0.1	0.1	0.0	0.0	0.0	0.0	0.8
1943	1.0	5.8	2.5	0.0	0.0	0.0	0.1	0.2	0.3	1.7	0.7	2.2
1944	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.8	0.4	0.2	0.2
1945	0.5	0.4	0.0	0.0	0.0	2.9	2.7	0.0	0.0	0.0	0.0	0.0
1946	0.0	0.0	0.0	0.0	0.0	4.1	4.9	0.1	0.1	0.3	0.3	0.4
1947	0.2	0.1	0.0	0.5	0.5	0.1	1.6	0.3	0.0	0.0	0.0	0.0
1948	1.5	1.2	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.1
1949	0.1	7.9	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
1950	0.8	7.7	3.3	6.8	2.9	0.0	0.0	0.0	0.0	0.3	0.4	0.7
1951	0.4	0.0	0.0	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.2	1.5
1952	1.8	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.9	1.0
1953	4.3	2.2	0.1	0.0	0.0	0.1	0.3	4.2	3.5	0.8	10.2	5.9
1954	0.3	1.7	0.4	2.8	5.9	1.6	0.0	0.0	0.0	0.1	0.1	0.1
1955	0.2	0.3	0.1	0.0	0.0	0.3	0.4	0.3	0.4	0.2	0.2	0.1
1956	0.3	0.3	0.3	0.3	0.6	2.1	0.2	0.1	0.9	0.5	0.7	3.5
1957	1.2	0.2	0.0	0.0	0.0	0.2	0.3	3.6	2.8	0.2	0.2	0.2
1958	0.1	0.0	0.0	0.6	0.7	4.2	5.2	1.9	0.2	0.6	1.9	0.6
1959	5.4	2.3	0.1	0.1	0.0	0.8	1.2	0.8	0.4	0.2	0.1	0.1
1960	0.1	0.3	0.9	0.2	0.2	5.1	6.1	1.9	0.3	0.1	0.1	0.1
1961	0.1	0.1	0.0	0.0	0.1	0.3	0.3	0.1	0.0	0.0	8.8	7.2
1962	3.6	3.2	0.4	0.0	0.0	6.6	4.1	0.1	0.1	0.2	0.2	0.0
1963	0.0	0.0	0.2	0.3	0.1	0.0	0.0	0.0	0.4	0.4	0.2	6.3
1964	3.1	0.2	0.0	0.0	0.0	0.2	0.2	0.7	0.6	0.1	0.1	0.1
1965	3.2	7.9	2.1	0.6	0.0	0.0	0.0	0.2	0.2	0.0	0.9	1.5
1966	0.2	0.0	0.0	0.0	0.1	1.9	11.4	9.2	1.8	0.8	0.3	1.5
1967	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.5	0.1	0.1
1968	0.1	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.0
1969	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.2
1970	0.2	0.2	0.0	0.0	0.3	0.3	0.4	0.9	0.7	1.4	6.7	2.0
1971	0.3	0.6	0.3	0.0	0.2	0.6	0.1	0.1	0.1	0.1	0.2	0.2
1972	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1
1973	0.0	0.1	0.1	0.2	0.4	0.3	0.1	0.3	0.3	0.0	0.1	0.1
1974	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	1.3
1975	1.2	0.3	0.2	0.0	0.0	0.3	0.2	0.1	0.1	0.2	0.1	0.1
1976	2.6	1.9	0.2	0.0	2.9	1.5	0.1	10.1	5.5	0.2	0.1	0.4
1977	0.2	0.8	0.5	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1
1978	0.1	0.4	0.3	0.0	0.0	0.0	0.0	0.2	0.2	0.6	1.0	1.8
1979	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4
1980	1.1	1.3	0.6	9.5	7.8	3.6	7.4	8.4	2.7	0.4	9.4	5.2
1981	0.5	0.2	0.1	0.0	0.0	0.1	7.0	4.2	0.6	0.5	0.2	3.6
1982	1.7	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.7	0.9	1.2
1983	2.1	0.8	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.3	0.0
1984	0.1	0.1	0.0	0.6	1.2	0.3	0.9	0.3	0.1	0.7	0.3	0.1
1985	2.3	2.6	2.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	7.0	6.2
1986	3.2	1.0	0.0	0.0	0.0	0.0	0.6	0.7	0.0	0.0	0.0	1.2
1987	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1
1988	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.0	0.0	0.0	0.0
1989	2.1	6.2	0.5	0.0	0.2	0.3	1.2	0.9	0.7	0.3	0.1	0.1
1990	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	2.4	3.0	0.3	0.1	0.3	0.3	0.2	0.0	0.1	0.9	0.6	0.2
1992	4.7	5.1	0.8	0.0	0.0	0.0	1.0	2.0	0.2	0.1	0.1	5.3
1993	2.5	0.1	1.0	0.5	0.0	0.1	0.1	0.1	0.1	0.1	2.1	1.3
1994	0.2	0.1	6.2	3.2	0.1	1.9	2.7	1.6	0.3	0.1	0.1	0.0
1995	0.0	7.8	6.8	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	2.4	16.8	6.2	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.7	0.3
1997	1.6	0.4	0.0	0.2	0.2	1.3	1.3	0.4	0.1	0.1	0.2	0.1
1998	0.0	0.1	0.4	2.3	1.6	1.1	0.2	0.1	0.0	0.0	0.0	0.1
1999	1.1	0.7	0.0	0.8	0.3	6.5	3.3	0.0	0.0	0.0	0.0	0.0
2000	0.0	0.1	0.2	0.1	0.0	0.3	3.4	1.7	0.1	0.0	0.1	0.2
2001	0.8	4.1	0.6	0.0	0.0	0.0	0.0	0.1	0.2	0.3	2.5	3.8
2002	0.6	0.1	0.0	0.0	0.1	5.7	5.5	6.3	3.0	0.3	0.2	0.2
2003	0.3	0.2	0.0	0.0	0.0	0.0	0.6	0.6	0.1	0.1	0.2	0.2
2004	5.1	1.4	4.0	4.6	1.0	0.0	0.3	0.3	0.1	0.7	0.3	0.0

Table 7.9 Simulated monthly flows (in m³/s) for Scenario 4 (refer to Table 3.1 for colour coding of abiotic states)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.1	0.0	0.2	0.2	1.7	1.5	2.8	1.4	0.6	0.6	0.7	0.7
1921	0.1	0.0	1.2	1.3	0.3	1.6	0.5	0.2	0.0	0.9	0.1	0.0
1922	0.0	2.7	0.1	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.1	0.0
1923	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.5
1924	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1925	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
1926	0.6	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1
1927	0.0	0.0	0.0	0.0	0.0	0.9	1.0	0.0	0.0	0.0	0.0	0.1
1928	0.1	12.3	12.8	0.6	0.0	0.0	0.0	0.0	0.1	0.3	0.5	1.6
1929	0.5	0.1	0.4	0.1	0.4	0.4	0.0	0.2	0.2	0.1	0.1	0.1
1930	0.2	0.1	0.0	0.0	0.0	0.2	0.5	0.3	0.0	0.0	0.0	0.0
1931	0.1	0.1	7.4	6.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0	10.4
1932	6.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.5	0.6
1933	0.1	0.6	0.6	0.2	0.3	0.7	0.1	0.0	0.0	0.2	0.9	0.7
1934	3.4	4.4	0.4	0.0	0.0	0.0	0.0	3.2	3.2	0.5	0.2	3.3
1935	1.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
1936	0.2	1.0	1.0	0.2	0.0	0.4	0.5	0.0	0.0	0.0	0.0	0.1
1937	0.1	0.0	0.1	0.1	0.0	0.1	0.3	0.1	0.0	0.0	0.0	0.0
1938	0.1	0.3	0.2	0.0	0.7	6.5	4.3	0.1	0.0	0.2	2.0	1.9
1939	0.3	0.1	0.0	0.0	5.8	4.4	0.3	0.1	0.1	0.0	0.0	0.0
1940	0.0	0.2	0.2	0.0	0.0	0.0	0.9	1.0	0.2	0.2	0.2	0.2
1941	1.8	1.0	0.0	0.3	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0
1942	0.0	0.0	0.1	0.6	0.6	0.1	0.1	0.0	0.0	0.0	0.0	0.8
1943	1.0	5.8	2.5	0.0	0.0	0.0	0.1	0.2	0.3	1.7	0.7	2.2
1944	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.8	0.4	0.2	0.2
1945	0.5	0.4	0.0	0.0	0.0	2.9	2.7	0.0	0.0	0.0	0.0	0.0
1946	0.0	0.0	0.0	0.0	0.0	4.1	4.9	0.1	0.1	0.3	0.3	0.4
1947	0.2	0.1	0.0	0.5	0.5	0.1	1.6	0.3	0.0	0.0	0.0	0.0
1948	1.5	1.2	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.1
1949	0.1	7.9	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
1950	0.8	7.7	3.3	6.8	2.9	0.0	0.0	0.0	0.0	0.3	0.4	0.7
1951	0.4	0.0	0.0	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.2	1.5
1952	1.8	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.9	1.0
1953	4.3	2.2	0.1	0.0	0.0	0.1	0.3	4.2	3.5	0.8	10.2	5.9
1954	0.3	1.7	0.4	2.8	5.9	1.6	0.0	0.0	0.0	0.1	0.1	0.1
1955	0.2	0.3	0.1	0.0	0.0	0.3	0.4	0.3	0.4	0.2	0.2	0.1
1956	0.3	0.3	0.3	0.3	0.6	2.1	0.2	0.1	0.9	0.5	0.7	3.5
1957	1.2	0.2	0.0	0.0	0.0	0.2	0.3	3.6	2.8	0.2	0.2	0.2
1958	0.1	0.0	0.0	0.6	0.7	4.2	5.2	1.9	0.2	0.6	1.9	0.6
1959	5.4	2.3	0.1	0.1	0.0	0.8	1.2	0.8	0.4	0.2	0.1	0.1
1960	0.1	0.3	0.9	0.2	0.2	5.1	6.1	1.9	0.3	0.1	0.1	0.1
1961	0.1	0.1	0.0	0.0	0.1	0.3	0.3	0.1	0.0	0.0	8.8	7.2
1962	3.6	3.2	0.4	0.0	0.0	6.6	4.1	0.1	0.1	0.2	0.2	0.0
1963	0.0	0.0	0.2	0.3	0.1	0.0	0.0	0.0	0.4	0.4	0.2	6.3
1964	3.1	0.2	0.0	0.0	0.0	0.2	0.2	0.7	0.6	0.1	0.1	0.1
1965	3.2	7.9	2.1	0.6	0.0	0.0	0.0	0.2	0.2	0.0	0.9	1.5
1966	0.2	0.0	0.0	0.0	0.1	1.9	11.4	9.2	1.8	0.8	0.3	1.5
1967	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.5	0.1	0.1
1968	0.1	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.0
1969	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.2
1970	0.2	0.2	0.0	0.0	0.3	0.3	0.4	0.9	0.7	1.4	6.7	2.0
1971	0.3	0.6	0.3	0.0	0.2	0.6	0.1	0.1	0.1	0.1	0.2	0.2
1972	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1
1973	0.0	0.1	0.1	0.2	0.4	0.3	0.1	0.3	0.3	0.0	0.1	0.1
1974	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	1.3
1975	1.2	0.3	0.2	0.0	0.0	0.3	0.2	0.1	0.1	0.2	0.1	0.1
1976	2.6	1.9	0.2	0.0	2.9	1.5	0.1	10.1	5.5	0.2	0.1	0.4
1977	0.2	0.8	0.5	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1
1978	0.1	0.4	0.3	0.0	0.0	0.0	0.0	0.2	0.2	0.6	1.0	1.8
1979	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4
1980	1.1	1.3	0.6	9.5	7.8	3.6	7.4	8.4	2.7	0.4	9.4	5.2
1981	0.5	0.2	0.1	0.0	0.0	0.1	7.0	4.2	0.6	0.5	0.2	3.6
1982	1.7	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.7	0.9	1.2
1983	2.1	0.8	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.3	0.0
1984	0.1	0.1	0.0	0.6	1.2	0.3	0.9	0.3	0.1	0.7	0.3	0.1
1985	2.3	2.6	2.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	7.0	6.2
1986	3.2	1.0	0.0	0.0	0.0	0.0	0.6	0.7	0.0	0.0	0.0	1.2
1987	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1
1988	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.0	0.0	0.0	0.0
1989	2.1	6.2	0.5	0.0	0.2	0.3	1.2	0.9	0.7	0.3	0.1	0.1
1990	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	2.4	3.0	0.3	0.1	0.3	0.3	0.2	0.0	0.1	0.9	0.6	0.2
1992	4.7	5.1	0.8	0.0	0.0	0.0	1.0	2.0	0.2	0.1	0.1	5.3
1993	2.5	0.1	1.0	0.5	0.0	0.1	0.1	0.1	0.1	0.1	2.1	1.3
1994	0.2	0.1	6.2	3.2	0.1	1.9	2.7	1.6	0.3	0.1	0.1	0.0
1995	0.0	7.8	6.8	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	2.4	16.8	6.2	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.7	0.3
1997	1.6	0.4	0.0	0.2	0.2	1.3	1.3	0.4	0.1	0.1	0.2	0.1
1998	0.0	0.1	0.4	2.3	1.6	1.1	0.2	0.1	0.0	0.0	0.0	0.1
1999	1.1	0.7	0.0	0.8	0.3	6.5	3.3	0.0	0.0	0.0	0.0	0.0
2000	0.0	0.1	0.2	0.1	0.0	0.3	3.4	1.7	0.1	0.0	0.1	0.2
2001	0.8	4.1	0.6	0.0	0.0	0.0	0.0	0.1	0.2	0.3	2.5	3.8
2002	0.6	0.1	0.0	0.0	0.1	5.7	5.5	6.3	3.0	0.3	0.2	0.2
2003	0.3	0.2	0.0	0.0	0.0	0.0	0.6	0.6	0.1	0.1	0.2	0.2
2004	5.1	1.4	4.0	4.6	1.0	0.0	0.3	0.3	0.1	0.7	0.3	0.0

7.3 ABIOTIC COMPONENTS

7.3.1 Hydrology

7.3.1.1 Low flows

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

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

Percentile	Monthly flow (m^3/s)					
	Reference	Present	1	2	3	4
30%	0.4	0.1	0.2	0.1	0.0	0.0
20%	0.3	0.1	0.2	0.1	0.0	0.0
10%	0.2	0.1	0.1	0.1	0.0	0.0
% Similarity in low flows		32.2	57.4	30.7	5.6	5.5

Confidence: High

7.3.1.2 Flood regime

There are no large dams proposed under Scenario 1 for the Klein Brak catchment, i.e. floods are similar to Present State. While Scenarios 2 and 3 simulates a dam with a 10 million m^3 capacity and Scenario 4 a dam with a 20 million m^3 capacity. An evaluation of the 10 highest floods in the simulated data set show that floods are significantly transformed under Future Scenarios 2 to 4 (**Table 7.11**).

Table 7.11 Summary of the ten highest simulated monthly volumes to the Klein Brak 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
Nov 1928	50.7	47.2	47.11	42.6	32.0	26.4
Nov 1996	45.9	43.3	43.354	43.5	43.7	40.0
Dec 1928	37.8	34.6	34.863	34.6	34.2	33.7
Dec 1931	37.0	32.9	32.667	24.0	19.8	11.6
Sep 1932	35.7	32.4	31.961	27.8	26.9	23.0
Aug 1962	35.2	31.6	30.884	26.1	23.5	15.4
Apr 1967	32.2	30.2	29.106	29.5	29.6	27.7
Jan 1981	30.8	29.7	28.106	28.4	25.6	12.9

Date	Monthly volume (million m^3/month)					
	Natural	Present	1	2	3	4
Mar 1939	30.6	27.7	27.84	22.5	17.5	11.0
Aug 1986	30.3	26.5	26.361	20.5	18.8	14.6
% Similarity in floods		**91.7**	**90.5**	**81.2**	**73.8**	**58.0**

Confidence: Medium

A summary of the hydrology score 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	32	57	31	6	6	L
b. % Similarity in mean annual frequency of floods	40	92	91	81	74	58	L
Hydrology: weighted mean (a,b)		**56**	**71**	**51**	**33**	**27**	**L**

7.3.2 Physical habitats

A summary of the expected changes in the physical habitat of the Klein Brak Estuary under each of the future scenarios is provided in **Table 7.13**.

Table 7.13 Summary of physical habitat changes under different scenarios

Scenario	Parameter	Summary of changes
1	Supra-, inter- and sub-tidal area and sediments, as well as estuary bathymetry/water volume	Similar to Present.
2	a. Supratidal area and sediments	Slightly less (quantity & frequency) of silt deposition on floodplain during floods.
	b. Intertidal areas and sediments	The loss of resetting events (~20 % reduction in floods) would lead to reduced mobility and flushing of sediments in the estuary, and increased penetration of marine sediments.
	c. Subtidal area and sediments	The loss of resetting events (~20 % reduction in floods) would lead to reduced mobility and flushing of sediments in the estuary, and increased penetration of marine sediments.
	d. Estuary bathymetry/water volume	Volume slightly reduced on average due to increased build-up of marine sediment in lower estuary.

Scenario	Parameter	Summary of changes
3	Supra-, inter- and sub-tidal area and sediments, as well as estuary bathymetry/water volume	Same progressive impacts in all four “domains” (a to d above) as for Scenario 2, except that the magnitude and rate of change would be significantly increased (~ “50% increase” of the impacts) due to further reduction from ~20% to ~30 % in floods.
4	Supra-, inter- and sub-tidal area and sediments, as well as estuary bathymetry/water volume	Same progressive impacts in all four “domains” (a to d above) as for Scenarios 2 and 3, except that the magnitude and rate of change would be further increased (~ “doubling” of the impacts) due to further reduction from ~20% to ~40 % in floods.

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	60	60	55	50	45	L(1) VL(2-4)
b	Intertidal areas and sediments	54	54	49	44	39	L(1) VL(2-4)
c	Subtidal area and sediments	75	75	70	65	60	L(1) VL(2-4)
d	Estuary bathymetry/water volume	95	95	90	85	80	L(1) VL(2-4)
Physical habitat score: min (a to d)		**54**	**54**	**49**	**44**	**39**	**L**

7.3.3 Hydrodynamics and mouth condition

A summary of the changes in mouth conditions under the future scenarios are presented in **Table 7.15**.

Table 7.15 Summary of change in mouth conditions under the future scenarios

Scenario	Summary of changes
1	Similar to Present. Tidal amplitude estimated to be about 0.8 m on average.
2	The reduction in baseflows and the loss of resetting events (~20 % reduction in floods) would lead to ingress of marine sediment and more frequent mouth closure in winter. These closures would last weeks to months. The probability of closures occurring is about 2 to 4 times out of ten years. Tidal amplitude estimated to be about 0.7 m on average.

Scenario	Summary of changes
3	The reduction in baseflows and the loss of resetting events (~30 % reduction in floods) would lead to significant ingress of marine sediment and extended mouth closure in winter. These closures would last weeks to months. The probability of closures occurring increase to about 3 to 5 times out of ten years. Tidal amplitude estimated to be about 0.65 m on average.
4	The reduction in baseflows and the loss of resetting events (~40 % reduction in floods) would lead to significant ingress of marine sediment and extended mouth closure in winter. These closures would last months at a time. The probability of closures occurring increase to about every 2 out of three years. Tidal amplitude estimated to be about 0.6 m on average.

Table 7.16 provides a summary of the hydrodynamics and mouth condition scores for the Klein Brak Estuary.

Table 7.16 Hydrodynamic 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	90	80	60	VL
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	92	94	88	84	78	L
Hydrodynamics and mouth: weighted mean (a to d)			**96**	**97**	**89**	**82**	**69**	**L**

7.3.4 Water quality

Table 7.17 provides a summary of the occurrence of the various abiotic states under various flow scenarios as derived from the long-term simulated runoff data. These data, together with the weighted volume ratios of the various zones are used in the calculation of the scores for the water quality parameters.

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

Abiotic State	Natural	Present	Scenario			
			1	2	3	4
State 1: Marine dominated	30	54	50	64	71	75
State 2: Full salinity gradient	60	38	42	29	23	21
State 3: Limited gradient	4	3	4	3	3	3
State 4: Freshwater dominated	6	5	5	4	4	2

Estimated changes in water quality conditions in the various zones of the Klein Brak Estuary under Reference Condition, Present State and Future Scenarios is presented in **Table 7.18**, while a summary description of such changes in presented in **Table 7.19**.

Table 7.18 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: Lower reaches	0.25	30	31	31	32	33	33
B: Middle reaches	0.30	23	27	27	29	30	31
C: Brandwag lower	0.15	12	18	17	21	26	31
D: Brandwag upper	0.05	7	1	1	1	1	1
E: Moordkuil lower	0.20	18	22	21	24	28	33
F: Moordkuil upper	0.05	7	1	1	1	1	1

Zone	Volume weighting	Estimated DIN concentration (µg/ℓ) based on distribution of abiotic states					
		Reference	Present	Scn 1	Scn 2	Scn 3	Scn 4
A: Lower reaches	0.25	100	100	101	100	101	101
B: Middle reaches	0.30	100	123	127	118	116	114
C: Brandwag lower	0.15	81	146	152	136	131	127
D: Brandwag upper	0.05	81	200	202	200	202	202
E: Moordkuil lower	0.20	53	100	101	100	101	101
F: Moordkuil upper	0.05	53	100	101	100	101	101

Zone	Volume weighting	Estimated DIP concentration (µg/ℓ) based on distribution of abiotic states					
		Reference	Present	Scn 1	Scn 2	Scn 3	Scn 4
A: Lower reaches	0.25	10	11	11	10	11	10
B: Middle reaches	0.30	10	11	12	11	11	11
C: Brandwag lower	0.15	10	11	11	11	11	10
D: Brandwag upper	0.05	10	15	15	15	15	15
E: Moordkuil lower	0.20	10	13	14	13	12	12
F: Moordkuil upper	0.05	10	21	21	20	21	20

Zone	Volume weighting	Estimated <u>TURBIDITY</u> (NTU) based on distribution of abiotic states					
		Reference	Present	Scn 1	Scn 2	Scn 3	Scn 4
A: Lower reaches	0.25	11	12	12	12	12	11
B: Middle reaches	0.30	11	13	13	13	13	12
C: Brandwag lower	0.15	21	30	32	27	26	23
D: Brandwag upper	0.05	28	40	43	36	34	31
E: Moordkuil lower	0.20	11	11	11	10	11	10
F: Moordkuil upper	0.05	11	11	11	10	11	10

Zone	Volume weighting	Estimated DISSOLVED OXYGEN (mg/ℓ) based on distribution of abiotic states					
		Reference	Present	Scn 1	Scn 2	Scn 3	Scn 4
A: Lower reaches	0.25	6	6	6	6	6	6
B: Middle reaches	0.30	6	6	6	6	6	6
C: Brandwag lower	0.15	6	4	4	4	4	4
D: Brandwag upper	0.05	6	5	5	5	5	5
E: Moordkuil lower	0.20	6	3	3	3	3	3
F: Moordkuil upper	0.05	6	5	5	5	5	5

Table 7.19 Summary of water quality changes under different scenarios

Parameter	Summary of changes
Changes in longitudinal salinity gradient and vertical stratification	Under Scenario 1 salinity ⇩ slightly, while under Scenario 2 to 4 Salinity ⇧ due to the increase in low flow conditions. Under Scenario 3 and 4 hyper-salinity of 40 and 45 is likely to develop under State 1
Inorganic nutrients in estuary	⇧ due to agricultural activities in the catchment, highest DIP coming from Moordkuil catchment
Turbidity in estuary	⇧ due to agricultural activities in the catchment, especially from the Brandwag catchment
Dissolved oxygen in estuary	⇩ due to organic enrichment associated with agricultural activities catchment and along the banks, especially in the deeper Moordkuil arm where stratification prevents re-aeration of bottom waters at times
Toxic substances in estuary	⇧ due to agricultural activities in catchment potentially introducing herbicides and pesticides

EHI scores for water quality under the various scenarios are presented in **Table 7.20**.

Table 7.20 Water quality health scores for present and future scenarios

Variable		Weight	Scenario					
			Present	1	2	3	4	Confidence
1	**Similarity in salinity**	**40**	**85**	**86**	**82**	**78**	**74**	**L**
2	**General water quality min (a to d)**	**60**						**M**
a	*DIN/DIP concentrations*		82	81	83	83	84	L/M
b	*Turbidity*		93	92	95	95	98	M/L
c	*Dissolved oxygen*		90	90	89	89	89	M/L
d	*Toxic substances*		80	80	80	80	80	L
Water quality score weighted mean (1,2)			**82**	**82**	**81**	**79**	**78**	**L**

7.4 BIOTIC COMPONENT

7.4.1 Microalgae

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

Table 7.21 Summary of change in microalgae under different scenarios

Scenario	Summary of changes
1	There will be a 3% increase in river flow compared to present. This will result in a slightly higher load of nutrients and TSS entering the estuary in river water supporting slightly higher phytoplankton biomass and a shift from the benthos to the water column.
2	The 15% decrease in river flow compared to present will result in the marine dominated state persisting for longer and phytoplankton biomass will decrease, seeing a shift in primary productivity from the water column to the benthos. The water column will be clearer and a lower load of nutrients will enter the estuary in river water. A 5% change in intertidal and subtidal areas as a result of reduced floods will is likely to result in shift in benthic community composition (5%).
3	The 24% decrease in river flow compared to present will result in the marine dominated state persisting for longer and phytoplankton biomass will decrease, seeing a shift in primary productivity from the water column to the benthos. The water column will be clearer and a lower load of nutrients will enter the estuary in river water. A 10% change in intertidal and subtidal areas as a result of reduced floods will is likely to result in shift in benthic community composition (10%).
4	The 34% decrease in river flow compared to present will result in the marine dominated state persisting for longer and phytoplankton biomass will decrease, seeing a shift in primary productivity from the water column to the benthos. The water column will be clearer and a lower load of nutrients will enter the estuary in river water. A 15% change in intertidal and subtidal areas as a result of reduced floods will is likely to result in shift in benthic community composition (15%).

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

Table 7.22 Microalgae health scores for present and future scenarios

Variable	Scenario					
	Present	1	2	3	4	Confidence
Phytoplankton						
b. Species richness	90	89	91	91	91	M
b Abundance	87	86	88	88	88	M
c. Community composition	86	85	87	87	87	M
Benthic microalgae						
a. Species richness	80	80	80	80	80	M
b Abundance	64	64	64	64	64	M
c. Community composition	90	90	85	80	75	M
Microalgae score: min (a to c)	**64**	**64**	**64**	**64**	**46**	**M**

7.4.2 Macrophytes

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

Table 7.23 Summary of change in macrophytes under different scenarios

Scenario	Summary of changes
1	Similar to present, although there has been an improvement in low flow conditions does not cause a measurable macrophyte response.
2	~20 % reduction in floods would result in some marine sediment penetration. Flushing of supratidal salt marsh areas by floods would be reduced. The mouth would close in winter and would remain closed from weeks to mouths. Macroalgal blooms are expected under these conditions (about 2 to 4 times out of ten years). Macroalgae will also proliferate in response to the increase in nutrients from surrounding agricultural activities. There would be a significant increase in salinity in the lower Brandwag section from 12 to 21 and in the lower Moordkuil section from 18 to 24. This would cause die-back of reeds and sedges and loss of salt marsh areas. 10% change from present in macrophytes expected.
3	Further reduction of floods to ~30% would significantly increase salinity in the supratidal salt marsh areas. The mouth would close in winter and would remain closed from weeks to mouths. Macroalgal blooms are expected under these conditions (about 3 to 5 times out of ten years). Macroalgae will also proliferate in response to the increase in nutrients from surrounding agricultural activities. There would be a significant increase in salinity in the lower Brandwag section from 12 to 26 and in the lower Moordkuil section from 18 to 28. Under Scenario 3 and 4 hyper-salinity of 40 and 45 is likely to develop under State 1 during closed mouth conditions? This would cause die-back of reeds and sedges and loss of salt marsh areas. Approximate change of 20% from present in macrophytes expected.

Scenario	Summary of changes
4	~ "doubling" of the impacts due to further reduction from ~20% to ~40 % in floods. Extended mouth closure would occur in winter lasting for months at a time, probability of closure would occur 2 out of three years. Macroalgal blooms are expected under these conditions. Macroalgae will also proliferate in response to the increase in nutrients from surrounding agricultural activities. There would be a significant increase in salinity in the lower Brandwag section from 12 to 31 and in the lower Moordkuil section from 18 to 33. Under Scenario 3 and 4 hyper-salinity of 40 and 45 is likely to develop under State 1 during closed mouth conditions. This would cause die-back of reeds and sedges and loss of salt marsh areas. Approximate change of 30% from present in macrophytes expected.

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

Table 7.24 EHI scores for macrophytes under different scenarios

Variable	Scenario					
	Present	**1**	**2**	**3**	**4**	**Confidence**
a. Species richness	80	80	75	70	65	L
b. Abundance	50	50	45	40	35	L
c. Community composition	58	58	53	48	43	L
Macrophyte score: min (a to c)	**50**	**50**	**45**	**40**	**35**	**L**

7.4.3 Invertebrates

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

Table 7.25 Summary of change in invertebrates under different scenarios

Scenario	Summary of changes
1	Very little change relative to present. Although a slight increase in baseflow conditions, the benefits to invertebrates will be marginal and difficult to discern.
2	Because of increasing salinity values upstream (reduction in low flows) and therefore increasing marine dominance, zooplankton biomass will decline throughout the estuary. There will be a comcomitant decline in zonation structures along the estuary – all invertebrate groups. The die-back of fringing reeds will reduce habitat available to carid sgrimps and therefore reduce population abundance levela – *Palaemon capensis* is an example. The 20% loss of floods will lead to increased penetration of marine sediments to the estuary and a concomitant increase in habitat available to the benthos. A sand-associated fauna will become more prevalent – the mysid *Gastrosaccus brevifissura* is an example. Because mouth closure now persists from weeks to months 2-4 times every 10 years, intertidal mudprawn populations will reflect increased variability in population structure (absence of smaller cohorts when mouth is closed) and reduced abundance levels (zero recruitment coupled with mortality – predation effects and loss of older cohorts when mouth is closed). Submerged macrophytes beds will become more expansive, leading to a shift in the benthic community composition – species such as ispods and attached bivales will become more abundant relative to open habitat species. Reducing oxygen concentrations below 50% surface saturation levels will lead to the disappearance of populations in the benthos, particularly in deeper areas.
3-4	Under Scenarios 3 and 4, there will be a progressive decline in invertebrate populations following the patterns noted in 2 above. Hypersalinity effects will be particularly severe under Scenario 4, as will be mouth closure in 2 out of 3 years for months at a time. Mudprawn populations will probably disappear from the estuary as the population progressively shrinks inter –annually. Suitable oligohaline conditions will only persist in the upper reaches of the two tributaries, leading to reduction in abundance of species associated with this habitat. Suitable habitat available reed-associated species (carid shrimps such as *Palaemon capensis*) will be reduced by up to 30%, leading to a decline in abundance levels of species associated with fringing vegetation habitats.

Table 7.26 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	L
b. Abundance	80	80	75	70	60	L
c. Community composition	70	70	65	60	50	L
Hyperbenthos						
a. Species richness	100	100	100	100	100	L
b. Abundance	80	80	75	70	60	L
c. Community composition	70	70	65	60	50	L
Benthos						
a. Species richness	100	100	100	100	100	L
b. Abundance	70	70	65	60	50	L
c. Community composition	70	70	65	55	45	L
Invertebrate score: min (a to c)	**70**	**70**	**65**	**55**	**45**	**L**

7.4.4 Fish

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

Table 7.27 Summary of change in fish under different scenarios

Scenario	Summary of changes
1	Very little difference to the present day i.e. reduced connectivity & recruitment windows. REI species in very low numbers but estuary-dependent marine species abundant throughout the system. Slight 3% increase in flow may see incremental increase in REI species and recruitment cues and window for juveniles and larvae entering from the sea. Benthic algae feeders / detritivore (mullet) numbers abundant and similar to present day. Large exploited species and alien species subject to non-flow relate influences and therefore no change.
2	Low flows and virtual absence of REI will see associated species even less than the present day. Floods still occur during peak recruitment periods but 20 % reduction in volume will see loss of connectivity about double that of the present day. Mouth closure would occur and persist in the winter months but not during peak recruitment of spring / early summer. Intrusion of marine sand, reduction in muds and increase in water clarity will favour visual benthic invertivores e.g. adult steenbras *L. lithognathus.* Sand and mouth closure will see benthic prey switching completely from mudprawn *U. africana* to sandprawn *C. kraussi* the latter becoming distributed throughout the system, Availability of these burrowing species to predators may increase due to increased salinity and shallower burrows. Psammophyllic species; especially commensal burrow dwellers e.g. *P. knysnaensis* will also increase in abundance. Benthic algae feeders / detritivore (mullet) species will also increase especially the opportunistic *L. richardsonii*. However, benthic algae abundance may be dampened by *C. kraussi* bioturbation. Decline in zooplankton biomass will be a limiting factor for most juvenile fish. Macro-algal blooms start to occur but not as prolific as in Scenarios 3 & 4. Most likely to cause night-time hypoxia and physiological stress.
3	REI zone and associated species e.g. *Myxus capensis* mostly absent from the estuary. A 30% reduction in flood volume will see loss of connectivity and recruitment cues three times that of the present day, Mouth closure would persist in winter but may extend into the spring recruitment period. Estuary-dependent marine species, abundant under Scenario 2 and the present day are now likely to decline in abundance. Intrusion of marine sand, reduction in muds and increase in water clarity will favour visual benthic invertivores e.g. adult steenbras *L. lithognathus* that manage to recruit into the system. Sand and mouth closure will see benthic prey switching completely from mudprawn *U. africana* to sandprawn *C. kraussi* the latter becoming distributed throughout the system, Availability of these burrowing species to predators may increase due to increased salinity and shallower burrows. Psammophyllic species; especially commensal burrow dwellers e.g. *P. knysnaensis* will also increase in abundance. Conversely, *Caffrogobius* species associated with mudprawn burrows likely to decrease. Benthic algae feeders / detritivore (mullet) species will also increase especially the opportunistic *L. richardsonii*. However, benthic algae abundance may be dampened by *C. kraussi* bioturbation. Decline in zooplankton biomass will be a limiting factor for most juvenile fish. Occurrence of macro-algal blooms likely to lead to nocturnal hypoxia, physiological stress and occasional fatalities. Low-oxygen events coupled with algal decay will result in mass mortalities.

Scenario	Summary of changes
4	Scenario 3 an intensified version of Scenario 4. REI zone and associated species e.g. *Myxus capensis* mostly absent from the estuary. A 40% reduction in flood volume will see loss of connectivity and recruitment cues four times that of the present day, Mouth closure would persist in winter but may extend into the spring recruitment period. Estuary-dependent marine species, abundant under Scenario 2 and the present day are now likely to decline in abundance. Intrusion of marine sand, reduction in muds and increase in water clarity will favour visual benthic invertivores e.g. adult steenbras *L. lithognathus* that manage to recruit into the system. Sand and mouth closure will see benthic prey switching completely from mudprawn *U. africana* to sandprawn *C. kraussi* the latter becoming distributed throughout the system, Availability of these burrowing species to predators may increase due to increased salinity and shallower burrows. Psammophyllic species; especially commensal burrow dwellers e.g. *P. knysnaensis* will also increase in abundance. Conversely, *Caffrogobius* species associated with mudprawn burrows likely to decrease. Benthic algae feeders / detritivore (mullet) species will also increase especially the opportunistic *L. richardsonii*. However, benthic algae abundance may be dampened by *C. kraussi* bioturbation. Decline in zooplankton biomass will be a limiting factor for most juvenile fish. Occurrence of macro-algal blooms likely to lead to nocturnal hypoxia, physiological stress and occasional fatalities. Low-oxygen events coupled with algal decay will result in mass mortalities.

Table 7.28 EHI scores for fish under different scenarios

Variable	Scenario					
	Present	1	2	3	4	Confidence
a. Species richness	80	80	75	60	55	M
b. Abundance	70	70	70	60	60	M
c. Community composition	60	60	55	50	45	M
Fish score: min (a to c)	**60**	**60**	**55**	**50**	**45**	**M**

7.4.5 Birds

A summary of the expected changes under various scenarios for the bird component in the Klein Brak Estuary is provided in **Table 7.29**, while the health scores for the present and future scenarios are provided in **Table 7.30.**

Table 7.29 Summary of change in birds under different scenarios

Scenario	Summary of changes
1. Class C EWR 77% MAR (+3%)	No measurable impacts
2. Moordkuil dam, 59% MAR	Increasing salinity, increased pnetration of marine sediments changes mouth community, variability in muprawn pops with overall decline, possible crash (benthos 90% of present), impacting negatively on mudflat waders;
3. Same dam, more abstraction, 50% MAR	As above, but impacts getting progressively more severe; mudprawns and crabs extinct benthos 85% of present –impact on large mudflat waders
4. Big dam + abstraction on other river, 40% MAR	Benthos 70% of present – impact on waders

Table 7.30 EHI scores for birds under different scenarios

Variable	Scenario					
	Present	1	2	3	4	Confidence
a. Species richness	70	70	70	65	60	L
b. Abundance	31	31	28	26	22	L
c. Community composition	41	41	38	35	36	L
Bird score: min (a to c)	**31**	**31**	**28**	**26**	**22**	**L**

7.5 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 Klein Brak Estuary under each of the future scenarios (refer to **Table 7.31**), again using the EHI.

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

Variable	Weight	Scenario					
		Present	1	2	3	4	Confidence
Hydrology	25	56	71	51	33	27	L
Hydrodynamics and mouth condition	25	96	97	89	82	69	L
Water quality	25	82	82	81	79	78	M/L
Physical habitat alteration	25	54	54	49	44	39	L
Habitat health score		**72**	**76**	**67**	**60**	**53**	
Microalgae	20	64	64	64	64	64	M
Macrophytes	20	50	50	45	40	35	L
Invertebrates	20	70	70	65	55	45	L

Variable	Weight	Scenario					
		Present	**1**	**2**	**3**	**4**	**Confidence**
Fish	20	60	60	55	50	45	M
Birds	20	31	31	28	26	22	L
Biotic health score		**55**	**55**	**51**	**47**	**42**	
ESTUARY HEALTH SCORE		**64**	**66**	**59**	**48**	**48**	**L**
ECOLOGICAL CATEGORY		**C**	**C**	**C/D**	**D**	**D**	**Low**

8 RECOMMENDATIONS

8.1 RECOMMENDED ECOLOGICAL FLOW SCENARIO

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

In the case of the Klein Brak Estuary a **Category C** was proposed as the REC, equivalent to the PES. However, it was concluded at the workshop that the Klein Brak Estuary was on a negative trajectory of change and if the current (low) base flow regime, as well as certain non-flow related impacts on the system continue as at present, the estuary is likely to move into a Category C/D, even a Category D. To account for some of the loss in base flows, Scenario 1 (i.e. present flows including EWR for a Category C River just upstream of the estuary) was therefore selected as the recommended ecological water requirement for the Klein Brak Estuary (**Table 8.1**).

Table 8.1 Recommended ecological flow scenario for the Klein Brak Estuary (Category C)

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	7.5	18.1	12.9	10.2	8.1	10.3	11.0	9.9	5.6	5.1	11.4	11.9
99	7.3	17.0	12.3	7.5	7.7	9.2	8.6	9.4	4.1	3.6	10.1	8.4
90	4.0	5.1	2.8	2.0	2.1	3.9	4.7	2.4	1.8	1.3	2.3	4.3
80	3.2	2.9	1.4	1.2	1.1	2.1	2.6	1.7	1.0	1.0	1.2	2.5
70	2.1	2.0	0.9	0.6	0.8	1.4	1.2	0.9	0.7	0.8	0.8	1.4
60	1.4	1.2	0.7	0.3	0.3	0.8	0.7	0.4	0.4	0.5	0.5	0.9
50	0.7	0.5	0.3	0.2	0.2	0.5	0.5	0.3	0.3	0.4	0.4	0.6
40	0.6	0.4	0.3	0.2	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.4
30	0.4	0.3	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3
20	0.3	0.3	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3
10	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1

However, in order to further address the negative trajectory of change, additional interventions in terms of **non-flow related impacts are essential** to maintain the ecological health of the estuary in a **Category C**, namely:

- On both the Brandwag (34◦03’43.51’”S; 22◦06’47.95”E) and Moordkuil arms (34◦03’15.32”S; 22◦ 07’55.24”E) there are obstructions across the estuary (i.e. roads) that prevent saline intrusion/tidal variation extending further upstream. To improve tidal connectivity these obstructions should either be removed or proper bridges should be consutructed. In doing so, the REI (roughly defined as the reach where salinity ranges between 10 and 0) will be

introduced more readily, enhancing nursery function in the upper estuaries and thus contributing to the recovery of collapsed and endangered fish species, e.g. dusky cob and white steenbras.
- Further upstream in the Moordkuil arm there is also a DWS weir (34◦03'11.14"S; 22◦08'02.85"E). As this weir fulfils an important gauging function it may not have to be removed, but fish ladders should be installed on both sides of the weir to allow migrating species (e.g. eels) to move upstream.
- Rehabilitate degraded areas in the estuary functional zone, e.g. consolidate present access routes so as not to have a web of small roads on the salt marshes.
- Removal of invasive alien plant species in the estuary functional zone, focussing especially in suptratidal areas.
- Reduce fishing pressures and (illegal) bait collecting through increased compliance (existing DAFF initiative).
- Institute a ban on night fishing to reduce the pressure on breeding stock of collapsed and endangered fish species, e.g. dusky cob (proposed DAFF initiative).

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 mechanisms through which to facilitate the implementation these interventions.

8.2 ECOLOGICAL SPECIFICATIONS

The EcoSpecs and associated TPCs representative of a **Category C** for the Klein Brak Estuary are presented in **Table 8.2**.

Table 8.2 EcoSpecs and Thresholds of Potential Concern for the Klein Brak Estuary (Category C)

Component	EcoSpecs	Thresholds of Potential Concern
Hydrology	Maintain a flow regime to create the required habitat for birds, fish, macrophytes, microalgae and water quality	River inflow: ▪ Monthly river inflow < 0.4 m^3/s persists for more than 30% of the time ▪ Monthly river inflow < 0.15 m^3/s persists for more than 15% of the time ▪ Monthly river inflow drops to 0 m^3/s
Hydrodynamics	Maintain connectivity with marine environment	▪ Mouth closer occurs ▪ Upper reaches above the weirs do not contribute to tidal flow to maintain open mouth conditions ▪ Average tidal amplitude < 20% of present observed data from the water level recorder in the estuary near the mouth

Component	EcoSpecs	Thresholds of Potential Concern
Sediment dynamics	▪ Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) for biota ▪ No significant changes in sediment grain size 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 bathymetry along main channel change by 30% in any survey along estuary from that of the Present State (2014 baseline, to be measured) (system expected to significantly fluctuate in terms of bathymetry between flood and extended closed periods)
Water quality	Salinity distribution not to cause exceedence of TPCs for biota (see below)	▪ No salinity gradient in the upper reaches of the estuary (Zone D and F) ▪ No REI in the upper reaches of the estuary (Zone D and F) ▪ Salinity > 35
	System variables (pH, dissolved oxygen and turbidity) not to cause exceedence of TPCs for biota (see below)	River inflow: ▪ 7.0 < pH > 8.5 ▪ DO < 5 mg/ℓ ▪ Suspended solids > 5 mg/ ℓ (low flow) Estuary: ▪ Average turbidity >10 NTU (low flow) ▪ Average 7.0 < pH > 8.5 (increasing with increase in salinity) ▪ Average DO < 5 mg/ℓ
	Inorganic nutrient concentrations (NO_3-N, NH_3-N and PO_4-P) not to cause in exceedance of TPCs for macrophytes and microalgae (see below)	River inflow: ▪ NO_x-N >150 µg/ℓ over two consecutive months ▪ NH_3-N> 20 µg/ℓ over two consecutive months ▪ PO_4-P > 20 µg/ℓ over two consecutive months Estuary (except during upwelling or floods): ▪ Average NO_x-N > 150 µg/ℓ during survey, 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 exceedence 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 medium median phytoplankton biomass ▪ Prevent median intertidal benthic microalgal biomass from exceeding 60 mg m^{-2}. ▪ 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 60 mg/m^2 ▪ Site specific chlorophyll *a* concentration exceeds 20 µg/ℓ and cell density exceeds 10 000 cells/m ℓ.
Macrophytes	▪ Maintain the distribution of sensitive macrophyte habitats (e.g. salt marsh, submerged macrophytes). ▪ Maintain the integrity of the salt marsh. ▪ Rehabilitate the floodplain habitat by removing weirs, berms and invasive plants. ▪ Prevent an increase in nutrient input leading to macroalgal blooms.	▪ Greater than 20 % change in the area covered by submerged macrophytes and salt marsh. ▪ 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 ▪ Drying of floodplain habitat. ▪ Invasive plants cover > 10% of total floodplain area. ▪ Macroalgal blooms cover > 50% of the open water area during closed mouth conditions.
Invertebrates	▪ Maintain rich populations of mudprawn *Upogebia africana* on intertidal banks in middle estuary. ▪ Maintain *Pseudodiaptomus hessei* as the numerically dominant copepod in the zooplankton of the estuary.	Mudprawn populations should not deviate from average baseline valuess (as determined in first three visits) by more 25%. *P. hessei* populations should not deviate from average baseline valuess (as determined in first three visits) by more 30%.

Component	EcoSpecs	Thresholds of Potential Concern
Fish	Fish assemblage should comprise the five estuarine association categories in similar proportions (diveristy and abundance) to that under the reference. Numerically assemblage should comprise: ▪ Ia estuarine residents (20-60%) ▪ Ib marine and estuarine breeders (10-30%) ▪ IIa obligate estuarine-dependent (20-40%) ▪ IIb estuarine associated species (5-20%), ▪ 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 four species (including *G.aestuaria, Hyporamphus capensis, Omobranchus woodii*). Category IIa obligate dependents should be well represented by large exploited species especially *A. japonicus, L. lithognathus, P. commersonnii, Lichia amia*. REI species dominated by both *Myxus capensis* and *G. aestuaria*.	▪ Ia estuarine residents < 20% ▪ Ib marine and estuarine breeders < 10% ▪ IIa obligate estuarine-dependent < 20% ▪ IIb estuarine associated species < 5% ▪ IIc marine opportunists < 20% ▪ 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	Estuary should contain a diverse avifaunal community that includes representatives of all the original groups. Saltmarsh/wetlands in the floodplain should be rich in birdlife. Intertidal areas should have a good density and diversity of both larger and smaller waders	▪ Numbers of waterbirds on the entire system drops below 30 species or below 250 birds for three consecutive counts ▪ Numbers of waterbirds in the lower estuary drops below 10 species or 50 birds (excluding terns and gulls) for three consecutive counts

8.3 BASELINE SURVEYS AND LONGTERM MONITORING PROGRAMME

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

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

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

Component	Action	Temporal scale (frequency and when)	Spatial scale (Stations)
Sediment dynamics	Monitoring berm height using appropriate technologies	Quarterly	Mouth
	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals but in more detail in mouth including berm (every 100 m). Vertical accuracy at least 5 cm	Once-off	Entire estuary
	Collect sediment grab samples (at cross-section profiles) for analysis of particle size distribution and 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 in Moordkuils (station K1H5) and Brandwag (station K1H4) rivers
	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 for two years	Entire estuary (10-13 stations)
	Measure pesticides/herbicides and metal accumulation in sediments (for metals investigate establishment of distribution models – see Newman and Watling, 2007)	Once-off	Entire estuary, including depositional areas (i.e. muddy areas)

Component	Action	Temporal scale (frequency and when)	Spatial scale (Stations)
Microalgae	▪ Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae. ▪ Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. spectrophotometer, HPLC, fluoroprobe. ▪ Intertidal and subtidal benthic chlorophyll-a measurements (4 replicates each) using a recognised technique, e.g. sediment corer or fluoroprobe.	Quarterly, preferably over two years	Along length of estuary minimum five stations (include stations in upper reaches of Brandwag and Moordkuil arms).
Macrophytes	▪ In the field map the area covered by the different macrophyte habitats. Record boundaries and the total number of macrophytes species. ▪ Assess extent of invasive species within the 5 m contour line. ▪ Locate the position of reed and sedge areas as indicators of future salinity changes. ▪ Identify supratidal salt marsh areas and their condition in terms of area of bareground. ▪ Map sensitive submerged macrophyte habitats such as Ruppia cirrhosa and Zostera capensis beds. ▪ Identify macroalgae present, their distribution and potential for future expansion (bloom formation) particularly under low flow conditions. ▪ 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.	Once-off	Entire estuary

Component	Action	Temporal scale (frequency and when)	Spatial scale (Stations)
Invertebrates	▪ Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh) ▪ Collect grab samples (five replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each samples to be sieved through 500 um). ▪ Collect sled samples (day) at same zooplankton sites for hyper benthos (190 um) ▪ Intertidal invertebrate hole counts using 0.25 m^2 grid (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 three sites along length of entire estuary For hole counts – three sites in muddy substrata on eastern shore below N2 bridge.

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

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (Stations)
Hydrodynamics	Record water levels	Continuous	At bridge near mouth
	Measure freshwater inflow into the estuary	Continuous	Near head of estuary in Moordkuils (K1H5) and Brandwag (K1H4) rivers
	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 500 m intervals but in more detail in mouth including berm (every 100 m). Vertical accuracy at least 5 cm	Every three years (and after large resetting event)	Entire estuary
	Collect sediment grab samples (at cross-section profiles) for analysis of particle size distribution and 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 in Moordkuils (K1H5) and Brandwag (K1H4) rivers

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (Stations)
	Collect samples for pesticides/herbicide and metal determinations in river inflow	Every 3 – 6 years, or when contamination is expected	Near head of estuary in Moordkuils (station K1H5) and Brandwag (station K1H4) rivers
	Collect in situ continuous salinity data with mini CTD probe at a depth of about 1 m	Continuous	Four to six sites Head of the estuary in the Brandwag and Moordkuils arms, Brandwag and moordkuil weirs/causeways, the confluence of the two arms, the lower bridge
	Record longitudinal in situ salinity and temperature pH, DO, turbidity profiles	Seasonally, every year	Entire estuary (10-13 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 water quality expected	Entire estuary (10-13 stations)
	Measure pesticides/herbicides and metal accumulation in sediments	Every 3 – 6 years, or when contamination is expected	Entire estuary, including depositional areas (i.e. muddy areas)
Microalgae	▪ Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae. ▪ Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. spectrophotometer, HPLC, fluoroprobe. ▪ Intertidal and subtidal benthic chlorophyll-a measurements (four replicates each) using a recognised technique, e.g. sediment corer or fluoroprobe.	Quarterly for 1st two years and then low flow surveys every three years	Along length of estuary minimum five stations (include stations in upper reaches of Brandwag and Moordkuil arms).
Macrophytes	▪ In the field map the area covered by the different macrophyte habitats. Record boundaries and the total number of macrophytes species. ▪ Assess extent of invasive species within the 5 m contour line.	Every three years during summer	Entire estuary

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (Stations)
	▪ Locate the position of reed and sedge areas as indicators of future salinity changes. ▪ Identify supratidal salt marsh areas and their condition in terms of area of bareground. ▪ Map sensitive submerged macrophyte habitats such as Ruppia cirrhosa and Zostera capensis beds. ▪ Identify macroalgae present, their distribution and potential for future expansion (bloom formation) particularly under low flow conditions. ▪ 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.		
Invertebrates	• Collect duplicate zooplankton samples at night from mid-water levels using WP2 nets (190 um mesh) • Collect grab samples (five replicates) (day) from the bottom substrate in mid-channel areas at same sites as zooplankton (each samples to be sieved through 500 um). • Collect sled samples (day) at same zooplankton sites for hyper benthos (190 um) • Intertidal invertebrate hole counts using 0.25 m^2 grid (five replicates per site). Establish the species concerned using a prawn pump. • Collect sediment samples using the grab for particle size analysis and organic content (at same sites as zooplankton)	Every two years in mid-summer	Minimum of three sites along length of entire estuary For hole counts – three sites in muddy substrata on eastern shore below N2 bridge.

Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (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 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)
Birds	Undertake counts of all non-passerine water birds, identified to species level (as for this study)	Annual winter and summer surveys	Entire estuary including floodplain. Divide into sections: lower to N2; lower estuary adjacent marshes; middle to confluence including marshes; Moorkuils to top, Brandwag to top; upper floodplain wetlands. (sections must be standardised)

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APPENDIX A: DATA SUMMARY REPORT FOR BATHYMETRY AND HYDRODYNAMICS

A.1 MOUTH SURVEYS

Historical mouth surveys (1988 to 1993) were done using a 'wading survey technique', which is performed by using standard line surveying techniques (**Figures A.1a** to **A.1c**). 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.

The mouth survey data shows significant changes over time in the estuary mouth region, with notable changes in sediment volumes in the lower reaches between surveys. Between 12 September 1986 and 6 July 1989 significant sediment buildup is noted in the vicinity of the estuary mouth. The build up of sediment in the lower reaches finally culminates in a closed mouth state in the survey of 26 September 1991. In contrast the 14 October 1993 survey shows a wide open channel.

A.2 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 left 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 MSL. Although the survey by ski boat and echo sounder covers only the deeper parts of the estuary which are accessible by boat, these are usually the main areas where changes in sedimentation and erosion take place. The vertical accuracy of the depths measured with the echo sounder are 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 1996 cross-section positions are given in **Figure A.2**, while the cross-sections are plotted in **Figure A.3**.

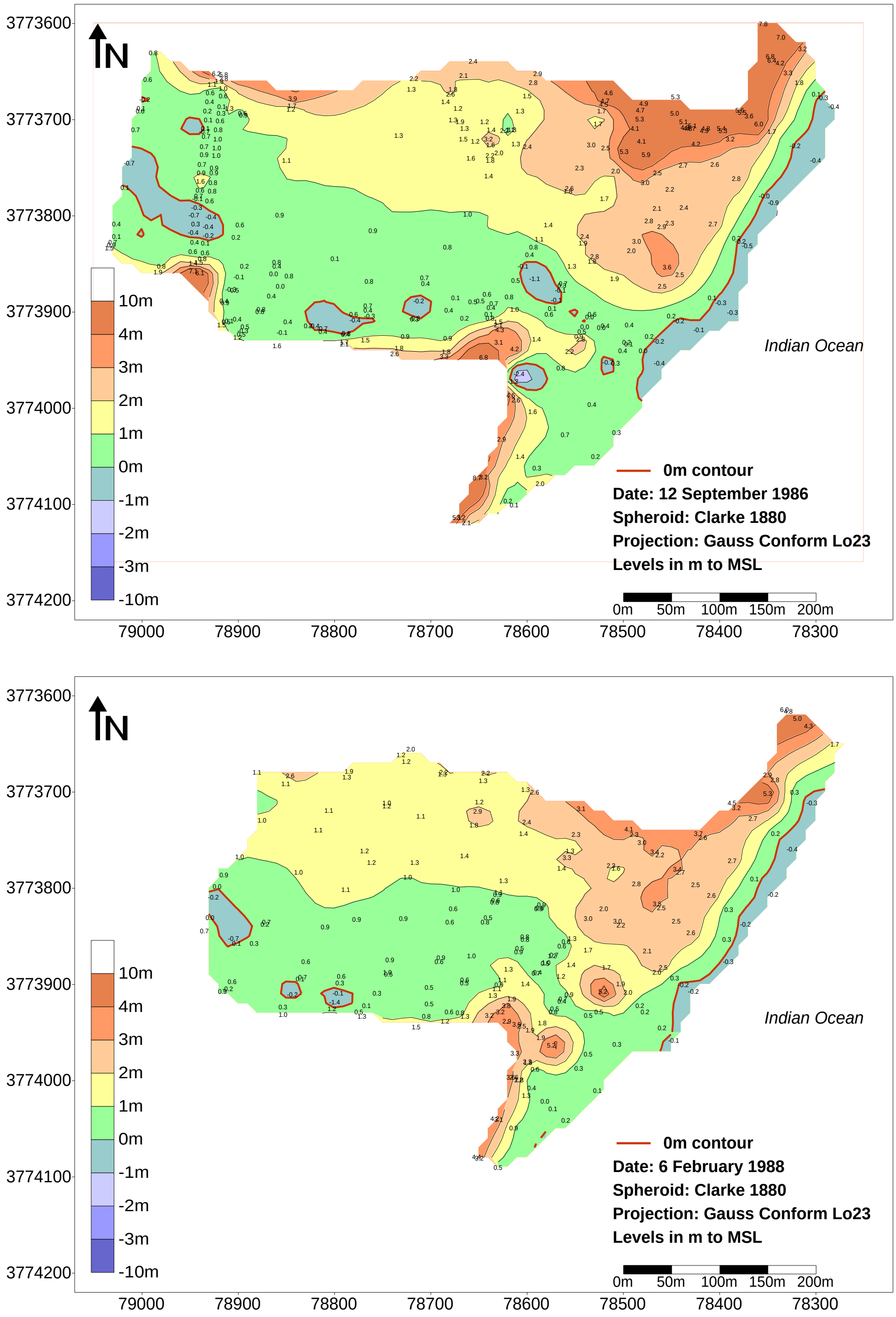


Figure A.1a Klein Brak Estuary: Mouth survey contour plots – 1986 and 1988

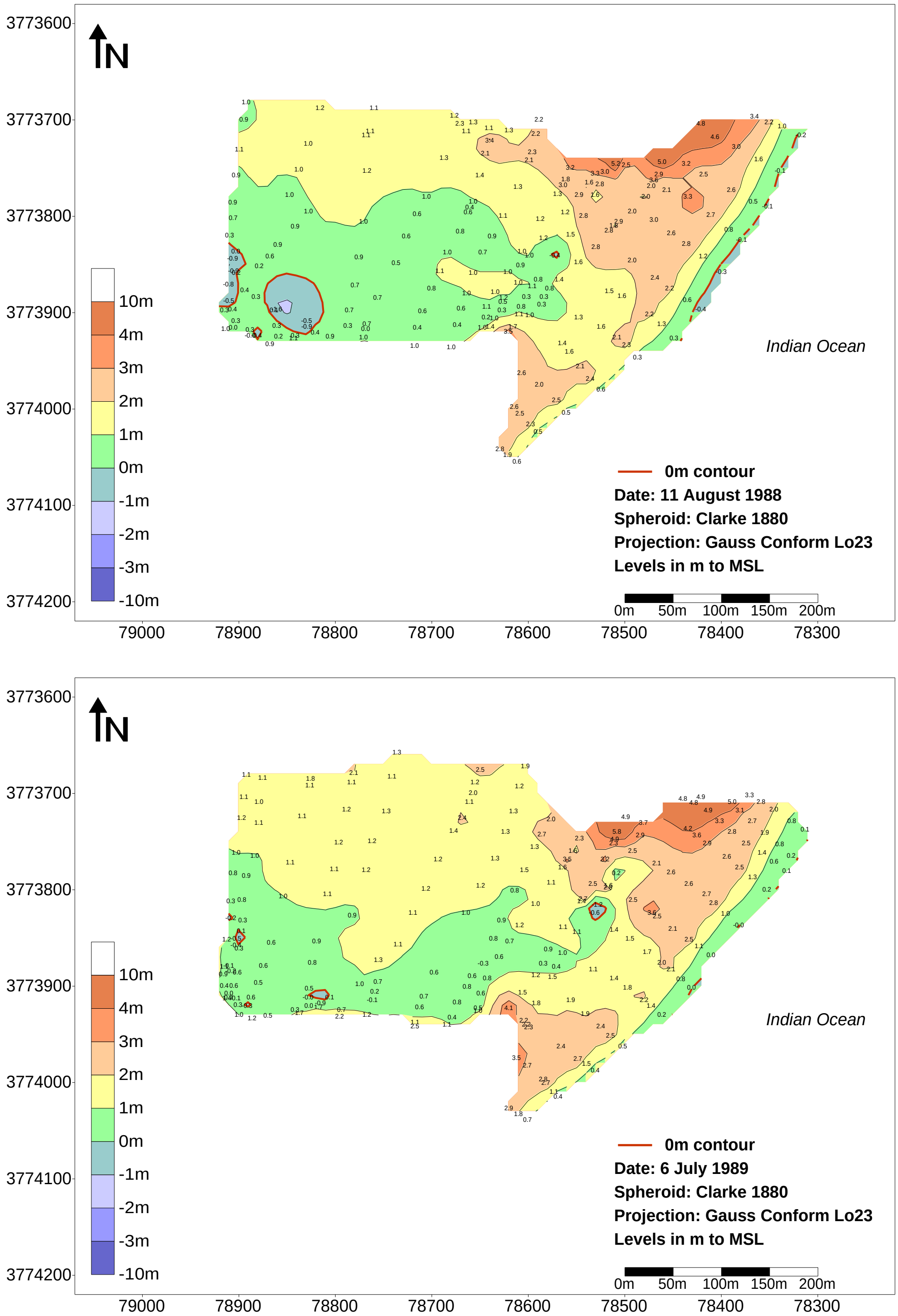


Figure A.1b Klein Brak Estuary: Mouth survey contour plots – 1988 and 1989

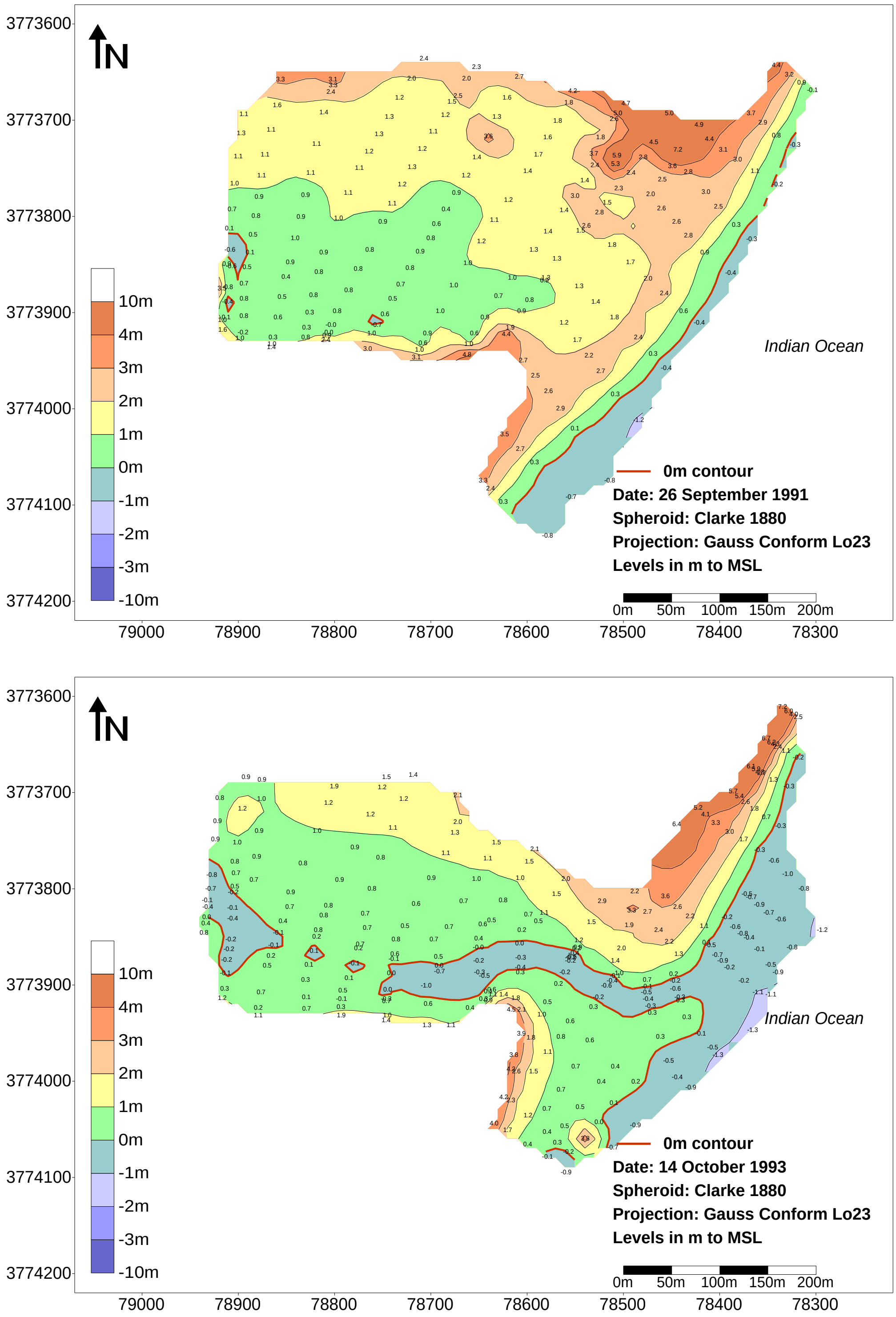


Figure A.1c Klein Brak Estuary: Mouth survey contour plots – 1991 and 1993

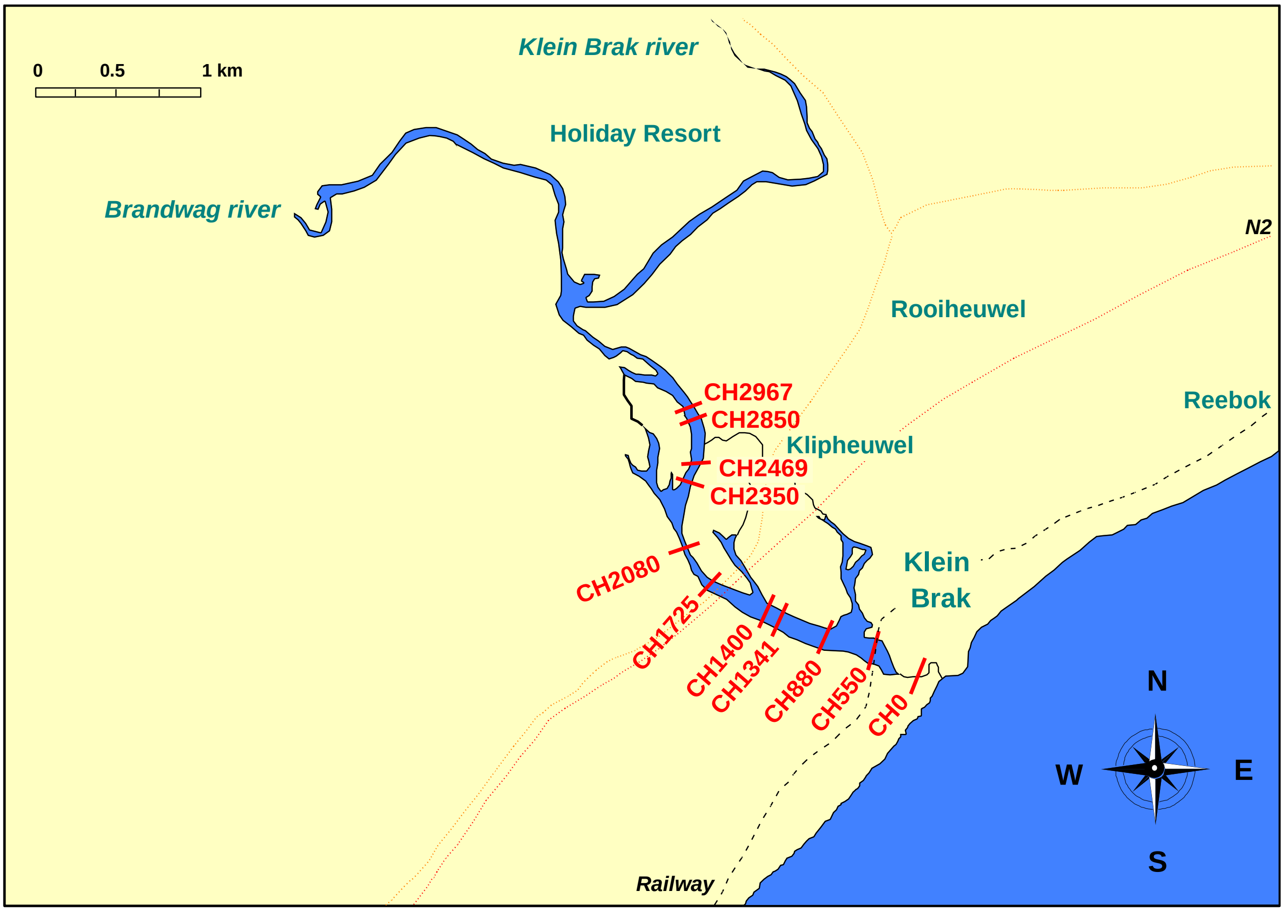


Figure A.2 Location of cross-section profiles taken in the Klein Brak Estuary

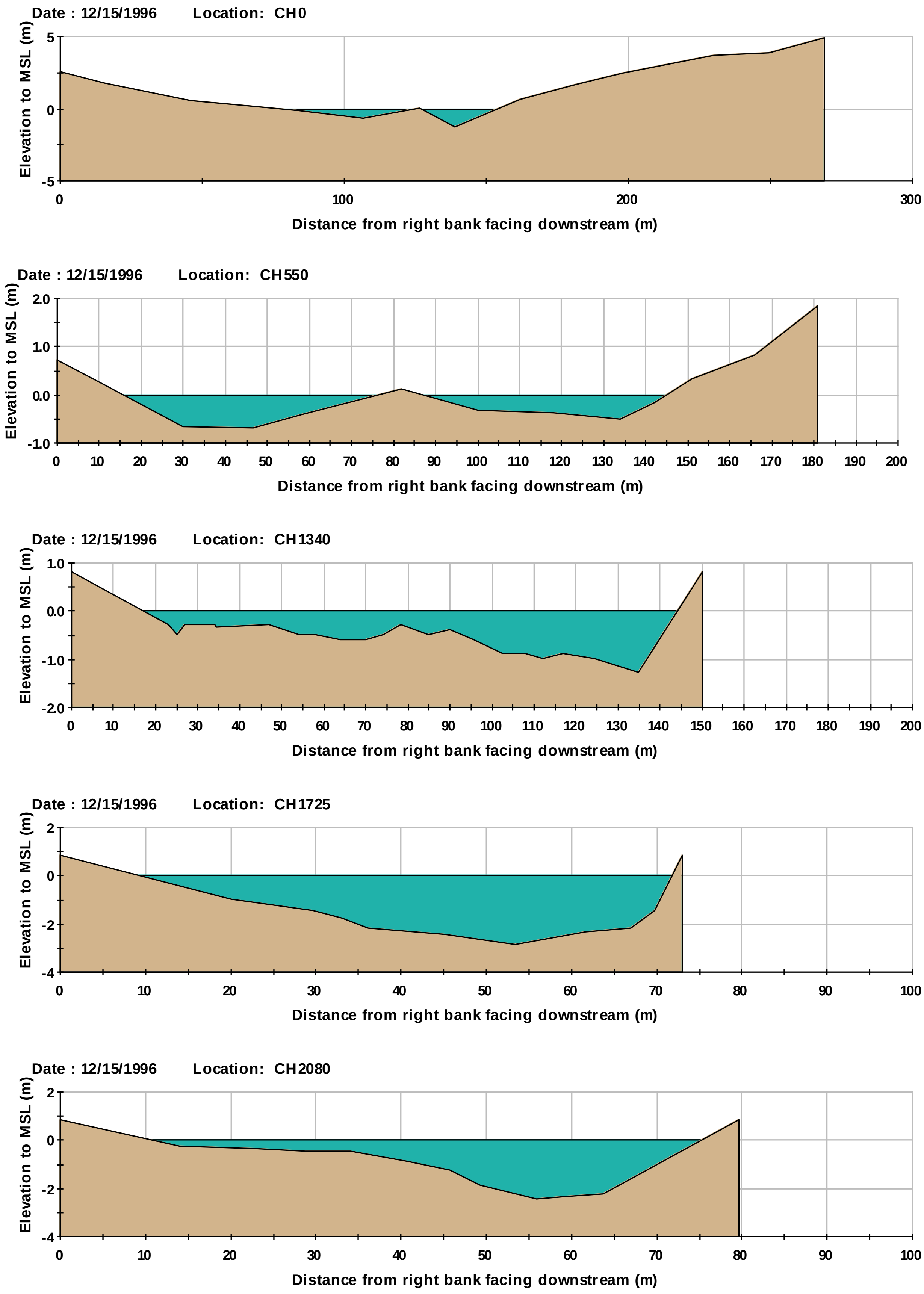


Figure A.3a Klein Brak Estuary: Cross-section profiles – 15 December 1996

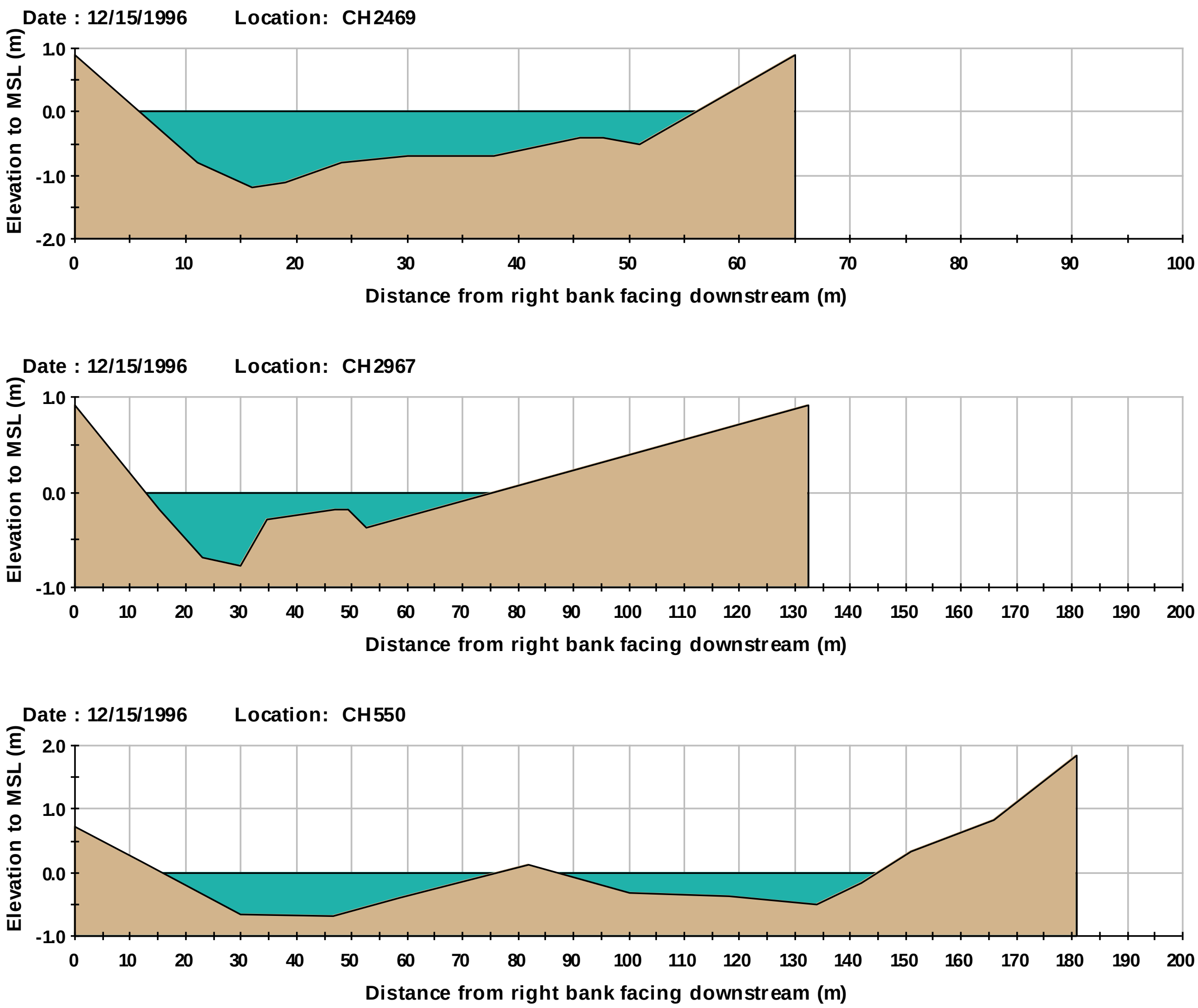


Figure A.3b Klein Brak Estuary: Cross-section profiles – 15 December 1996

A.3 MOUTH CONDITIONS

In addition to the mouth closure observed on the 1991 survey, mouth closure was also recorded in 2005 and 2006 on the DWS water level recorder K1T020 situated near the Klein Brak Estuary mouth. The tidal record of 2004 shows no mouth closure events (demonstrated by tidal fluctuation throughout the time period) (refer to **Figure A.4a**), but the tide becomes severely constricted to amplitudes of less than 0.5 m during July/August as a result of low flows and higher waves associated with winter.

A series of mouth closures can be observed in the tidal records of 2005 between 3 July 2005 to 10 September 2005, with the estuary mouth solid closed 2 August to 10 September 2005 (refer to **Figure A.4b**). Flow varied between 0.2 m^3/s and 0.4 m^3/s in the 8 weeks before closure. Breaching occurred as result of a gradual infilling and overtopping, i.e. not a flood, and did not remove significant sediment from the mouth.

An additional mouth closure is also observed between 4 March 2006 and 20 April 2006. Flow varied between 0.06 m^3/s and 0.4 m^3/s in the 8 weeks before closure. What is also notable from this **Figure A.4c** is that the estuary mouth remained constricted (low tide levels are still truncated) until a resetting flood on 2 August 2006, which scoured the system significantly (low tide levels are about 60 cm lower after the flood). This shows the important role floods play in the mouth dynamics of the Klein Brak Estuary.

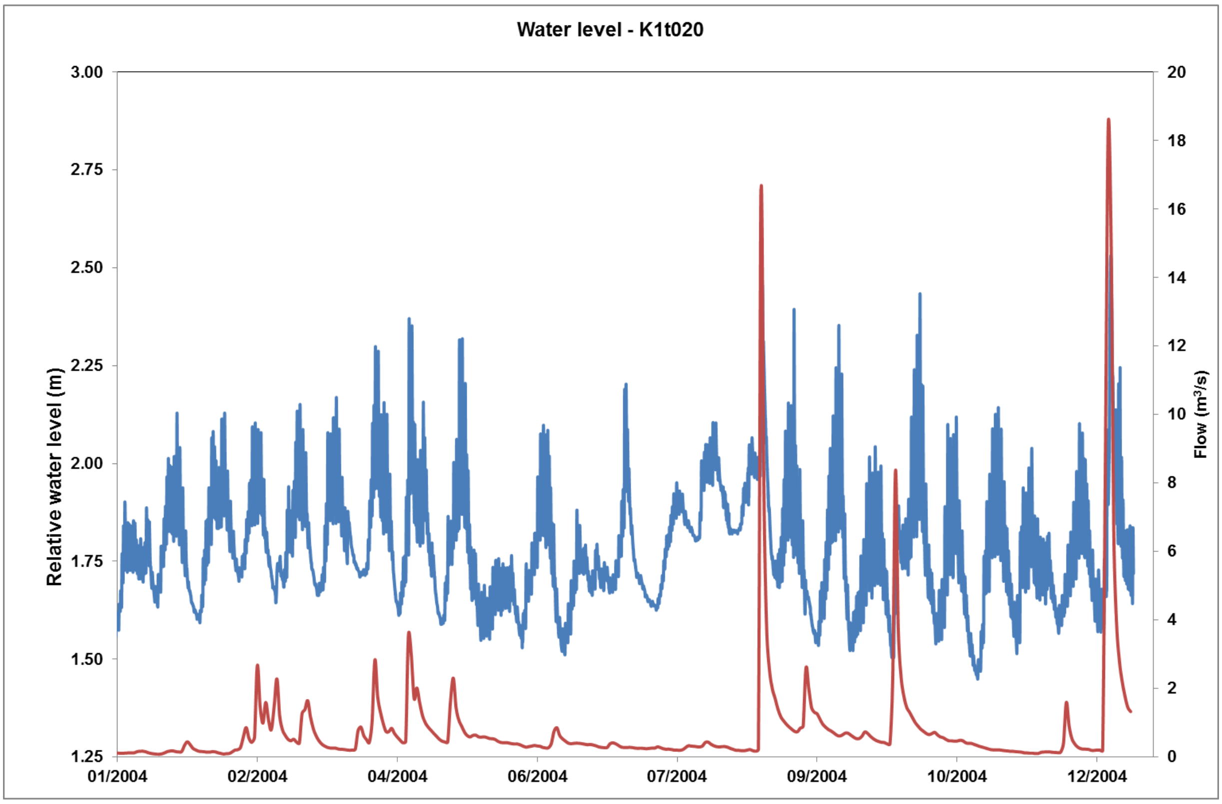


Figure A.4a Klein Brak Estuary water levels (blue) (Tidal gauge K1T020) correlated with inflow (red) from the Moordkuil and Brandwag tributaries for 2004

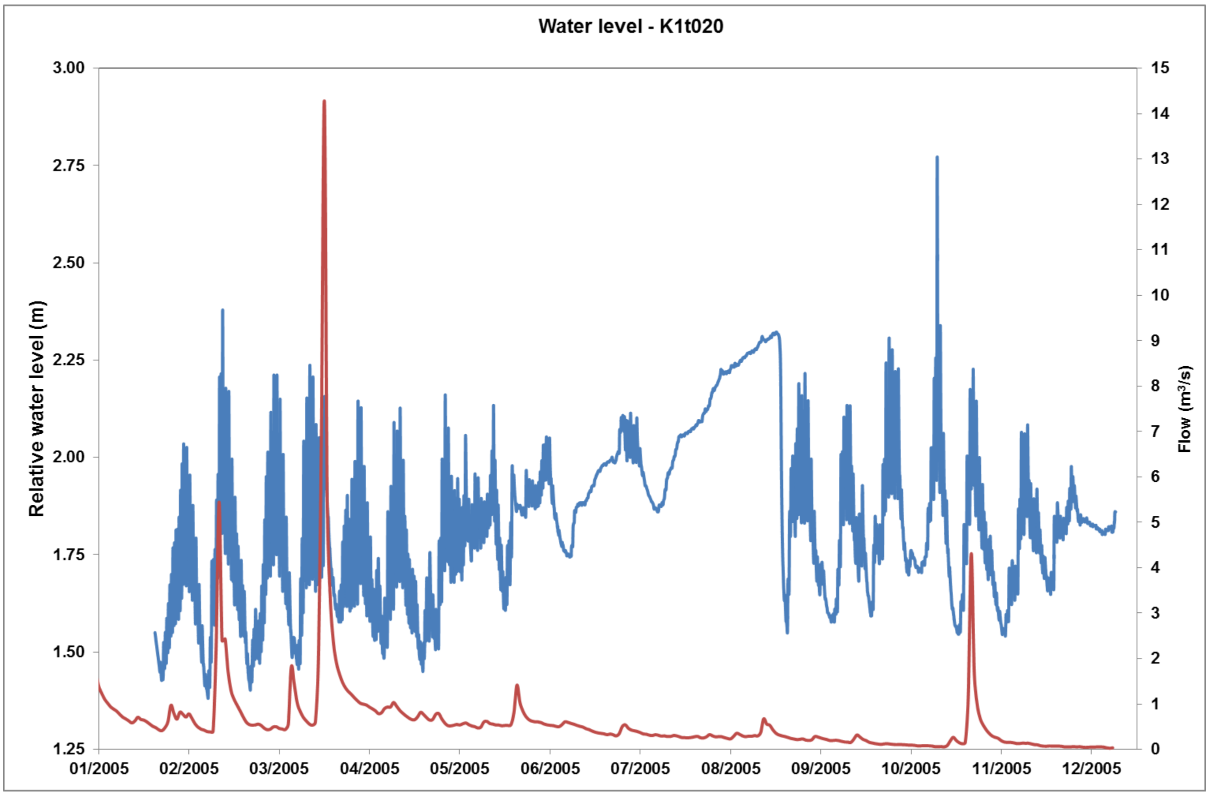


Figure A.4b Klein Brak Estuary water levels (blue) (Tidal gauge K1T020) correlated with inflow (red) from the Moordkuil and Brandwag tributaries for 2005

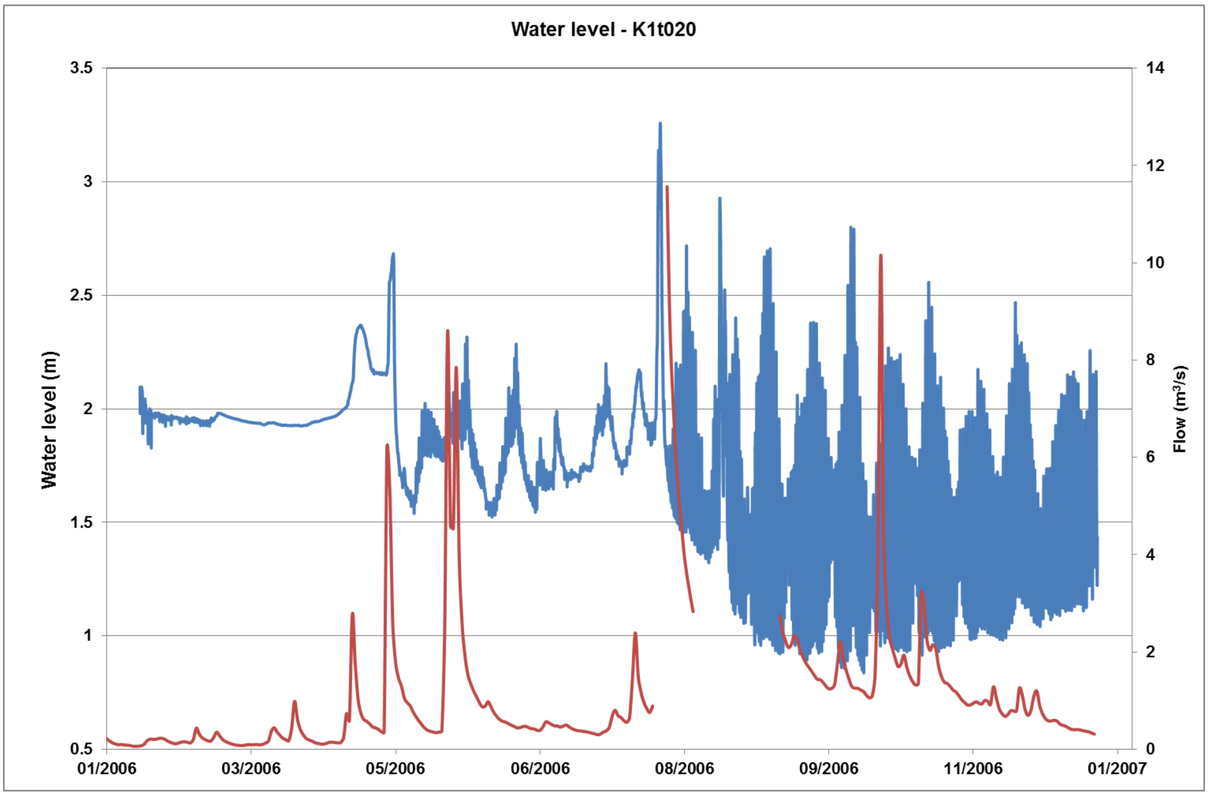


Figure A.4c Klein Brak Estuary water levels (blue) (Tidal gauge K1T020) correlated with inflow (red) from the Moordkuil and Brandwag tributaries for 2006

A closed and restricted mouth state is indicated in **Figures A.5a** and **A.5b**, respectively.

Figure A.5a Satellite image of the Klein Brak Estuary for 7 August 2005 showing closed mouth conditions (Source Google Earth)

Figure A.5b Satellite image of the Klein Brak Estuary for 3 December 2005 showing a very constricted mouth conditions (Source: Google Earth)

A.4 TIDAL AMPLITUDE AND MARINE SEDIMENT INTRUSION

Historical photographs of the Klein Brak Estuary show significant accumulation of marine sediment up to the railway bridge or just upstream from this bridge (refer to **Figure A.6a** to **A.6d**). It is possible that this bridge therefore affects the sediment dynamics of the lower estuary. The degree to which this “sediment plug” develops between flood events is a major contributing factor to the mouth state of the Klein Brak Estuary. Significant ingress of marine sediments in the lower reaches results in the increase of tidal friction, reduced tidal amplitude, reduced open water area resulting in a decrease in tidal flows. During periods when reduced tidal flow coincides with low river inflow (< 0.5 m^3/s) and high waves conditions (often associated with winter) this can result in mouth closure. Historical imagery from 1940-1970 shows sediment accumulation up to the railway bridge. Imagery from 1972 shows progression well past the railway bridge, with a resetting to below the bridge between April and December 1980. By 1987 the sediment once again intrudes past the rail way bridge and reaches its maximum intrution on the 2005 imagery**.**

A major flood occurred in the Klein Brak River on 22 November 2007 when large quantities of sediments were flushed out of the estuary. This could be the reason that the sand banks connected to the berm seem to extent further upstream on the Google photographs taken before that date and less far on the photographs taken after this date.

1940

30 April 1970 (possible closed mouth)

Figure A.6a Klein Brak Estuary mouth showing sedimentation in the lower reaches below railway bridge (Source: Google Earth)

22 September 1972 (possible closed mouth)

4 April 1976

8 April 1977

21 April 1979

Figure A.6b Klein Brak Estuary mouth showing progressive sedimentation in the lower reaches above railway bridge (Source: Google Earth)

9 April 1980 (possibly closed mouth)

December 1980

December 1981

February 1987

Figure A.6c Klein Brak Estuary mouth showing progressive sedimentation in the lower reaches above railway bridge (Source: Google Earth)

28 February 2010

13 September 2013

Figure A.6d Klein Brak Estuary mouth showing progressive sedimentation in the lower reaches above railway bridge (Source: Google Earth)

A.5 TIDAL AMPLITUDE AND LOSS OF UPPER REACHES

Tidal flows have also been reduced as a result of the reduction in open water areas caused by dirt roads and blocked culverts on both the Moordkuil and Brandwag arms of the Klein Brak Estuary (refer to **Figure A.7**). The loss in tidal flows is estimated at about 5%.

Figure A.7 Roads and blocked culverts preventing tidal flows and salinity penetration into the upper reaches of the Klein Brak Estuary

APPENDIX B: DATA SUMMARY REPORT FOR SEDIMENT DYNAMICS

B.1 AVAILABLE DATA

Very little data are available on sediment dynamics and estuarine morphology of the Klein Brak Estuary. The main sources of information related to sediment dynamics and morphology (largely anecdotal or circumstantial) are Cooper (2001), Day (1981), Harrison *et al.* (2000) and Moore *et al.* (2010). A number of significant impacts on physical drivers and morphologic and sediment dynamics characteristics were observed during a site investigation conducted on 7 December 2013.

Sediment samples were collected in the mouth (between the high and low water mark) of the Kleinbrak Estuary on 27 January 1996. This sediment sample had a median grain size of 0.46 mm which is just inside the limit of medium sands based on the Udden-Wentworth classification (Tanner, 1969).

B.2 PERTINENT IMPACTS ON PHYSICAL DRIVERS AND MORPHOLOGIC & SEDIMENT DYNAMICS CHARACTERISTICS

Large floods are important in flushing out sediment accumulations within the estuary (both from riverine and marine origin), and preventing the encroachment of reeds and sedges into the main estuary channel. There are no large dams in the catchment of the Klein Brak Estuary. Freshwater abstraction from the Moordkuil tributary is transferred to the off-schannel Klipheuwel Dam to supply the town of Mossel Bay. In addition, there are numerous relatively small farm dams in the catchment capturing first flushes and freshettes, as well as run of river abstraction. Thus, it is estimated that there is a significant reduction in river inflow to the estuary. Flood events are expected to occur relatively untransformed from Reference Condition to Present State, i.e. in the order of 10% change from Reference. Thus slightly reduced mobility and flushing of sediments in the estuary, and potentially increased penetration of marine sediments. The small dams will preferentially trap a larger proportion of the coarser sediments, but have very low sediment trapping efficiency and capacity, and with the Klipheuwel Dam an off-channel impoundment, thereis also little effect on sediment yield from the catchment.

Figure B.1 Accummulation of sediment downstream of railway bridge in the Klein Brak Estuary (Source Google Earth)

The railway bridge near the mouth has a significant effect on the hydrodynamics as well as on the sediment dynamics in the area (Image courtesy of Google Earth). **Figure B.1** shows the major accumulation of sand from the sea up to the railway bridge or just upstream from this bridge. This bridge therefore appears to affect the sediment dynamics of the lower estuary. A major flood occurred in the Klein Brak River on 22 November 2007 when large quantities of sediments were flushed out of the estuary during this flood. This could be the reason that the sand banks connected to the berm seem to extent further upstream on the Google photographs taken before that date and less far on the photographs taken after this date (refer to **Figures A.6a** to **A.6d**).

The intertidal and subtidal reef area in the surf zone on the southwestern side of the mouth is clearly visible in this image. These rocky areas help to keep the mouth open. Also noticeable is the edge of the Klein Brak River town development on the northern banks of the lower estuary. There are extensive formal and informal settlements on the floodplain of the Klein Brak Estuary in the lower reaches. Besides direct habitat destruction, stormwater runoff from these settlements is likely to comprise higher suspended solids.

Cattle were observed trampling supratidal floodplain along the Klein Brak Estuary (Photo: A Theron):

Grazing and trampling of salt marsh areas also occurs. These farming practices give rise to impacted vegetation cover and increased potential for land erosion and sediment inputs (also higher suspended solids) into the estuary. Significant agricultural activities in the catchment such as these and especially crop cultivation lead to increased land erosion and thus sediment yield to the estuary. Farming (fruit orchards) as observed on the banks of estuary can result in increased sedimentation.

An example of a "low-water drift" and culvert impeding flow in the upper reaches of the estuary (Photo: A Theron) is provided below:

Such channel modifications and flow impediments are found on both of the main arms of the estuary along the upper reaches.

Example of bank protection impacting on estuarine habitat and morphology in upper reaches (Photo: A Theron) is provided below:

Besides the direct impacts within the footprint of the structure, such works often lead to increased erosion of adjacent areas (erosion hot spots). In addition, such ad hoc works are prone to structural failure during higher floods, resulting in episodic inputs of “construction materials” (e.g. tyers, planks, poles, rock rip-rap, concrete blocks, etc.) into the estuary.

Example of rubble revetment, bank protection and slipway impacting on estuarine habitat and morphology near Klein Brak Town (in middle reaches) (Photo: A Theron) is as follows:

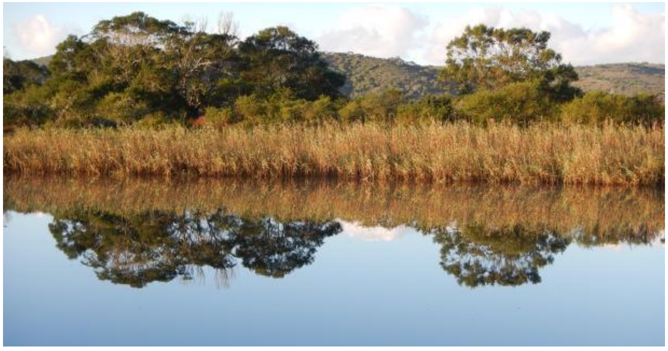
Multiple road bridges and abutments impacting on estuary banks and supratidal area (Photo: A Theron):

Due to large open spans the impacts on tidal flows are not expected to be large.

Silt/mud banks near the confluence of the two main arms of the estuary, subject to erosion and undercutting from wind waves, boat wash, peak tidal flows and river floods (Photo: A Theron):

New sediment deposits may (partially) rebuild such banks during the waning phase of river floods carrying high loads of fine sediments.

Invasive alien plant species have colonized some channel banks and floodplain areas (Photo: A Theron) as illustrated below:



These may significantly hinder “natural” bank erosion during floods, allowing for compaction/consolidation of sediments and further establishment of “permanent” vegetation, with associated dampening of natural channel variability.

Significant modification of the banks for recreational activities and access at a camping site (Photo: A Theron) as illustrated below:

Besides direct physical habitat destruction, the removal of vegetation such as reeds, sedges, etc., can also potentially lead to higher erosion during large river floods.

APPENDIX C: DATA SUMMARY REPORT FOR WATER QUALITY

C.1 AVAILABLE DATA

The following water quality data were available on the Klein Brak Estuary:

Description	Availability	Reference
Longitudinal salinity and temperature profiles (in situ) collected over a spring and neap tide during high and low tide at: ▪ end of low flow season ▪ peak of high flow season	May 2010 Apr 2013 Dec 2013	Moore, Breetzke, van Niekerk and James(2010) Lemley (2015) This study (Annexure C1 for data)
Water quality measurements (i.e. system variables, and nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at: ▪ end of low flow season ▪ peak of high flow season	May 2010 Apr 2013 Dec 2013	Moore, Breetzke, van Niekerk and James (2010) Lemley (2015) This study (see Annexure C1 for data)
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary	July 1978 (trace metals)	Watling and Watling (1982)
Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary	Moordkuil (station K1H5), Brandwag (station K1H)	DWA water quality monitoring programme
Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater	From literature	DWAF, 1995

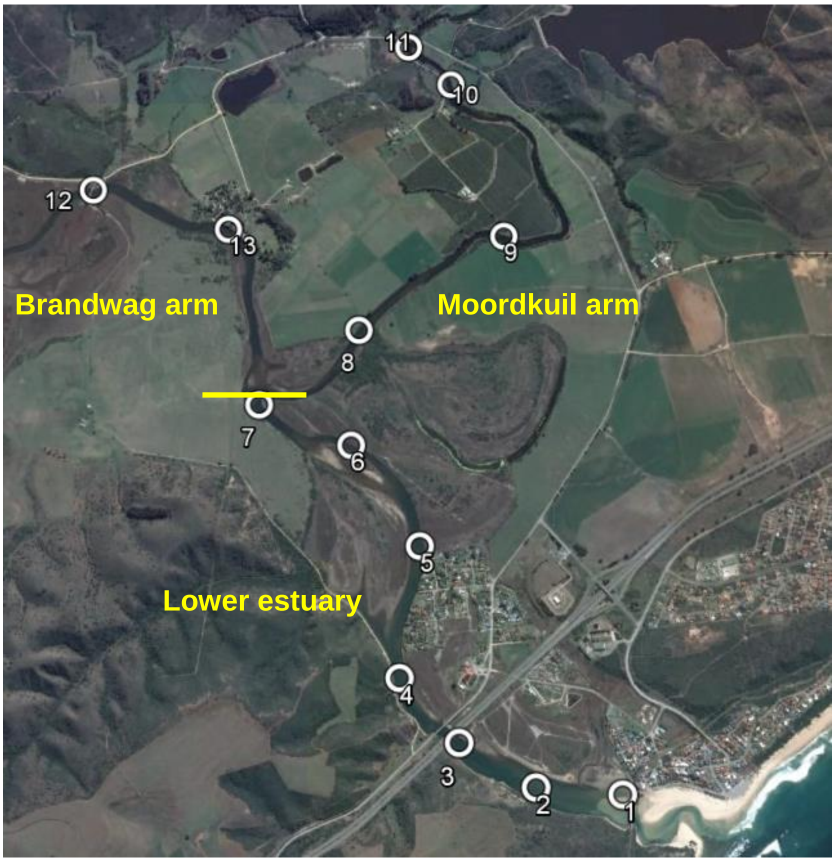


Figure C.1 Position of water quality sampling stations in the Klein Brak Estuary (May 2010 and December 2013) (see annexure C1 for distance from mouth)

C.2 SALINITY

Salinity measurements taken in the Klein Brak Estuary during May 2010 (**Figure C.2**) show the estuary in a marine dominated condition throughout, with measurements between 35 at the mouth and 31 at the culverts in the Moordkuil arm (and about 32 at the Brandwag Culvert). River inflow was about 0.1 m^3/s during this period.

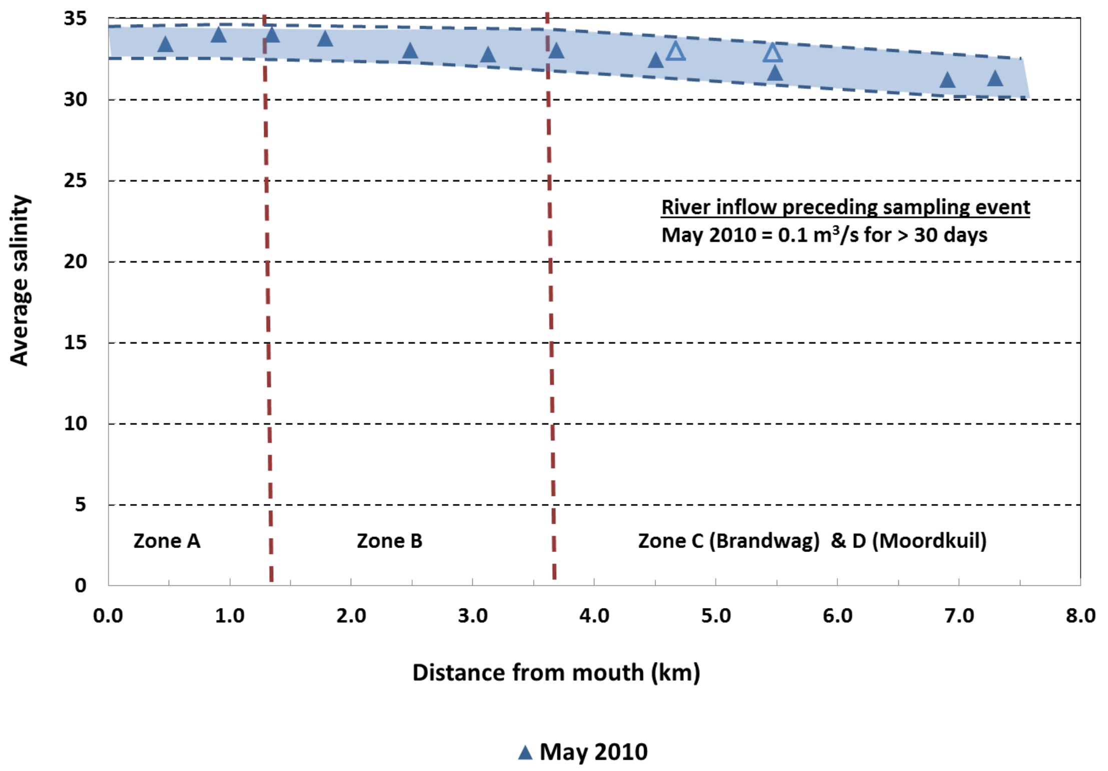


Figure C.2 Salinity penetration along the length of the Klein Brak Estuary at very low flows (~0.1 m^3/s)

Salinity measurements (refer to **Figure C.3, top**) taken under intermediate flow conditions (0.7 to 1.2 m^3/s) indicate that the system was marine dominated in the lower reaches (Zone A), between 33 and 15 in the middle reaches (Zone B), between 15 (bottom) and 5 (surface) in the lower part of the Moordkuil arm (Zone D) and relatively saline in the lower part of the Brandwag arm (Zone C) at between 25 (bottom) and 13 (surface). Limited stratification was observed in the middle and upper reaches of the system.

Similar, salinity measurements taken within about two weeks of a significant flood event (refer to **Figure C.3, bottom**) shows how responsive the Klein Brak Estuary is to seawater penetration - with salinity in the lower reaches (Zone A) varying between 35 and 20, the middle reaches (Zone B) between 35 (in deeper areas) and 10 (surface water), the Moordkuil arm between 15 (bottom waters) and 0, and the Brandwag arm between 17 (bottom waters) and 0 (surface). The estuary were highly stratified in areas where it was deeper than ~ 2.0 m with pockets of high salinity bottom waters especially notable in the middle reaches and the Moordkuil arm.

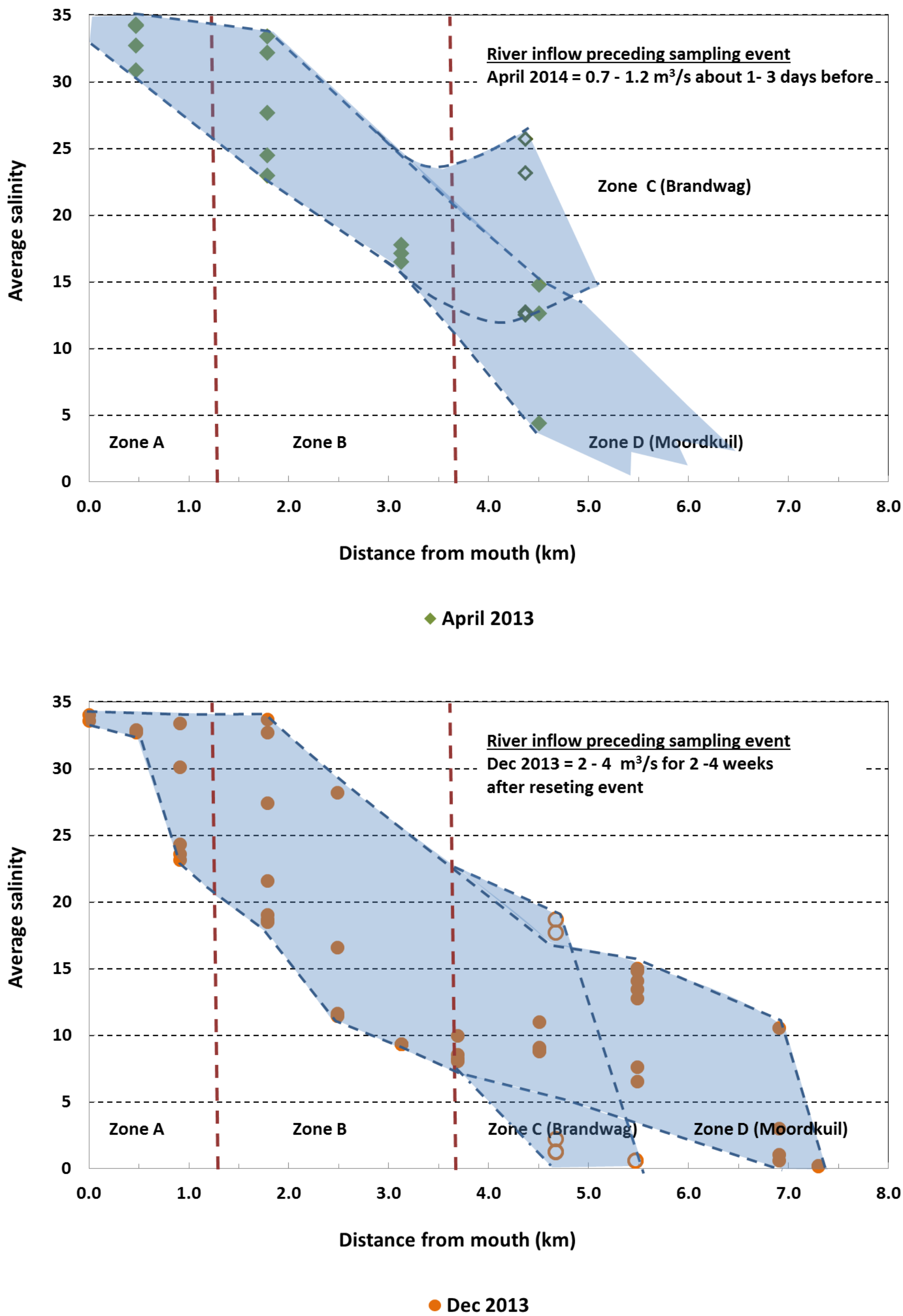


Figure C.3 Salinity penetration along the length of the Klein Brak Estuary at intermediate flow conditions (1.0 to 4.0 m^3/s)

C.3 TEMPERATURE

Average temperature measured along the length of the estuary on three occasions (May 2010, April 2013 and December 2013) is presented in **Figure C.4**. As expected, temperatures were highest during summer (December 2013) ranging between 18.9 and 22.5 ^{o}C. The lower temperatures were recorded in saline water near the mouth (reflecting temperatures in the sea). Moving upstream influence of warmer atmospheric temperatures became evident. During the April 2013 survey, temperatures of as low as 13.6 ^{o}C were measured in the lower estuary. Winter temperature (May 2010) ranged between 17.5-20 ^{o}C.

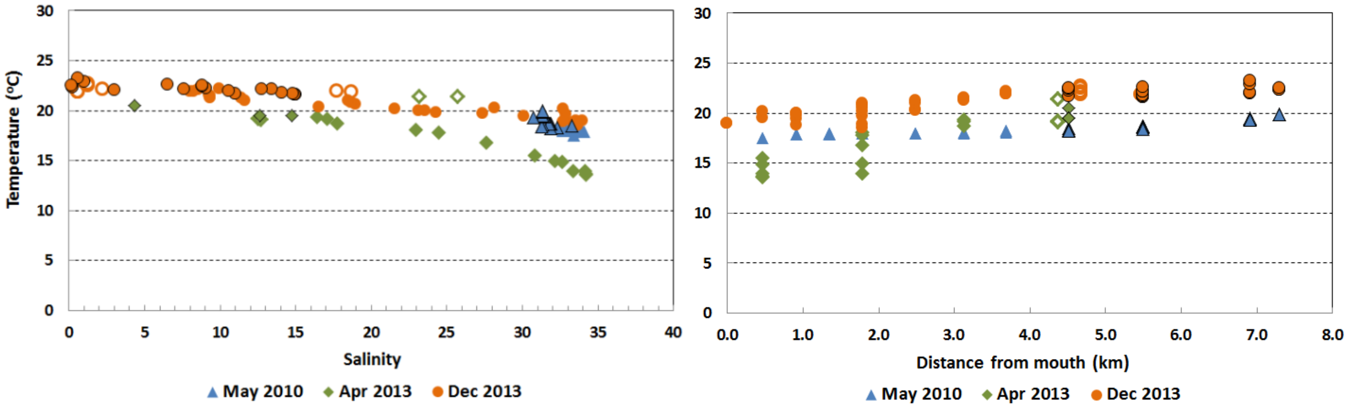


Figure C.4: Temperature measured against salinity (left) and along the length of the estuary (right in the Klein Brak Estuary in May 2010, April 2013 and December 2013 (Solid marker – Lower estuary, Open marker – Brandwag arm and Solid marker with black – Moordkuil arm)

C.4 pH

Annual median pH levels measured in the Brandwag (K1h004) and Moordkuil (K1h005) tributaries between 1976 and 2013 are presented in **Figure C.5a**.

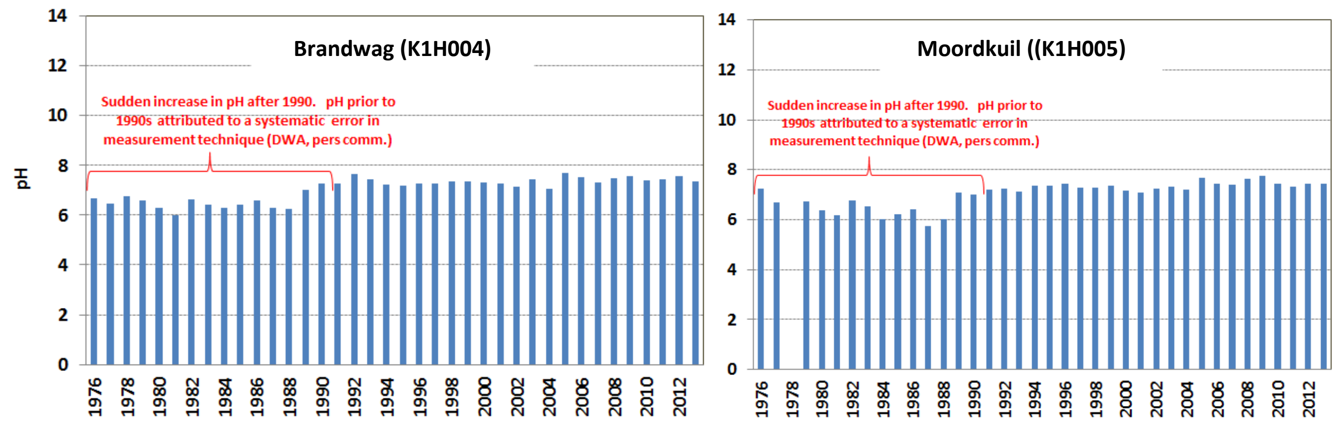


Figure C.5a Median annual pH levels measured in the Brandwag and Moorkuil tributaries between 1976 and 2013

Medina annual pH levels ranged between 7 and 8 with no marked trends over the years.

pH levels showed a tendency to decrease with decrease in salinity (moving upstream) and ranged between 8.5 and 6.9 (**Figure C.5b**).

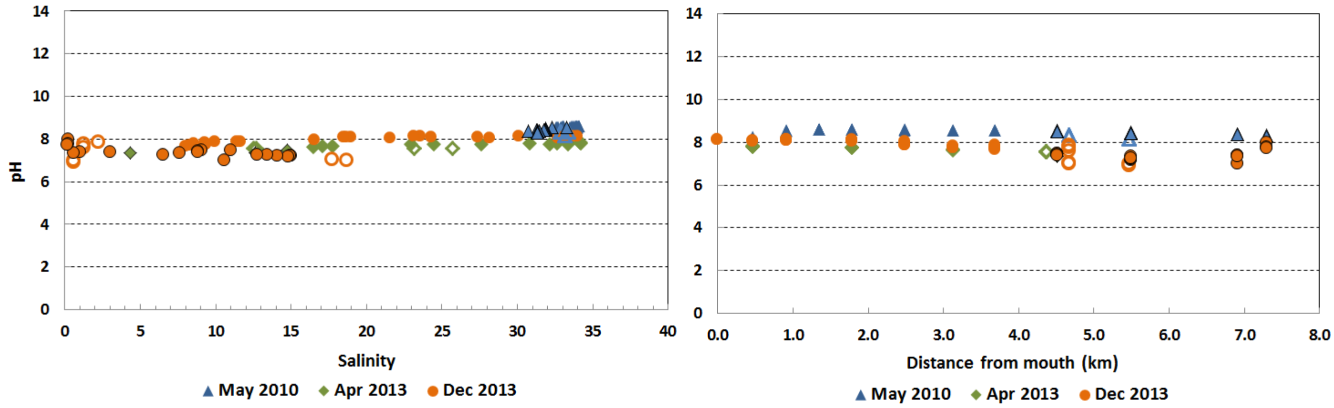


Figure C.5b pH measured against salinity (left) and along the length of the estuary (right in the Klein Brak Estuary in May 2010, April 2013 and December 2013 (Solid marker – Lower estuary, Open marker – Brandwag arm and Solid marker with black – Moordkuil arm)

C.5 DISSOLVED OXYGEN

Average dissolved oxygen (DO) concentrations measured along the estuary during May 2010 and December 2013 is presented in **Figure C.5a**.

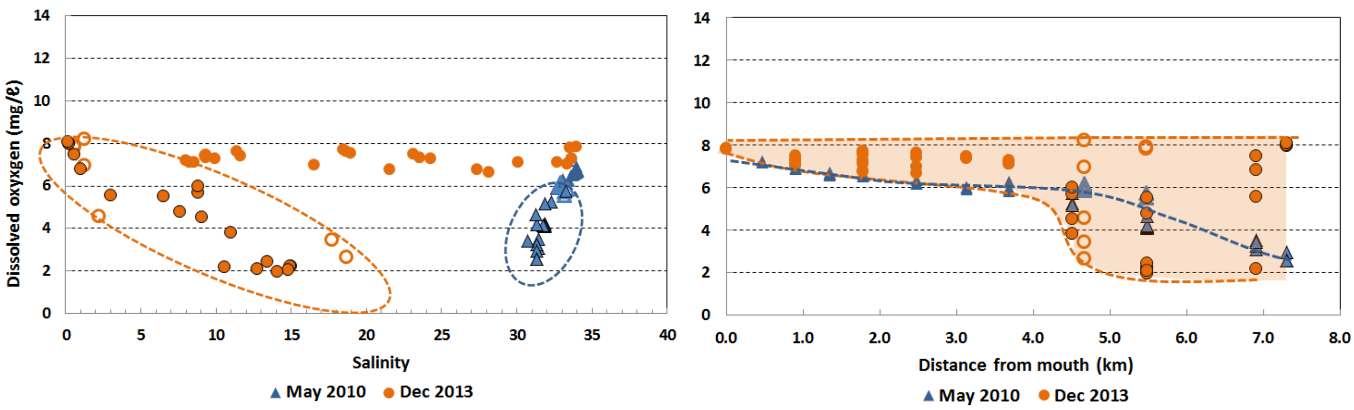


Figure C.6a Dissolved oxygen concentrations measured against salinity (left) and along the length of the estuary (right in the Klein Brak Estuary in May 2010 and December 2013 (Solid marker – Lower estuary, Open marker – Brandwag arm and Solid marker with black – Moordkuil arm)

On both occasions the system was well-oxygenated in the lower estuary (up to 4.5 km from the mouth), but showed a tendency to decrease moving upstream, especially along the Moordkuil arm. This is also reflected in the dissolved oxygen profiles plots (refer to **Figure C.6b**). During both surveys lowest DO concentrations were measured in the Moordkuil arm. The recovery of DO levels towards the upper section of the Moordkuil arm during December 2013 was probably the result of "new" river water entering the system at the time. Results therefore suggest that DO concentrations in the upper Moordkuil arm is likely to decrease during period when water remains in the area for extended periods when river inflow in very low (e.g. May 2010) or in deeper bottom waters when the water column is stratified (e.g. December 2013). Reduction in DO may have been aggravated as a result of increased organic loading into the system from adjacent land-use.

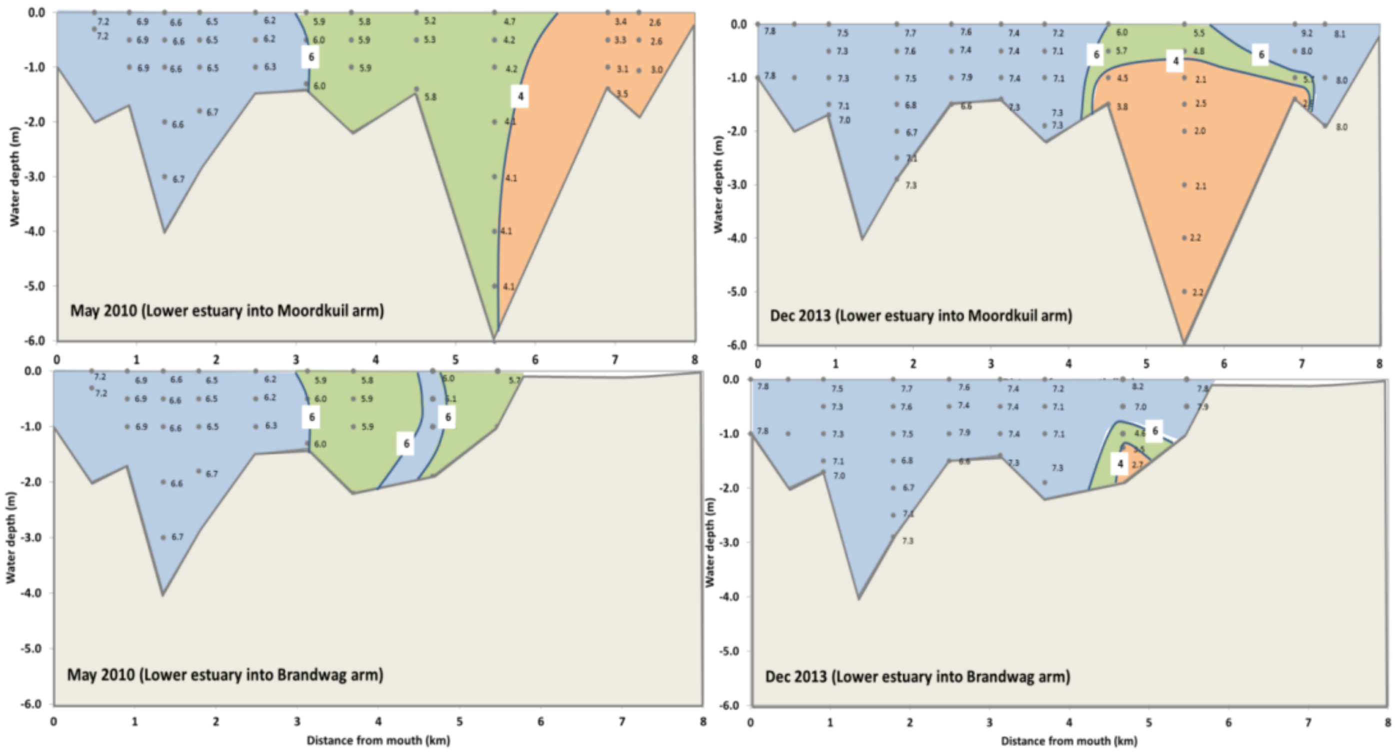


Figure C.6b Dissolved oxygen profiles along the Klein Brak Estuary into Moordkuil (top) and Brandwag (bottom) arms in May 2010 and December 2013

C.6 SUSPENDED SOLIDS (TURBIDITY)

Average turbidity concentrations, suspended solid concentration and Secchi depths measured along the length of the Klein Brak Estuary during 2010 and 2013 are presented in **Figure C.7**.

Turbidity results from the May 2010 survey indicate that during periods of low river inflow when the estuary become mostly saline, turbidity concentrations are low (< 10 NTU). During periods when there is a strong river signal (fresher water) present in the estuary (e.g. December 2013) turbidity and suspended solid concentrations tend to increase moving into fresher upstream waters, especially the Brandwag arm. This is also reflected in the Secchi depths for both the April and December 2013 surveys when water clarity reduced moving into fresher upstream sections, especially the Brandwag arm (December 2013). This reflects the character of river water with more turbid runoff entering the estuary from the Brandwag Tributary compared with runoff from the Moordkuil. It is expected for agriculture in the catchment to have contributed to increased turbidity levels compared with reference.

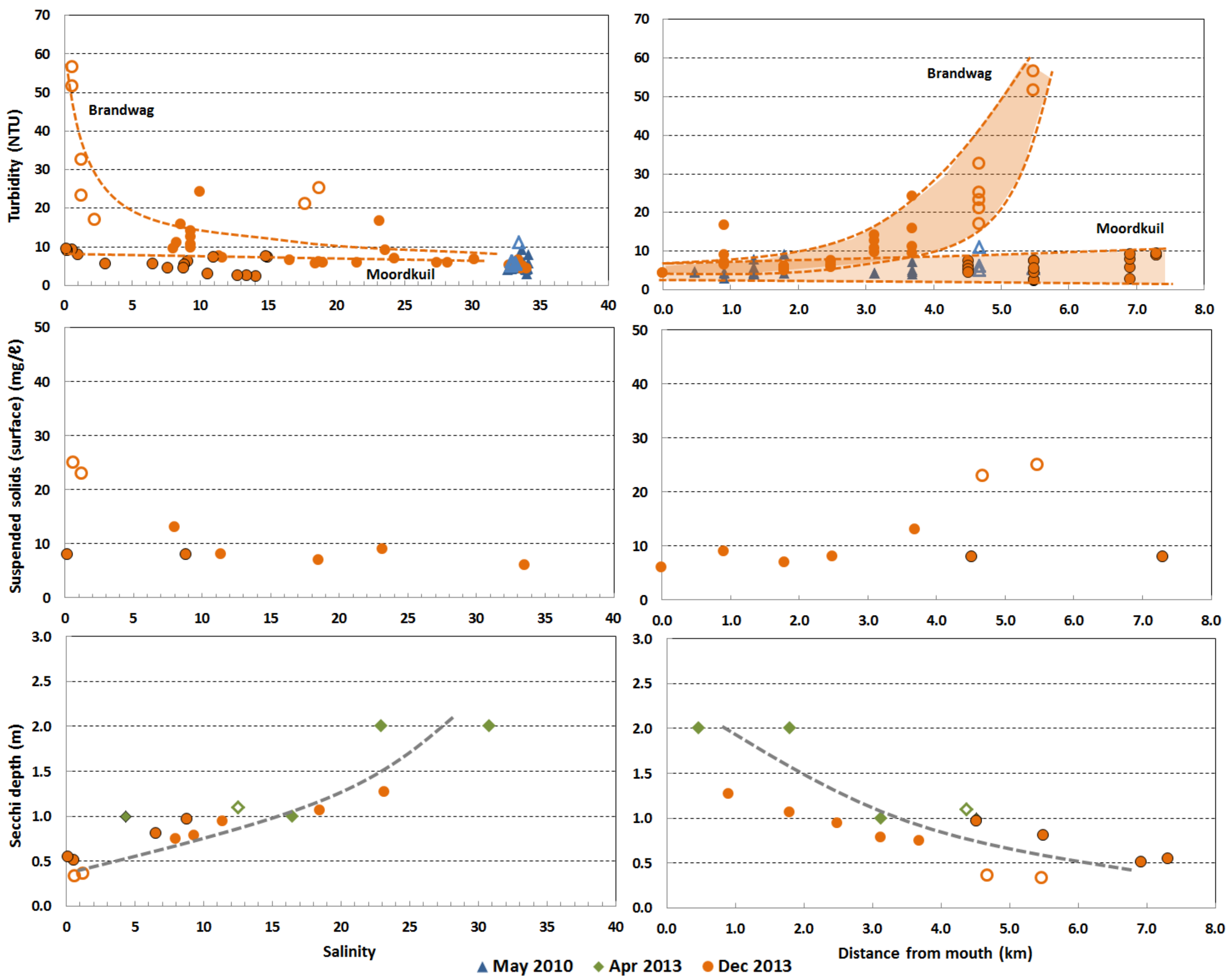


Figure C.7 **Turbidity (top), Suspended solids concentrations (middle) and Secchi depth (bottom) measured against salinity (left) and along the length of the estuary (right in the Klein Brak Estuary in May 2010, April 2013 and December 2013 (Solid marker – Lower estuary, Open marker – Brandwag arm and Solid marker with black – Moordkuil arm)**

C.7 DISSOLVED INORGANIC NUTRIENTS

The Klein Brak Estuary receives river inflow from two catchments (Moordkuil and Brandwag tributaries). As a result it was not considered appropriate to apply property-salinity plots in this assessment. The mixing diagram approach relies on the freshwater source (salinity 0) to be uniform which in this instance is not the case. It was therefore chosen to explore nutrient distribution patterns along the length of the estuary, but to still relate these to salinity distribution patterns to gain understanding on sources (refer to **Figure C.8b**). Nutrient concentrations did not show marked vertical gradients in the various surveys and depth averaged concentrations were therefore considered here. Annual median concentration of inorganic nutrient concentrations measured in the Brandwag (station K1H4) and Moordkuil (station K1H5) tributaries between 1976 and 2013 are presented in **Figure C.8a**. Average inorganic nutrient concentrations measured along the length of the Klein Brak Estuary during April and December 2013 are presented in **Figure C.8b**.

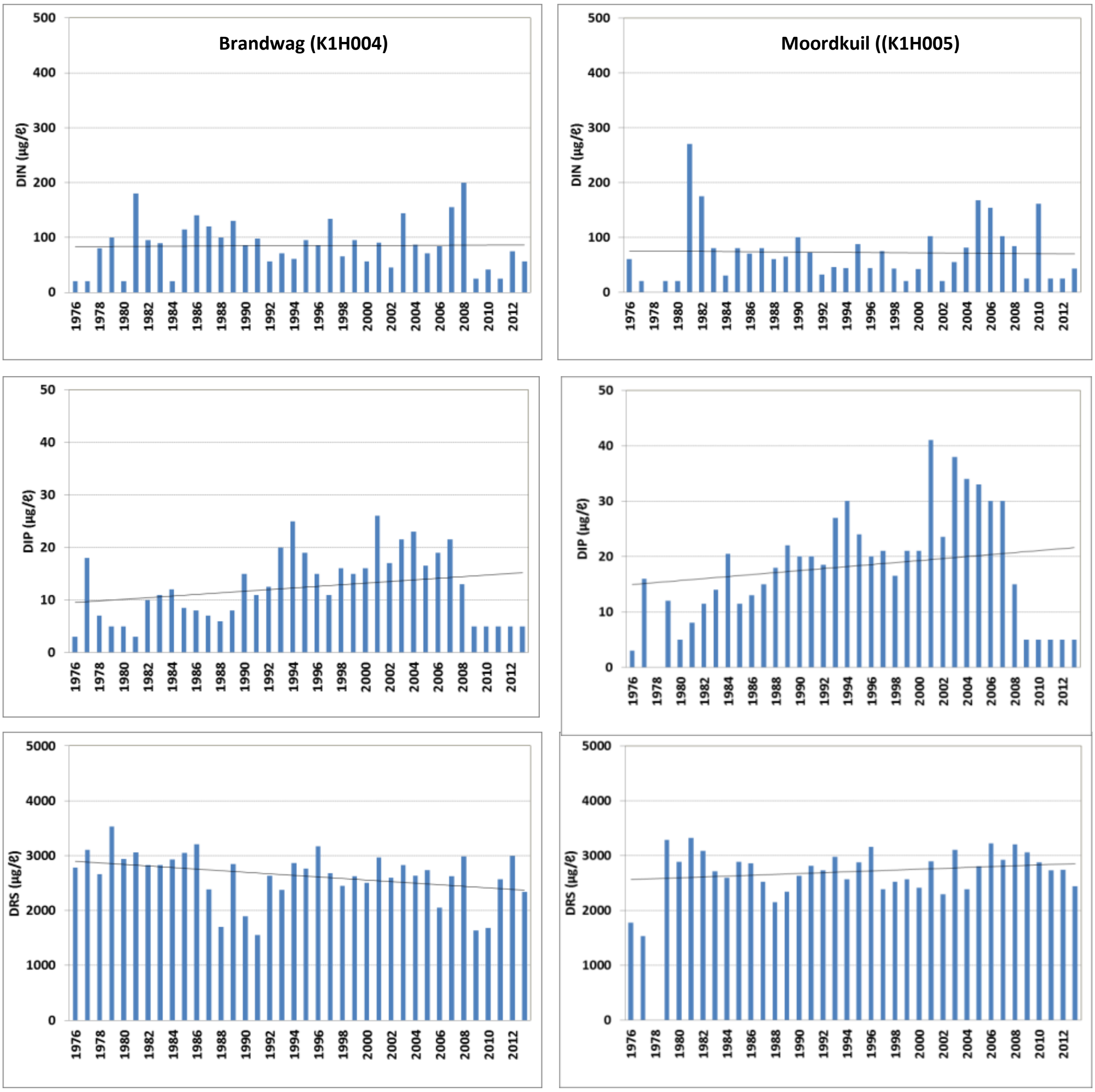


Figure C.8a Median annual dissolved inorganic nitrogen-N (DIN) (top), dissolved inorganic phosphate-P (DIP) (middle) and dissolved reactive silicate-Si (DRS) (bottom) measured in the Brandwag and Moorkuil tributaries between 1976 and 2013

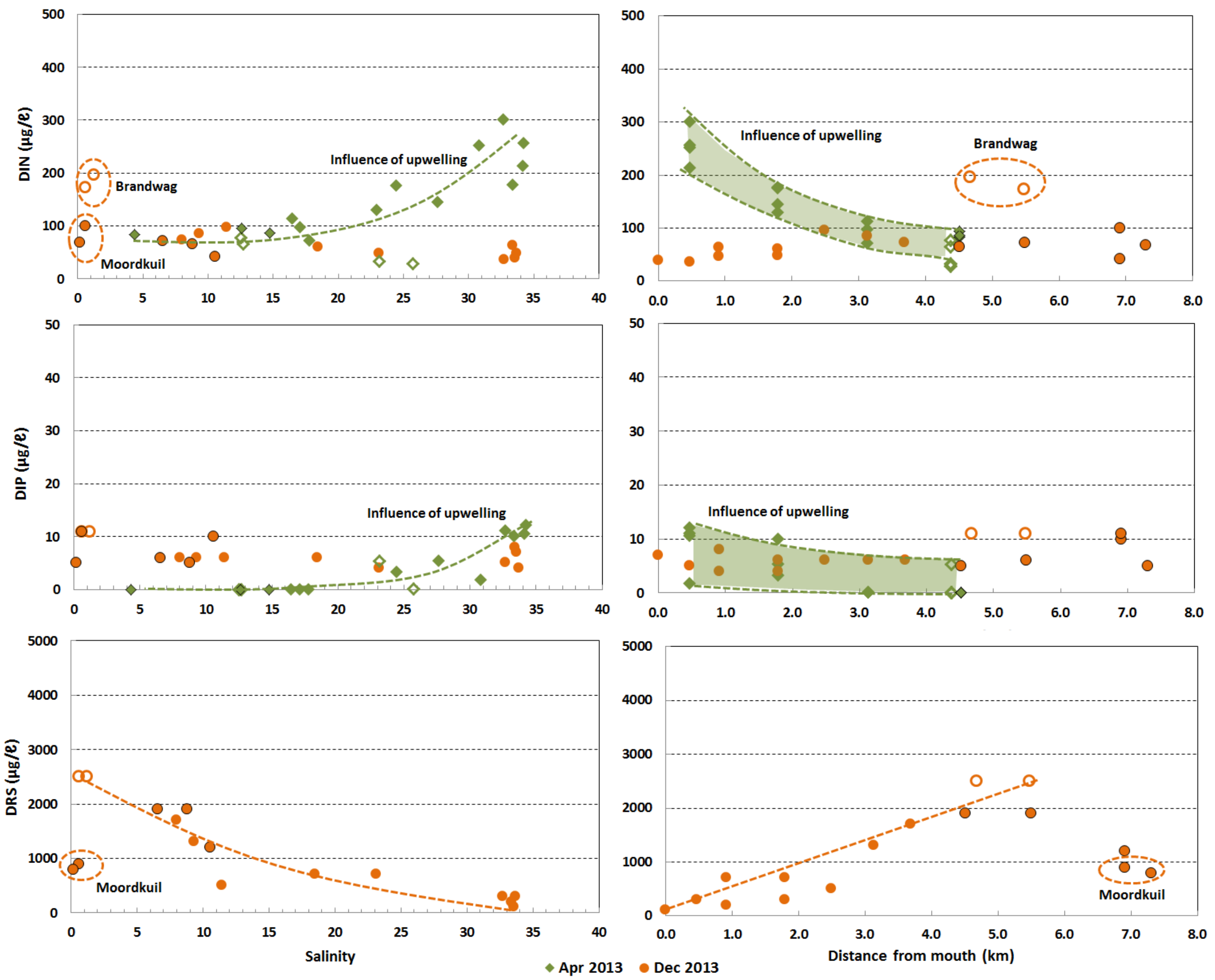


Figure C.8b Dissolved inorganic nitrogen-N (DIN) (top), dissolved inorganic phosphate-P (DIP) (middle) and dissolved reactive silicate-Si (DRS) (bottom) measured against salinity (left) and along the length of the estuary (right in the Klein Brak Estuary in April 2013 and December 2013 (Solid marker – Lower estuary, Open marker – Brandwag arm and Solid marker with black – Moordkuil arm)

C.7.1 Dissolved inorganic nitrogen (DIN)

Annual median DIN concentrations over the period 1976 to 2013 in the Brandwag and Moordkuil rivers (**Figure C.8a**) did not show significant increase with time and were generally below 100 µg/ℓ. Overall, concentrations in the Brandwag Tributary were higher (average 90 µg/ℓ) than in the Moordkuil Tributary (average 70 µg/ℓ). These concentration levels were also reflected in the 2013 surveys (**Figure C.8b**), except in the lower reaches of the estuary (April 2013) and in the Brandwag arm (December 2013). During April 2013 salinities in the lower reaches were high (~30) while temperatures were very low (~13°C). These characteristics are typical of newly upwelled waters containing elevated inorganic nutrient concentrations, including DIN. Higher concentrations in the

Brandwag arm during December 2013 mimicked the overall pattern in river inflow (Brandwag has slightly higher concentrations compared with Moordkuil).

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

C.7.2 Dissolved inorganic phosphate (DIP)

Annual median DIP concentrations over the period 1976 to 2013 in the Brandwag and Moordkuil rivers are presented in **Figure C.8a.**

Although concentrations were generally low (10-30 µg/ℓ), it increased from 1976 to 2007. In contrast to DIN, DIP concentrations in the Brandwag were generally lower compared to Moordkuil. However, in both systems annual median DIP concentrations decreased markedly from 2008 to 2013 (< 5 µg/ℓ), returning to levels below Reference Condition (see De Villiers and Thiart, 2007). This drastic decrease could not be explained.

Low DIP concentrations were recorded in the Klein Brak Estuary during the 2013 surveys (**Figure C.8b**), mostly 10µg/ℓ or less. Slightly higher concentrations occurring in the lower reaches compared with the upper reaches in April 2013 probably attributed to newly upwelled waters (containing elevated inorganic nutrient concentrations) that entered the estuary at the time.

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

C.7.3 issolved reactive silicate (DRS)

Annual median DRS concentrations over the period 1976 to 2013 in the Brandwag and Moordkuil tributaries are presented in **Figure C.8a**. Concentrations typically ranged between 1000 and 3000 µg/ℓ with varying trends – slightly decreasing over time in the Brandwag and increasing over time in Moordkuil. High DRS concentrations are typical of freshwater systems and are not attributed to anthropogenic enrichment. Estimated DRS concentrations in seawater along this part of the coast is expected to be relative low (100 µg/ℓ) (DWAF, 1995) compared with concentrations in freshwater. Distribution patterns of DRS in the Klein Brak Estuary (December 2013) also reflected this trend with concentrations generally increasing from the saline lower reaches into the fresher upper reaches (refer to **Figure C.8b**).

C.8 TOXIC SUBSTANCES

Data on toxic substances (specifically metals) was collected from the Klein Brak in July 1978 (Watling and Watling, 1982). A comparison of this data with quality guidelines recommended for the

Western Indian Ocean (UNEP/Nairobi Convention Secretariat and CSIR, 2009) is presented in **Table C.1**.

Table C.1 Average metal concentrations measured in the Klein Brak Estuary during July 1978, as well as recommended quality guidelines for the protection of marine aquatic life (UNEP/Nairobi Convention Secretariat and CSIR, 2009)

Metal	Mean in water (µg/ℓ)	Mean in sediment (mg/kg)	Guideline	
			Water	Sediment
Cd	0.9	0.04	5.5	0.68
Cu	**2.6**	4.0	**1.3**	18.7
Ni	<0.1	4.2	70	15.9
Pb	0.3	10.7	4.4	30.2
Zn	1.3	12.4	15	124

Results suggest that at the time (1978) average metal concentrations in system were well within the recommended guidelines (UNEP/Nairobi Convention Secretariat and CSIR, 2009), except for copper which was slightly higher than recommended in the water column. The authors concluded that these levels remain generally low and do not reflect significant levels of pollution. Interestingly, metal concentrations in the sediment were highest at the confluence of the Brandwag and Moordkuil tributaries possibly linked to flocculation processes.

However, since the late 1970s extensive formal and informal settlements have developed along the floodplain of the lower reaches of the estuary. Here stormwater runoff is likely to have introduced some toxic substances (e.g. hydrocarbons and metals) over time, although not considered to have results in heavy toxic pollution.

No data are available on pesticides and herbicide levels in the estuary which is likely to have occurred considering the intensive agricultural activities (e.g. fruit and vegetables and sheep and cattle farming) along the systems and in its catchment. Again, it is not considered to be heavily polluted.

Addendum C1: Water quality data collected on 7 December 2013

Date	Time	Stn	X Cordinates	Y Coordinates	Distance from mouth (km)	Depth (m)	Temp	Salinity	pH	NTU	SS (mg/l)	DO (mg/l)	DO (%)	Secchi (m)	NO2-N (µg/l)	NH4-N (µg/l)	NOX-N (µg/l)	DIN (ug/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tot P (µg/l)
07-Dec-13	10:00	Mouth			0.00	1.00	19.0	34.0	8.1	4.4		7.8	103								
07-Dec-13	10:00	Mouth			0.00	0.00	18.9	33.6	8.1	4.4	6	7.8	103	>1	1	33	5	38	7	100	<250
07-Dec-13	10:15	1	34 05 24.9	22 08 37.3	0.47	1.00	19.6	32.9	8.1												
07-Dec-13	10:15	1	34 05 24.9	22 08 37.3	0.47	0.00	20.1	32.7	8.0						1	31	5	36	5	300	
07-Dec-13	10:50	2	34 05 23.8	22 08 20.2	0.91	1.70	18.8	33.4	8.1	6.4		7.0	91		10	58	5	63	8	200	
07-Dec-13	10:50	2	34 05 23.8	22 08 20.2	0.91	1.50	19.4	30.1	8.1	6.7		7.1	91								
07-Dec-13	10:50	2	34 05 23.8	22 08 20.2	0.91	1.00	19.8	24.3	8.1	7.0		7.3	92								
07-Dec-13	10:50	2	34 05 23.8	22 08 20.2	0.91	0.50	19.9	23.6	8.1	9.0		7.3	93								
07-Dec-13	10:50	2	34 05 23.8	22 08 20.2	0.91	0.00	19.9	23.2	8.1	16.7	9	7.5	94	1.3	2	29	18	47	4	700	<250
07-Dec-13	11:00	4	34 05 06.4	22 07 53.2	1.79	2.90	18.5	33.7	8.1	5.0		7.3	95		1	40	8	48	4	300	
07-Dec-13	11:00	4	34 05 06.4	22 07 53.2	1.79	2.50	18.9	32.7	8.1	5.2		7.1	92								
07-Dec-13	11:00	4	34 05 06.4	22 07 53.2	1.79	2.00	19.7	27.4	8.1	5.9		6.7	87								
07-Dec-13	11:00	4	34 05 06.4	22 07 53.2	1.79	1.50	20.2	21.6	8.0	5.9		6.8	85								
07-Dec-13	11:00	4	34 05 06.4	22 07 53.2	1.79	1.00	20.6	19.0	8.1	5.9		7.5	94								
07-Dec-13	11:00	4	34 05 06.4	22 07 53.2	1.79	0.50	20.8	18.7	8.1	6.0		7.6	95								
07-Dec-13	11:00	4	34 05 06.4	22 07 53.2	1.79	0.00	20.9	18.5	8.1	5.7	7	7.7	97	1.1	2	36	24	60	6	700	70
07-Dec-13	11:45	5	34 04 44.7	22 07 57.1	2.49	1.50	20.3	28.2	8.0	5.8		6.6	86								
07-Dec-13	11:45	5	34 04 44.7	22 07 57.1	2.49	1.00	20.3	16.6	7.9	6.5		7.0	85								
07-Dec-13	11:45	5	34 04 44.7	22 07 57.1	2.49	0.50	21.0	11.6	7.9	7.2		7.4	89								
07-Dec-13	11:45	5	34 04 44.7	22 07 57.1	2.49	0.00	21.2	11.4	7.9	7.5	8	7.6	92	0.9	2	44	52	96	6	500	<250
07-Dec-13	12:02	6	34 04 27.8	22 07 43.0	3.13	1.40	21.3	9.3	7.8	9.7		7.3	89								
07-Dec-13	12:02	6	34 04 27.8	22 07 43.0	3.13	1.00	21.5	9.3	7.8	10.6		7.4	89								
07-Dec-13	12:02	6	34 04 27.8	22 07 43.0	3.13	0.50	21.3	9.3	7.7	14.1		7.4	89								
07-Dec-13	12:02	6	34 04 27.8	22 07 43.0	3.13	0.00	21.4	9.3	7.7	12.6		7.4	89	0.8	2	25	60	85	6	1300	
07-Dec-13	13:20	7	34 04 21	22 07 24.1	3.69	1.90	22.2	10.0	7.9	24.1		7.3	88								
07-Dec-13	13:20	7	34 04 21	22 07 24.1	3.69	1.00	22.0	8.6	7.8	15.8		7.1	85								
07-Dec-13	13:20	7	34 04 21	22 07 24.1	3.69	0.50	21.9	8.3	7.7	11.1		7.1	86								
07-Dec-13	13:20	7	34 04 21	22 07 24.1	3.69	0.00	21.9	8.0	7.7	9.4	13	7.2	86	0.7	2	22	51	73	6	1700	<50
07-Dec-13	13:03	8	34 04 08	22 07 44.3	4.51	1.50	21.7	11.0	7.5	7.4		3.8	46								
07-Dec-13	13:03	8	34 04 08	22 07 44.3	4.51	1.00	22.3	9.1	7.5	6.2		4.5	56								
07-Dec-13	13:03	8	34 04 08	22 07 44.3	4.51	0.50	22.5	8.8	7.5	5.3		5.7	70								
07-Dec-13	13:03	8	34 04 08	22 07 44.3	4.51	0.00	22.6	8.8	7.4	4.5	8	6.0	73	1.0	2	21	44	65	5	1900	<250
07-Dec-13	13:20	9	34 03 51.3	22 08 14.2	5.49	5.00	21.6	15.0	7.2			2.2	27								
07-Dec-13	13:20	9	34 03 51.3	22 08 14.2	5.49	4.00	21.6	15.0	7.2	7.4		2.2	27								
07-Dec-13	13:20	9	34 03 51.3	22 08 14.2	5.49	3.00	21.7	14.8	7.2	7.6		2.1	25								
07-Dec-13	13:20	9	34 03 51.3	22 08 14.2	5.49	2.00	21.8	14.1	7.2	2.4		2.0	25								
07-Dec-13	13:20	9	34 03 51.3	22 08 14.2	5.49	1.50	22.2	13.4	7.3	2.5		2.5	30								
07-Dec-13	13:20	9	34 03 51.3	22 08 14.2	5.49	1.00	22.1	12.8	7.3	2.6		2.1	33								
07-Dec-13	13:20	9	34 03 51.3	22 08 14.2	5.49	0.50	22.2	7.6	7.4	4.6		4.8	59								
07-Dec-13	13:20	9	34 03 51.3	22 08 14.2	5.49	0.00	22.6	6.5	7.3	5.6		5.5	67	0.8	2	22	50	72	6	1900	
07-Dec-13	14:00	10	34 03 24.06	22 08 03.1	6.91	1.40	22.0	10.6	7.0	2.9		2.2	26		2	36	5	41	10	1200	
07-Dec-13	14:00	10	34 03 24.06	22 08 03.1	6.91	1.00	22.1	3.0	7.4	5.7		5.6	67								
07-Dec-13	14:00	10	34 03 24.06	22 08 03.1	6.91	0.50	22.9	1.0	7.4	8.0		6.8	82								
07-Dec-13	14:00	10	34 03 24.06	22 08 03.1	6.91	0.00	23.3	0.6	7.4	9.2		7.5	88	0.5	2	36	64	100	11	900	
07-Dec-13	14:13	11	34 03 17.3	22 07 54.1	7.30	1.90	22.3	0.2	8.0	9.1		8.0	92								
07-Dec-13	14:13	11	34 03 17.3	22 07 54.1	7.30	1.00	22.4	0.2	7.8	9.0		8.0	92								
07-Dec-13	14:13	11	34 03 17.3	22 07 54.1	7.30	0.00	22.5	0.2	7.7	9.4	8	8.1	94	0.6	3	63	5	68	5	800	<50
07-Dec-13	15:51	13	34 03 50.3	22 07 16.9	4.67	1.50	21.9	18.7	7.0	25.2		2.7	33								
07-Dec-13	15:51	13	34 03 50.3	22 07 16.9	4.67	1.25	22.0	17.7	7.1	21.1		3.5	43								
07-Dec-13	15:51	13	34 03 50.3	22 07 16.9	4.67	1.00	22.1	2.2	7.9	17.1		4.6	54								
07-Dec-13	15:51	13	34 03 50.3	22 07 16.9	4.67	0.50	22.5	1.3	7.8	23.3		7.0	83								
07-Dec-13	15:51	13	34 03 50.3	22 07 16.9	4.67	0.00	22.7	1.2	7.6	32.6	23	8.2	96	0.4	2	31	165	196	11	2500	<50
07-Dec-13	16:11	12	34 03 43.6	22 06 48.5	5.47	0.50	21.9	0.6	6.9	56.6		7.9	90								
07-Dec-13	16:11	12	34 03 43.6	22 06 48.5	5.47	0.00	21.9	0.6	7.0	51.7	25	7.8	90	0.3	2	36	137	173	11	2500	<50
07-Dec-13		Drain into Moordkuil (north bank) at Fish Station 8													3	45	18	63	15	1400	

APPENDIX D: DATA SUMMARY REPORT FOR MICROALGAE

D.1 AVAILABLE DATA

Based on Whitfield's review of available information (unpublished "*Bibliography of South African Estuaries*"), the only biological information on the Klein Brak Estuary is that of James & Harrison (2008), which focuses on ichthyofauna. However, Harrison (formerly CSIR, pers. comm) did sample three sites in the Klein Brak Estuary on 15 June 1994 (winter). The sites ranged from 0.5 m to 1.7 m in depth and Secchi depth was to the bottom at all three sites indicating clear water, presumably near-marine water close to the mouth of the estuary. The pH range was 7.9 - 8.0, temperature 12 – 14ºC, salinity 24 - 32, and dissolved oxygen 10.0 – 11.7 mg/ℓ. This suggests that the sites were well mixed with strong marine intrusion diluted with fresh riverine water. Nutrient concentrations were low at the first two sites (NH_3-N = 0 - 1 µg/ℓ; PO_4-P = 0 - 30 µg/ℓ; NO_3-N = 0 µg/ℓ) and elevated at the third site (NH_3-N = 0 - 1 µg/ℓ; PO_4-P = 20 - 30 µg/ℓ; NO_3-N = 110 - 160 µg/ℓ). Phytoplankton chlorophyll *a* was below detectable limits at all three sites.

Lemley (2015) sampled five sites within the Klein Brak Estuary on 4 April 2013 (**Figure D.1**) measuring water quality and microalgal variables. These data included phytoplankton and microphytobenthos (MPB) biomass (using chlorophyll *a* as an index), phytoplankton group composition, dominant (> 10% of relative abundance) benthic diatoms, and epiphytic microalgae.

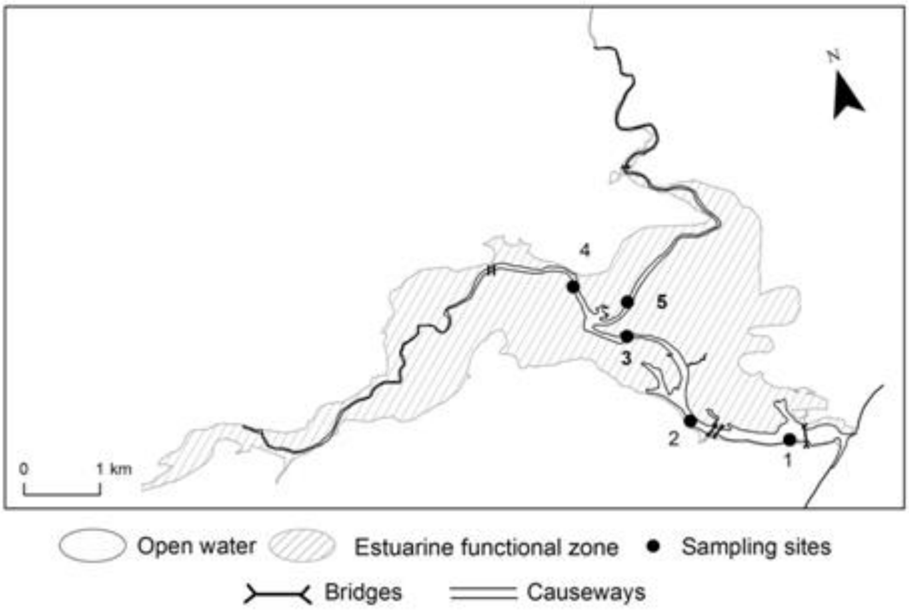


Figure D.1 Study site map of the Klein Brak Estuary indicating the locations of sampling stations, 04 April 2013 (Lemley, 2015) (Distance from mouth 1= 0.7 km; 2 = 1.9 km; 3 = 3.4 km; 4 = 4.5 km; 5 = 4.5 km)

Vertically averaged phytoplankton chlorophyll *a* ranged from 0 to 8.44 ± 3.53 µg/ℓ, average subtidal chlorophyll *a* from 10.95 ± 1.06 mg/m^2 to 57.59 ± 7.42 mg.m^{-2}, and intertidal chlorophyll *a* from 2.47 ± 0.35 mg/m^2 to 42.75 ± 0.35 mg/m^2 (refer to **Table D.1**).

Table D.1 Average phytoplankton and microphytobenthos biomass, using chlorophyll *a* as an index, in the Klein Brak Estuary on 04 April 2013

Site (km from mouth)	Phytoplankton Chlorophyll *a* (µg/ℓ)	Intertidal Chlorophyll *a* (mg/m^2)	Subtidal Chlorophyll *a* (mg/m^2)
1 (0.7 km)	0	2.47 ± 0.35	10.95 ± 1.06
2 (1.9 km)	0	42.75 ± 5.30	39.93 ± 6.01
3 (3.4 km)	1.78 ± 0.79	33.57 ± 3.18	42.05 ± 4.59
4 (4.5 km) - BR	8.44 ± 3.53	34.27 ± 1.77	23.67 ± 8.83
5 (4.5 km) - MR	0.39 ± 0.39	42.75 ± 0.35	57.59 ± 7.42

Phytoplankton group composition was dominated (up to 88%) by flagellates throughout the estuary, ranging from a low vertical average of 206 to 468 cells/ml (refer to **Figure D.2**). Diatoms ranged from 14 to 52 cells/ml, dinoflagellates from 3 to 39 cells/ml, cyanobacteria from 0 to 9 cells/ml and no chlorophyte cells were recorded.

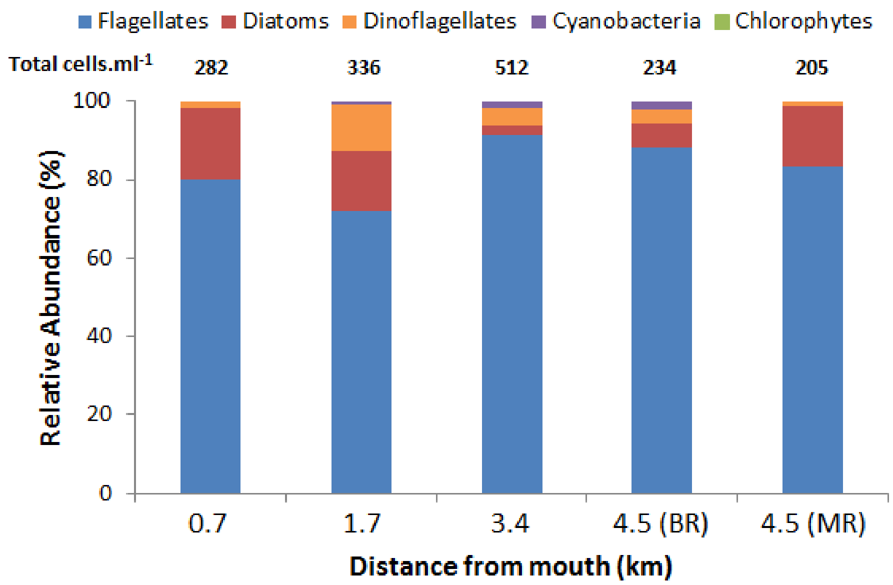


Figure D.2 Relative abundance (%) of phytoplankton groups at five sites in the Klein Brak Estuary (4 April 2013) (total cell density data are included as cells/ml) (Lemley, 2015)

Lemley (2015) sampled a number of estuaries within the Gouritz WMA in 2013 and found that the diversity and the evenness of dominant (> 10% of relative abundance) benthic diatoms in the Klein Brak Estuary was considerably higher than other estuaries in the study. The Shannon Diversity Index and Species Evenness scores were 3.07 and 0.84 respectively.

Ten benthic diatoms were dominant in the Klein Brak Estuary (Lemley, 2015) during the April 2013 survey; *Amphora coffeaeformis, A. exigua, A. micrometra, Cocconeis placentula var. euglypta, Entomoneis paludosa, Navicula gregaria, Nitzschia laevis, N. paleaformis, Parlibellus* sp. and *Tryblionella constricta* (refer to **Table D.2***)*. Most of the taxa are typically found in brackish water and are cosmopolitan. There is very little information available information about their respective pollution tolerances except for *Navicula gregaria* and *Cocconeis placentula* that can tolerate eutrophic conditions.

Table D.2 Description of the general environments associated with the dominant diatom species (≥ 10% relative abundance) recorded within estuaries of the Gouritz WMA (Lemley, 2015). Diatoms recorded in the Klein Brak Estuary (KB) are presented in blod text

Species	Description	Estuaries
Achnanthes delicatula (Kützing) Grunow	Fresh/brackish water (Sims, 1996)	GK; HB
Achnanthes engelbrechtii Cholnoky	Fresh water species (Bate *et al.*, 2004)	KM
Achnanthes minutissima Kützing	Fresh water species (Bate *et al.*, 2004)	GK
Achnanthidium minutissimum (Kützing) Czarnecki	Well oxygenated, clean fresh waters (Taylor *et al.*, 2007)	GW
Amphora arcus Gregory	Marine species (Lange-Bertalot, 2000)	GB
***Amphora coffeaeformis* (C. Agardh) Kützing**	**Cosmopolitan species found in waters with a high electrolyte content; brackish/saline (Taylor *et al.*, 2007)**	**GK; GB; KB**
Amphora cognata Cholnoky	-	KM
***Amphora exigua* Gregory**	**Cosmopolitan species inhabiting brackish and marine waters (Lange-Bertalot, 2000)**	**KB**
Amphora laevissima Gregory	Widespread marine species (Lange-Bertalot, 2000)	GB
***Amphora micrometra* Giffen**	**-**	**KB**
Amphora montana Krasske	Cosmopolitan species found in alkaline waters, rarely become dominant (Taylor *et al.*, 2007)	GK
Amphora ovalis (Kützing) Kützing	Cosmopolitan species found in waters with a moderate electrolyte content; brackish/saline (Taylor *et al.*, 2007)	GK
Amphora ovalis var. *affinis* (Kützing) van Heurck	-	GK
Amphora proteoides Hustedt	Marine species (Lange-Bertalot, 2000)	GW
Caloneis permagna (Bailey) Cleve	Fresh water species (Sims, 1996)	GK
***Cocconeis placentula* var. *euglypta* (Ehrenberg) Grunow**	**Occurring in meso- to eutrophic flowing and standing waters (Taylor *et al.*, 2007)**	**GB; HB; KB**
Diploneis stroemii Hustedt	Widespread in the marine littoral and brackish waters of the temperate zone (Lange-Bertalot, 2000)	GK
***Entomoneis paludosa* (W. Smith) Reimer**	**Cosmopolitan brackish water species (Lange-Bertalot, 2000)**	**KB**
Eunotia minor (Kützing) Grunow	Occurs in circumneutral waters (Lange-Bertalot, 2000)	KM
Fallacia sp.	-	GW
Fragilaria fasciculata (C. Agardh) Lange-Bertalot	-	GW
Frustulia weinholdii Hustedt	Thought to occur in oligo- to eutrophic waters with a low to moderate electrolyte content (Taylor *et al.*, 2007)	GB; KM

Species	Description	Estuaries
Gomphonema parvulum (Kützing) Kützing	Cosmopolitan species which is widespread in a range of waters, and generally considered to be tolerant to extremely polluted conditions (Taylor *et al.*, 2007)	GW
Gyrosigma prolongatum var. *closteroides* (Grunow) Cleve	Marine species (Sims, 1996)	GB
Hantzschia distinctepunctata Hustedt	Cosmopolitan species found in waters with a very high electrolyte content, and in brackish waters (Taylor *et al.*, 2007)	GK; KB
Melosira sp.	-	GK
***Navicula gregaria* Donkin**	**Cosmopolitan, very common in eutrophic to hypereutrophic fresh waters with moderate to high electrolyte content. Also found in brackish waters. Tolerant of strongly polluted conditions; good indicator species for these conditions (Taylor *et al.*, 2007)**	**GB; GW; KB**
Navicula perminuta Grunow	Cosmopolitan species, abundant in brackish zones of rivers and along the coast (Lange-Bertalot, 2000)	GK; KB
Navicula recens (Lange-Bertalot) Lange-Bertalot	Cosmopolitan species found in eutrophic rivers with elevated electrolyte content, also found in brackish waters. Tolerant to critical levels of pollution. Free-living or in mucilage tubes (Taylor *et al.*, 2007)	HB
Navicula tenelloides Hustedt	Cosmopolitan, aerophilic species found in waters with a wide range of electrolyte content and varied trophic status. Tolerant of extremely polluted conditions (Taylor *et al.*, 2007)	KM
Navicula tripunctata (O.F. Müller) Bory	Cosmopolitan, free-living and in mucilage tubes. Good indicator of eutrophic waters with moderate to high electrolyte content. Tolerant to critical levels of pollution (Taylor *et al.*, 2007)	GB; GK
Nitzschia erosa Giffen	Marine species (Lange-Bertalot, 2000)	KM
Nitzschia fonticola (Grunow) Grunow	Fresh water species (Sims, 1996)	KM
Nitzschia fontifuga Cholnoky	-	GW; KM
***Nitzschia laevis* Hustedt**	**Cosmopolitan marine species (Lange-Bertalot, 2000)**	**KB**
***Nitzschia paleaformis* Hustedt**	**Fresh water species (Sims, 1996)**	**KB**
Nitzschia pellucida Grunow in Cleve & Grunow	Cosmopolitan species inhabiting marine coasts (Lange-Bertalot, 2000)	GW
Opephora minuta (Cleve-Euler) Witkowski	Marine species (Lange-Bertalot, 2000)	GB; HB
***Parlibellus* sp.**	**-**	**KB**
Planothidium engelbrechtii (Cholnoky) Round & Bukhtiyarova	Cosmopolitan in brackish-water of estuaries (Lange-Bertalot, 2000). Capable of tolerating critical to very heavy organic pollution (Taylor *et al.*, 2007)	GK
Pleurosigma salinarum (Grunow) Grunow	Cosmopolitan, found in brackish and saline inland waters (Taylor *et al.*, 2007)	GW
Staurosira elliptica (Schumann) Williams & Round	Found in benthos of electrolyte-rich fresh or brackish waters (Taylor *et al.*, 2007)	HB

Species	Description	Estuaries
Tryblionella constricta **(Kützing) Poulin**	**-**	**KB**

D.2 THIS STUDY (7 DECEMBER 2013)

Five sites were sampled in the Klein Brak Estuary on 07 December 2013 (refer to **Figure D.3**) measuring microalgal variables. These data included phytoplankton and microphytobenthos (MPB) biomass (using chlorophyll *a* as an index), phytoplankton group composition, and dominant (> 10% of relative abundance) benthic diatoms.

Phytoplankton chlorophyll *a* ranged from 1.73 ± 0.27 µg/ℓ to 5.64 ± 0.29 µg/ℓ, subtidal chlorophyll *a* from 6.93 ± 0.66 mg/m^2 to 72.50 ± 2.03 mg/m^2, and intertidal chlorophyll *a* from 5.04 ± 0.85 mg/m^2 to 75.23 ± 6.78 mg/m^2 (refer to **Table D.3**).

The average relative abundance of phytoplankton was dominated by flagellates (67.2% at 0.1 km to 94.2% at 3.8 km) (refer to **Figure D.4**). Other groups that were present include the diatoms (1.4% at 3.8 km to 27.7% at 0.1 km), dinoflagellates (0 at 5.5 km to 27.4 at 1.6 km) and blue-greens (1.9% only recorded at 0.1 km). The average cell density for the estuary (± standard error) was 365 ± 39.5 cells ml^{-1}, which is regarded as being low (cell densities exceeding 10 000 cells/ml typically indicate blooms). The lowest vertically averaged cell densities were measured just downstream of the bridges at the upper reaches of the two tributaries (118 cells/ml at 5.5 km and 214 cells/ml at 7.4 km).

Figure D.3 Study site map of the Klein Brak Estuary indicating the locations of sampling stations, 07 December 2013 (Distance from mouth: 1 = 0.1 km; 2 = 1.6 km; 3 = 3.8 km; 4 = 7.3 km; 5 = 5.5 km)

Table D.3 Phytoplankton and microphytobenthos biomass, using chlorophyll a as an index, in the Klein Brak Estuary (7 December 2013)

Site (km from mouth)	Phytoplankton Chlorophyll *a* (µg/ℓ)	Intertidal Chlorophyll *a* (mg/m^2)	Subtidal Chlorophyll *a* (mg/m^2)
1 (0.1 km)	1.73 ± 0.27	5.04 ± 0.85	6.93 ± 0.66
2 (1.6 km)	4.31 ± 0.36	64.61 ± 10.53	72.50 ± 2.03
3 (3.8 km)	5.64 ± 0.29	75.23 ± 6.78	53.56 ± 2.59
4 (7.3 km) - BR	0.76 ± 0.11	35.14 ± 3.02	13.85 ± 1.70
5 (5.5 km) - MR	2.52 ± 0.15	56.06 ± 1.70	34.27 ± 11.00

The number of benthic diatom species at each site, intertidal and subtidal, ranged from two (0.1 km, subtidal) to 68 species (1.6 km, subtidal) (refer to **Table D.4**). In general, the number of cells in samples was low and it was not possible to count and identify a minimum of 300 cells. Of the dominant species there were a few with known tolerances for pollution; *Navicula gregaria* (cosmopolitan species that tolerates moderate to heavy pollution), *Planothidium delicatulum* (tolerates heavy organic pollution), *P. engelbrechtii* (tolerates critical to very heavy organic pollution), and Achnanthes oblongella (pollution sensitive but can tolerate mild pollution) (Taylor *et al.*, 2007; Kelly *et al.*, 2005). This confirms the phytoplankton and benthic microalgal biomass results that suggested the microalgae were largely dependent on nutrients released from the sediment through mineralisation, from a relatively high organic content (> 3%) in the sediment.

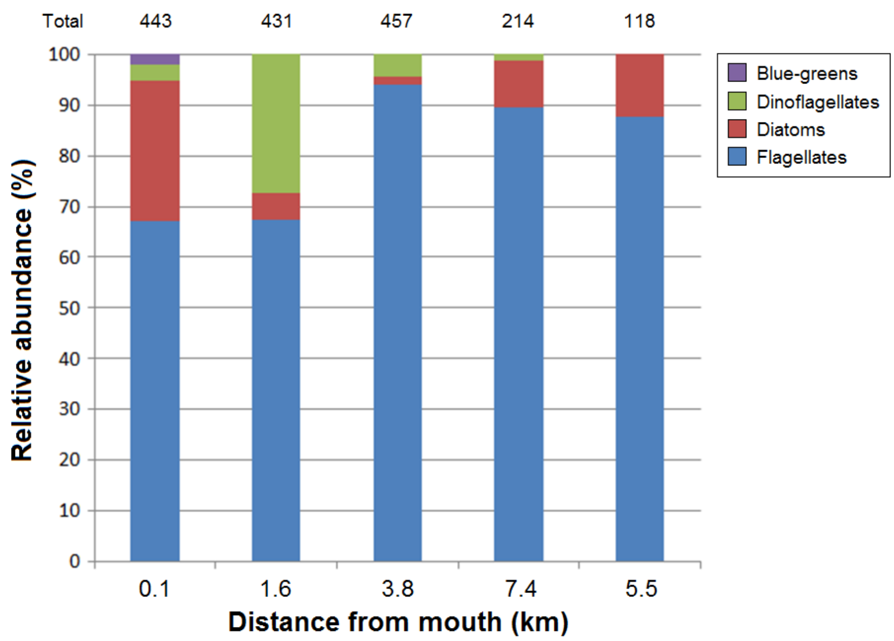


Figure D.4 Relative abundances (%) of phytoplankton in the Klein Brak Estuary (7 Dec 2013) (total cell density at each site is provided)

Table D.4 Total cell counts, species identified and dominant species (> 10%) of benthic diatoms in the Klein Brak Estuary (7 December 2013)

Distance (km)	Inter-/Subtidal	Total cell count	Spp. Identified	Dominants (> 10%)
0.1	Intertidal	34	11	*Navicula rajmundii*, *Hantzschia* sp.
	Subtidal	2	2	Too few cells
1.6	Intertidal	72	16	*Stauroneis* sp., *N. gregaria*
	Subtidal	339	68	*Achnanthes oblongella*, *Planothidium delicatula*, *Navicula* sp.
3.8	Intertidal	307	19	*P. delicatula*, *H. distinctepunctata*
	Subtidal	88	12	*P. delicatula*
7.3	Intertidal	323	16	*Planothidium engelbrechtii, N. gregaria, A. oblongella*
	Subtidal	154	43	*A. oblongella*
5.5	Intertidal	205	22	N. microcari, *P. engelbrechtii*, *Fallacia scaldensis*
	Subtidal	60	12	*N. microcari*

The Shannon diversity and evenness index scores for the Klein Brak Estuary on 4 April 2013 were 3.2 and 0.84 respectively (**Figure D.5**). These are regarded as being ‘good’ (> 3 index score) and with a much higher evenness than other estuaries in the Gouritz WMA (refer to **Figure D.5**). The scores did drop in December 2013 to 2.0 (diversity) and 0.7 (evenness), which could be the result of the pulse in rivers flows a couple weeks prior to sampling.

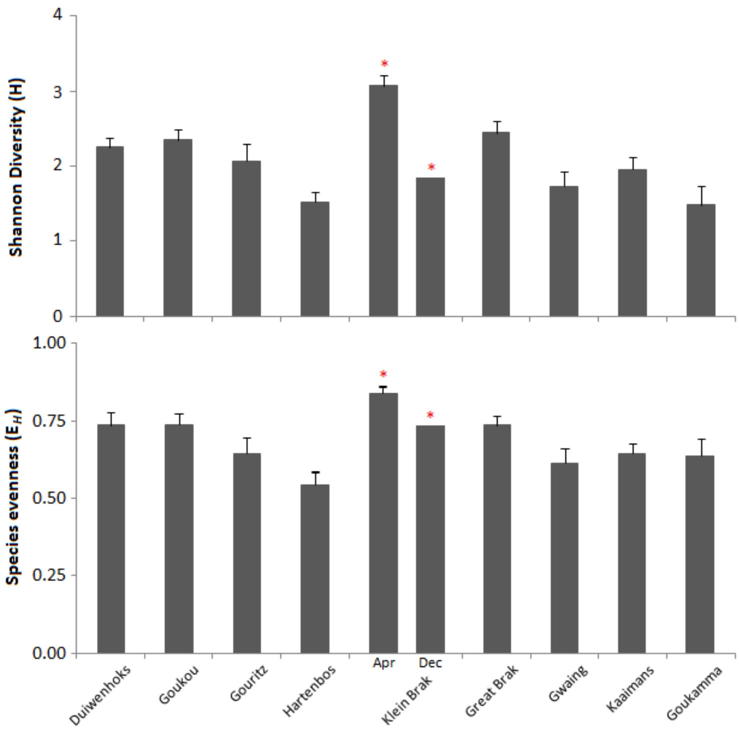


Figure D.5 Benthic diatom diversity (Shannon Diversity) and evenness (Shannon equitability) scores based on benthic diatoms in estuaries in the Gouritz WMA. The Klein Brak Estuary is highlighted (*) sampled 4 April 2013

APPENDIX E: DATA SUMMARY REPORT FOR MACROPHYTES

E.1 AVAILABLE DATA

Description	Availability	Reference
Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the reference condition (earliest year available). A GIS map of the estuary must be produced indicating the present and reference condition distribution of the different plant community types.	The estuary was mapped in 2009 from SPOT 5 2008 satellite imagery. The estuary was remapped in this study (2014) using SPOT 5 2013 satellite imagery and 2009 Google Earth imagery. GIS vegetation map from 1940 aerial photographs produced for this study. Other photographs consulted; 1940, 1977, 1979 and 1980.	Adams *et al*., 2010
Number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit. The extent of anthropogenic impacts (e.g. trampling, mining) must be noted.	Yes The estuary was visited in August 2009 to update the botanical database and provide input to the estuaries component of the National Biodiversity Assessment.	Adams *et al*., 2010
Permanent transects (fixed monitoring stations that can be used to measure change in vegetation in response to changes in salinity and inundation patterns) must be set up along an elevation gradient: Measurements of percentage plant cover of each plant species in duplicate quadrats (1 m^2).Measurements of sediment salinity, water content, depth to water table and water table salinity.	Padayachy (2013) assessed the status of invasive vegetation and disturbance of salt marshes and floodplains in the Great Brak, Klein Brak and Hartenbos estuaries. Transects were placed in disturbed and undisturbed areas focussing on the salt marsh terrestrial boundary. Sediment and water table characteristics were measured.	Padayachy, 2013

E.2 HABITAT AREA

Previous estimates of estuarine open water area are given by Harrison *et al.* (2000) at 96 ha, with no indication of floodplain area or any other habitat type. The NBA 2011 (Van Niekerk and Turpie, 2012) estimated the total functional estuarine zone within the 5 m contour line at 976.53 ha. Adams *et al.* (2010) sampled the estuary on 22 August 2009 and identified four estuarine macrophyte habitat types; supratidal salt marsh (278 ha), intertidal salt marsh (17 ha), reeds and sedges (2 ha), and submerged macrophytes (< 1 ha) (refer to **Figure E.1**). Present assessments of the latest aerial photography and using GIS, estimate the total open water surface area at 98 ha, which is comparable to Harrison *et al.'s* (2000) estimate. **Table E.1** provides a breakdown of the total area cover of the various habitat types found for the Klein Brak Estuary in 2014.

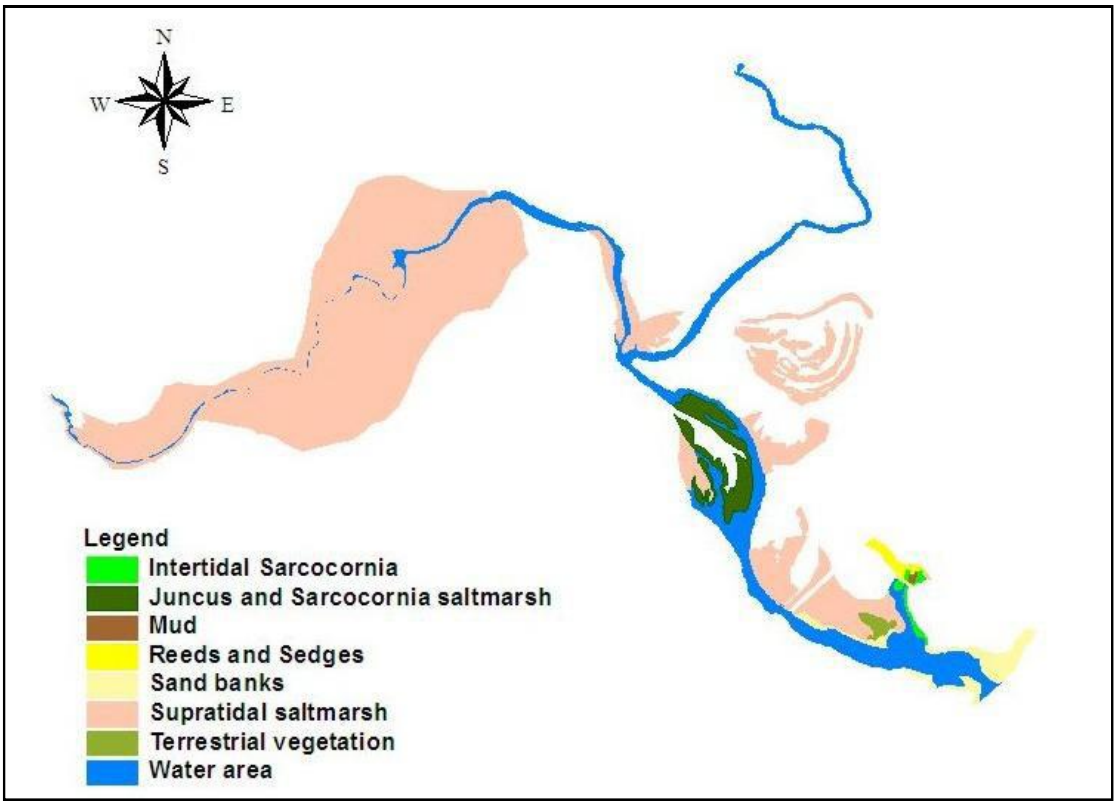


Figure E.1 Vegetation map of the Klein Brak Estuary (Adams *et al*. 2010)

E.3 SPECIES COMPOSITION AND DISTRIBUTION

The intertidal salt marsh in the lower reaches of the Klein Brak Estuary consisted of a mosaic of *Triglochin striata*, *Sarcocornia decumbens* and *Spartina maritima*; all typical intertidal species (Adams *et al.*, 2010). These species require frequent tidal inundation and dominated the areas closest to the water channel and within the creeks. *Spartina maritima* is common in large permanently open Cape estuaries and can grow to heights of 80 cm (Adams *et al.*, 1999). Further upstream in the middle reaches of the estuary the salt marsh area (16 ha) is dominated by *Sarcocornia decumbens* and sharp rush *Juncus kraussii*. Throughout the estuary at higher elevations supratidal salt marsh (278 ha) is the dominant macrophyte habitat and is characterized by five species: samphire *Sarcocornia pillansii*, brakbos *Conyza scabrida*, kweekgras *Cynodon dactylon*, round-leaf pigface *Disphyma crassifolium* and buffalo grass *Stenotaphrum secundatum*.

Only two species of reeds and sedges were dominant namely *Juncus kraussii* and *Phragmites australis*. These macrophytes were found in the lower reaches of the estuary in areas of freshwater seepage as salinity is the main controlling factor in the distribution of these species within estuaries (Adams *et al.*, 1999). A single species of submerged macrophyte was observed by Adams *et al.* (2010), i.e. *Zostera capensis*, in the lower reaches of the estuary where salinity was favourable for growth. Day (1981), however, also observed *Ruppia* sp. in the upper reaches of the estuary; however, strong freshwater flow may be responsible for the removal of this macrophyte as they are highly susceptible to mechanical damage and uprooting.

Table E.1 Macrophyte habitat areas for the Klein Brak Estuary

Habitat type	Defining features, typical/dominant species	2010 area (ha)	2014 area (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	77	98
Sand and mud banks	Intertidal zone consists of sand/mud banks that provide a possible area for microphytobenthos to inhabit.	10	48
Macroalgae	Filamentous green algae could establish during low flow, closed mouth conditions and in response to an increase in nutrients.	0	2
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. *Zostera capensis* as well as *Ruppia* spp. have been found in the estuary.	1	3
Salt marsh	The following species have been recorded: *Disphyma crassifolium, Salicornia meyeriana, Sarcocornia decumbens, Sarcocornia pillansii, Stenotaphrum secundatum, Sporobolus virginicus* and *Triglochin striata*	278 (supratidal) + 17 (intertidal) =295	494
Reeds and sedges	*Juncus kraussii* (sharp rush) and *Phragmites australis* (common reed) are dominant.	2	18
Floodplain	This is a mostly grassy area which occurs within the 5 m contour line. Agriculture takes place in 507 ha. Invasive plants are present covering approximately 2 ha		565
Total Estuarine Area (ha)		**384**	**1224**

(2010 – Adams *et al*. 2010; 2014 – this study)

Padayachy (2013) described the composition and distribution of salt marsh species occurring in the upper intertidal and supratidal regions of the Klein Brak Estuary. These species included; *Aizoon rigidum*, *Atriplex verstita*, *Bassia diffusa*, *Bolboschoenus maritimus*, *Chenopodium album*, *Cotula filifolia*, *Delosperma crissum*, *Disphyma crassifolium*, *Salicornia meyeriana*, *Sarcocornia decumbens*, *S. pillansii*, *Sporobolus virginicus* and *Triglochin bulbosa*. Some reed and sedge species were found mainly in areas of disturbance and at sites of freshwater inflow, e.g. *Phragmites australis*, *Juncus kraussii* and a *Cyperus* species. Padayachy's (2013) study focused on the distribution of invasive species within the supratidal, fringe and terrestrial environment adjacent to estuaries. Consequently species and environmental data are restricted to these areas and do not extend further towards the water's edge. Sampling was done along transects at a disturbed (34°5'35"S, 22°8'13"E) and pristine site (34°5'83"S, 22°8'20"E). Macrophyte cover was measured in 1 x 1 m quadrats placed at every 5 m on either side of the transect. 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. *In situ* measurements of the groundwater salinity and electrical conductivity were conducted using an YSI handheld multiprobe.

The environmental data showed that sediment moisture, organic content and salinity influenced the distribution of species within the supratidal salt marsh areas and groundwater salinity was also important (refer to **Figure E.2**).

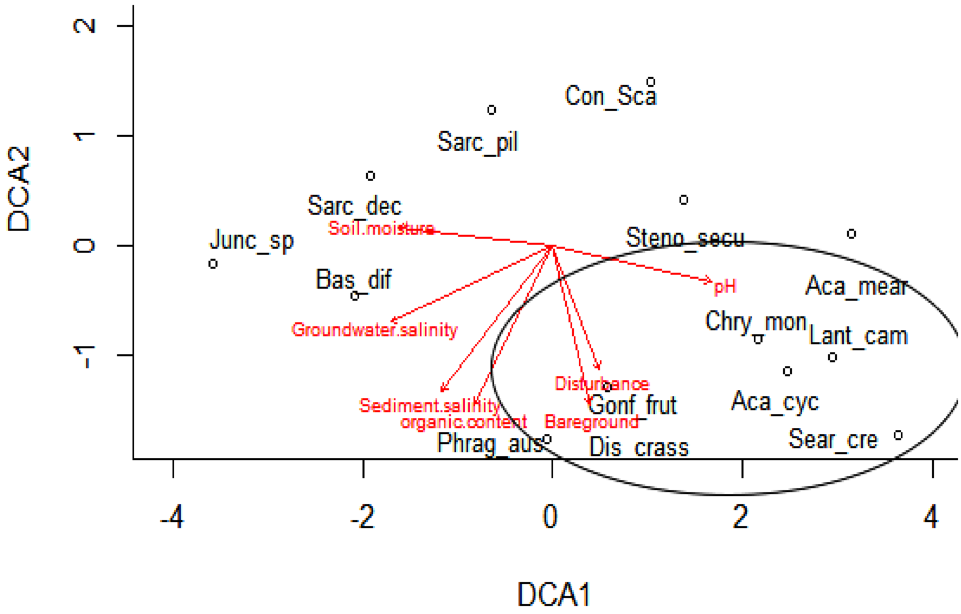


Figure E.2 A combined Detrended Correspondence Analysis of species cover together with environmental variables measured from disturbed and pristine sites in the Klein Brak Estuary. Each site represents two replicate transects

E.4 ENVIRONMENTAL DRIVERS FOR HABITAT TYPES

Previous surveys of the Klein Brak Estuary found pronounced vertical stratification with fresh surface water and saline bottom water extending throughout the system, as well as a longitudinal salinity gradient (Day 1981, Moore *et al.*, 2010) which affects the distribution and zonation of estuarine macrophyte habitat types and species (Adams *et al.*, 1999). However, during reduced freshwater inflow periods or droughts, these salinity gradients disappear and the system becomes homogenous with very little variation between surface and bottom water or between the upper and lower reaches (i.e. 31 and 34, respectively; Moore *et al.*, 2010). Sediment analyses and groundwater measurements indicated high salinity in the disturbed sites compared to the pristine sites (55 and 25, and 42 and 12, respectively, $p < 0.05$; **Figure E.3**, Padayachy, 2013). Salinity in the terrestrial and fringe communities were much lower than that recorded in the salt marsh. The sediment and groundwater in the disturbed fringe was markedly higher than the values in the pristine fringe. There was no significant difference in terms of organic matter (~9%) and sediment moisture (28 – 31%) between the two sites ($p < 0.05$).

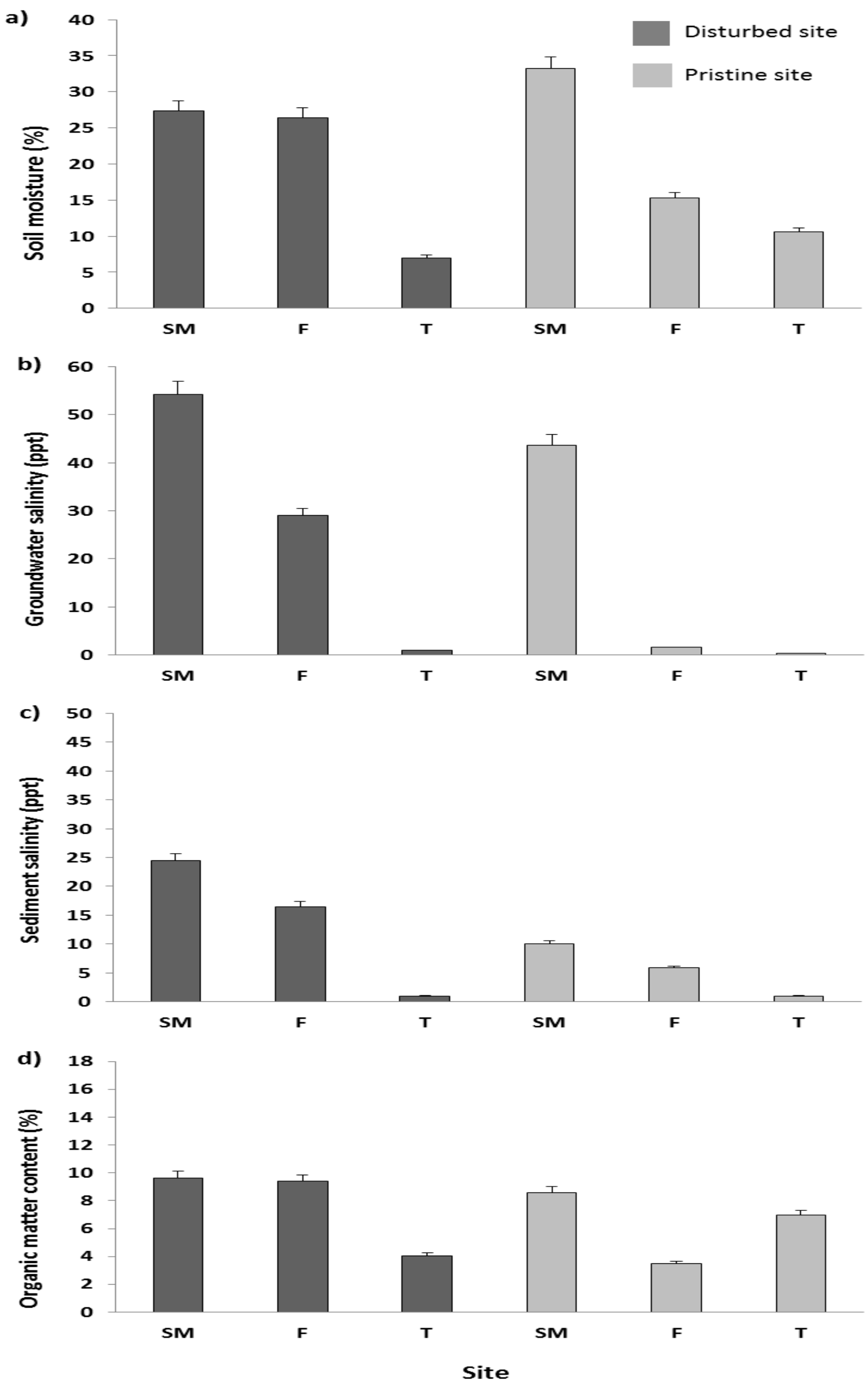


Figure E.3 Environmental variables for disturbed and pristine sites in the Klein Brak Estuary (Padayachy, 2013)

Table E.2 summarises the abiotic characteristics and processes, as well as other biotic components on macrophyte habitats within the Klein Brak Estuary.

Table E.2 Effect of abiotic characteristics and processes, as well as other biotic components on macrophyte habitats within the Klein Brak Estuary

Process	Macrophytes
Mouth condition	Open mouth conditions create intertidal habitat. There are areas of intertidal salt marsh within the lower reaches, with supratidal salt marsh occurring in the middle to upper reaches of the estuary.
Retention times of water masses	Closed mouth conditions and longer water retention times promote macroalgal growth.
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.
Total volume and/or estimated volume of different salinity ranges	The longitudinal salinity gradient promotes species richness, different macrophyte habitats are distributed along the length of the estuary, for example salt marsh in the lower reaches and reeds and sedges in the upper reaches.
Floods	Large floods are important in flushing out salts from the salt marsh area. Hypersaline sediments caused by evaporation and infrequent flooding will result in dry bare patches in the supratidal salt marsh areas. High groundwater level and freshwater flooding maintains suitable moisture conditions for plant growth in the marsh.
Salinity	Base flow is sufficient to maintain longitudinal salinity gradients from the mouth to head of the estuary which promotes macrophyte diversity.
Turbidity	Increase sediment load within the water column results in a reduction in the photic zone and will limit submerged macrophyte establishment.
Dissolved oxygen	The estuary is well oxygenated.
Nutrients	Increased nutrient inputs would increase macrophyte growth particularly in areas of freshwater seepage (i.e. reeds and sedges).
Sediment characteristics (including sedimentation)	There has been some marine sedimentation in the lower reaches of the estuary. This area is very dynamic with few macrophytes establishing except for dune vegetation further up the elevation gradient.
Other biotic components	Grazing and trampling has occurred in certain sections of salt marsh. Invasive plants are common.

E.5 CHANGES OVER TIME IN MACROPHYTE HABITATS

Previous surveys of the catchment of the Klein Brak Estuary indicate that significant areas of the floodplain has been modified by agriculture and urban development (refer to **Figure E.4**; Padayachy 2013). There are however, large areas of natural vegetation still present, but changes in water quality and quantity may have significant impacts on the ecological functioning of these areas in the future. Analysis of past and present vegetation mapping (refer to **Figure E.5**) and aerial photographs (refer to **Figure E.6**) indicate the changes in land use and habitat areas for the Klein Brak since 1940 (refer to **Table E.3**). There has been substantial loss of natural floodplain and salt marsh due to agriculture, settlements, multiple road bridges, artificial stabilisation of banks and infilling of salt marsh areas. Invasive alien plant species have colonized riparian zones and floodplain areas. There is some cattle grazing and trampling.

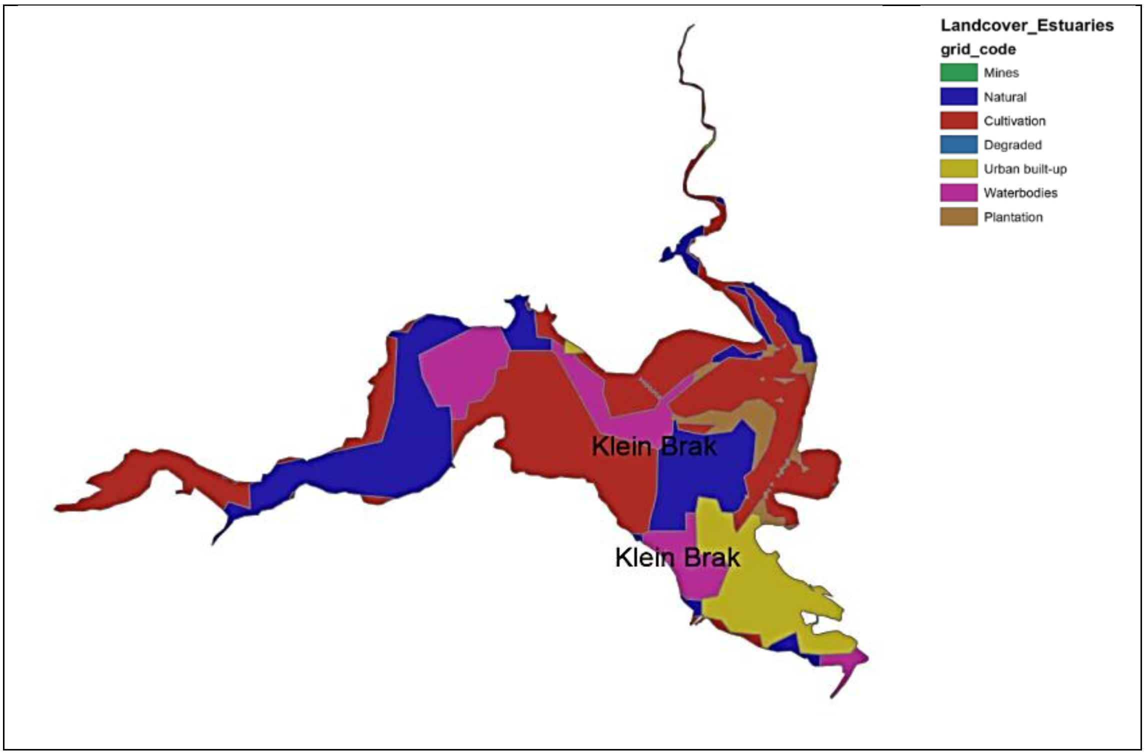


Figure E.4 Catchment land use for the Klein Brak Estuary (Veldkornet, NMMU, pers. comm.)

E.5.1 Submerged macrophytes

Zostera capensis as well as *Ruppia* sp. have been found in the estuary. Past and present surveys of the aerial photographs cannot with certainty assess the distribution and area cover of submerged macrophytes for this system. However, blind channels within the floodplains can provide suitable conditions for *Ruppia* sp. to establish whereas *Z. capensis* would occur in the intertidal habitat in the lower estuary reaches. A small increase from 1 ha (reference) to 3 ha (present day) is predicted.

E.5.2 Salt marsh

Past aerial photographs indicate that large areas of floodplain had already been disturbed and destroyed by agriculture prior to 1940. Since then however, salt marsh surface area has remained fairly stable with no further agricultural development. Urban development in the lower reaches of the estuary and above the N2 highway bridge, have increased and led to loss of habitat in those areas.

E.5.3 Reeds and sedges

In both the past and present assessments of aerial photographs, reeds and sedges were present in the upper reaches of the two main arms of the Klein Brak. The total area cover of reeds and sedge in 1940 was 12 ha, compared with the present area of 18 ha. It should be noted that the extent of the 1940 aerial photographs only allowed for a portion of the total estuarine area to be mapped.

E.5.4 Floodplain

Large areas of floodplain have been degraded over time, and prior to 1940 agriculture had already changed areas of the supratidal salt marsh. Agriculture currently occupies 507 ha of the floodplain.

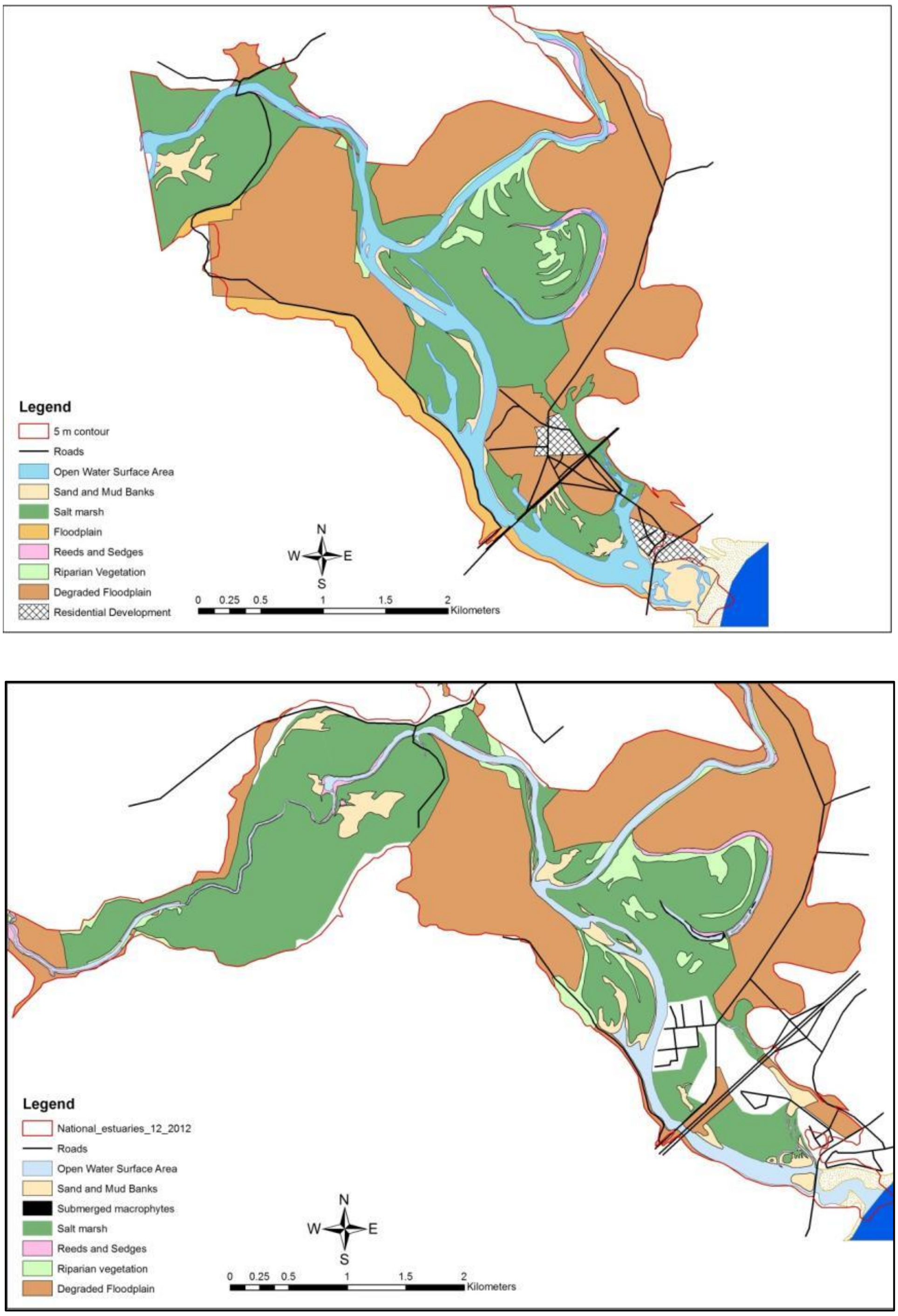


Figure E.5 Past (1940) and present (2014) vegetation of the Klein Brak Estuary

E.5.4 Macroalgae

No macroalgae have been reported for this system, however, as with submerged macrophytes, blind back-channels may provide suitable conditions for especially nuisance macroalgae to establish. Some may also be washed into the lower reaches of the estuary during strong marine tidal exchange. A small area was considered for reference (1 ha) compared with present (2 ha) conditions.

E.5.5 Mud and sand banks

Areas of the mud and sand banks were restricted to the lower reaches of the estuary, with large areas occurring below the railway bridge near the mouth. Some areas of mud and sand bank also occurred in the upper reaches. Past area was 42 ha and at present this is 48 ha, which again indicates very little change since 1940.

Table E.3 Area covered by different habitats in the Klein Brak Estuary in 2014 compared with 1940

Habitat	Area (ha) in 1940	Comparable area (ha) in 2014
Floodplain agriculture	475	507
Floodplain developed	51	
Floodplain undisturbed	30	52
Supratidal salt marsh	321	329
Intertidal salt marsh		
Submerged macrophytes		1
Reeds & sedges	12	16
Mud & sandbanks	42	46
Open water surface area	114	95
Total Functional Estuarine area	1045	1046

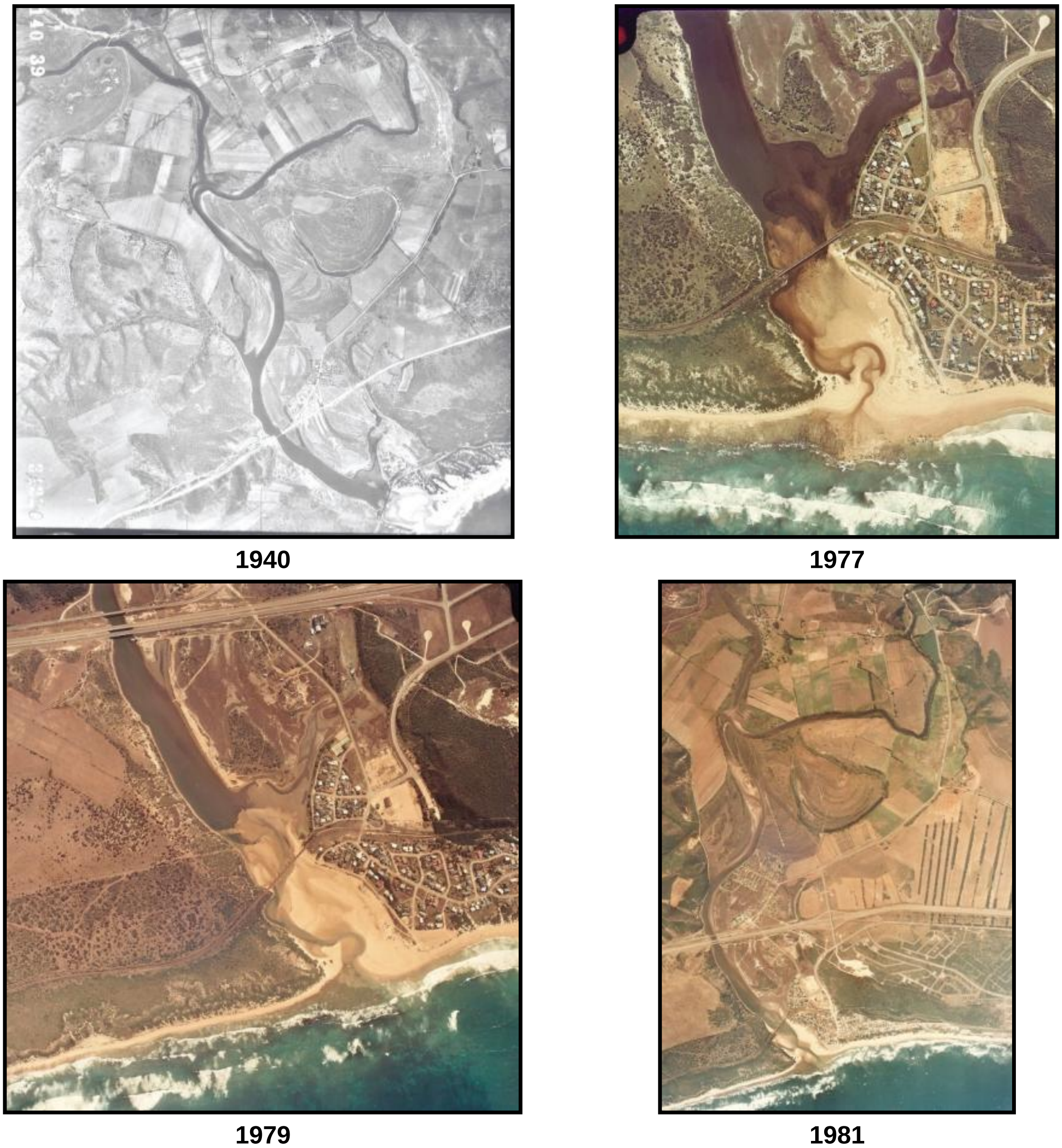


Figure E.6 Changes over time in the lower to middle reaches of the Klein Brak Estuary

E.6 CONCLUSIONS

The middle and upper reaches of the Klein Brak Estuary have been extensively transformed by agriculture, development and invasive vegetation. Pressures such as cattle grazing and trampling should be controlled as they can reduce salt marsh cover leading to bare hypersaline areas. Any changes in flooding or an increase in salinity due to a decrease in base flow would cause loss of species. From reference to present conditions low baseflow and an increase in salinity has reduced macrophyte species richness. Development, disturbance and loss of salt marsh and floodplain habitat would also result in loss of species as well as area cover. There is now a large area of agriculture and degraded floodplain.

APPENDIX F: DATA SUMMARY REPORT FOR INVERTEBRATES

F.1 AVAILABLE DATA

Little information on invertebrates from the Klein Brak Estuary is known. Day (1981) recorded 11 invertebrate species and concluded that the Klein Brak Estuary supported a '*poor fauna*'. Mudprawn *Upogebia africana* was sparse and *Eumarcia paupercula* was the only bivalve found. However, at the time of the survey, oil pollution from the Venpet-Venoil collision extended two kilometres up the estuary. By contrast to Day's findings, Wooldridge & Loubser (1996) recorded prawn-hole densities of *Upogebia africana* that ranged between 500 and 700 holes/m^2 immediately below the N2 road bridge and on the eastern bank. These densities are considered to be high in comparison to other permanently open estuaries (refer to **Figure F.1**).

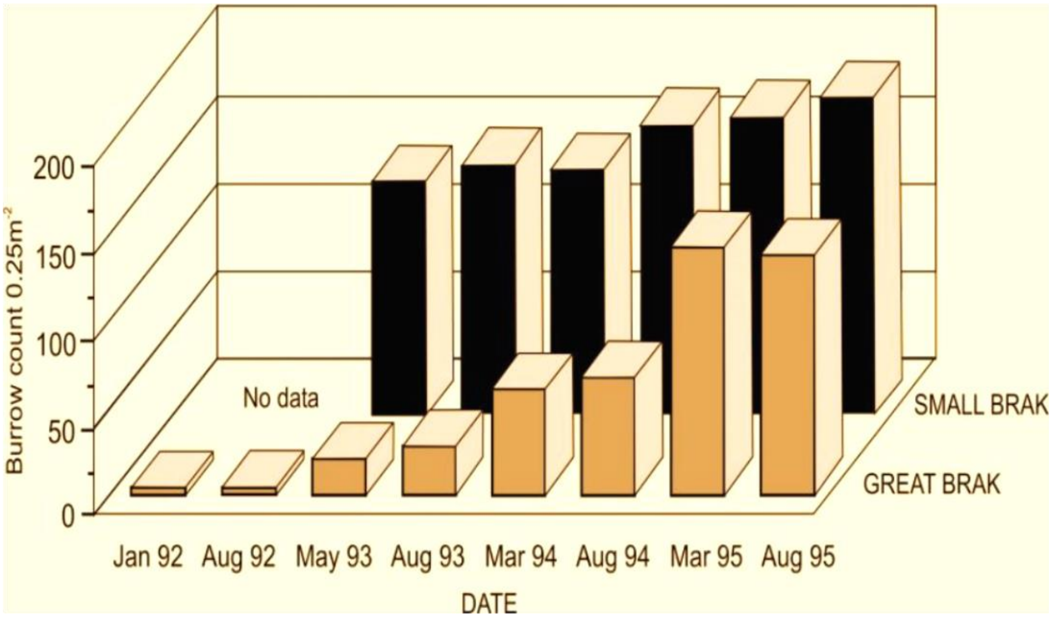


Figure F.1 Density of *Upogebia africana* prawn holes in the Great Brak and Klein Brak estuaries. Data represent the recovery phase of the population in the Great Brak following mouth closure after the completion of the storage reservoir in the catchment. At the time, the Klein Brak remained open to the sea

F.2 SUMMARY OF RESULTS FROM THIS STUDY (DEC 2013)

F.2.1 Physico-chemical data

Physico-chemical information was collected at each of five sites (refer to **Figure F.2**), particularly water temperature, salinity, and oxygen content of the water. Data were collected at the surface ant 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 was also blowing, particularly at the mouth. Results are shown in **Table F.1** and in **Figure F.3** for water temperature and salinity near the surface and just above the substrate.

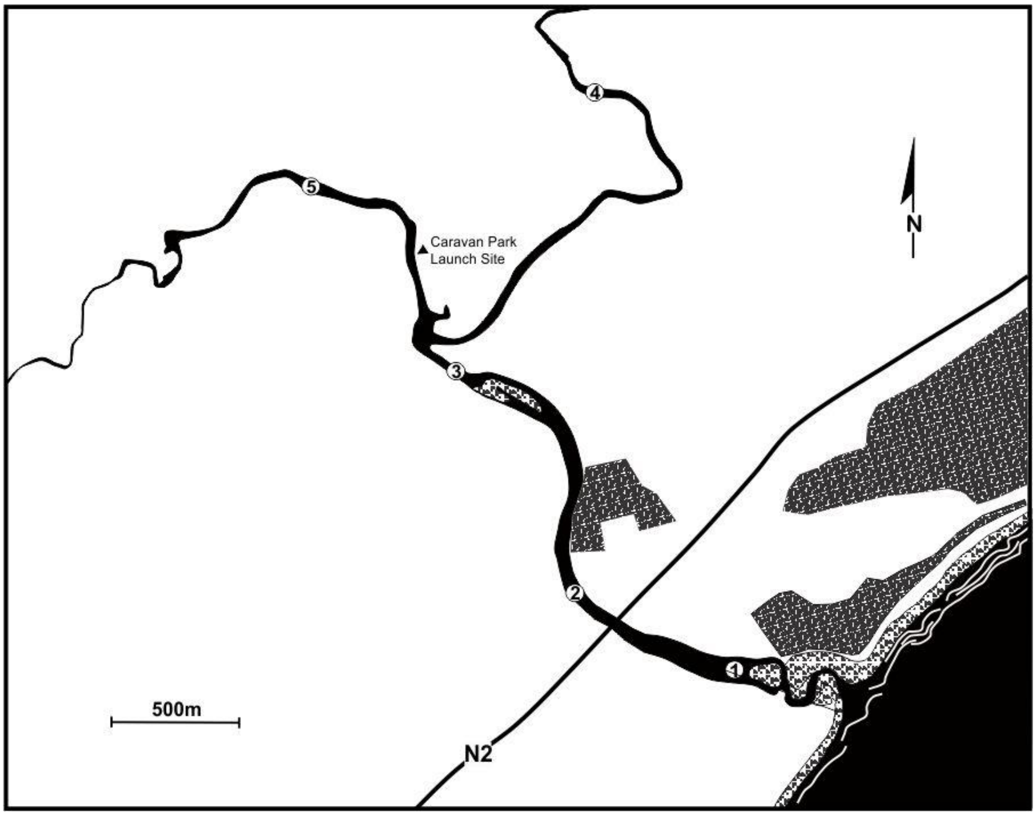


Figure F.2 Invertebrate station positions in Klein Brak Estuary 2013 (Distance from mouth: 1 = 0.1 km; 2 = 1.6 km; 3 = 3.8 km; 4 = 7.3 km; 5 = 5.5 km)

A sediment sample collected at each station provided information on particle size distribution and percent organic content. Dry samples (dried at 60°C for 48 h and then weighed) were incinerated at 550°C for 12 hours 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 hours to remove salts. Excess water was carefully siphoned off and the sample again dried at 60°C for 72 hours. 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).

The water column was generally well-mixed, except for Station 2 where bottom water salinity was close to that of seawater (refer to **Figure F.3**). Near-surface salinity was < 20. All other stations recorded relatively low salinity values, with oligohaline conditions above Station 3.

Water temperatures were homogeneous throughout the water column, except at Station 2 which was ca 2°C cooler relative to near-surface temperatures (refer to **Figure F.3**). A strong temperature gradient was also evident along the length of the estuary, ranging between 2-4°C cooler in the middle-upper reaches.

Table F.1 Physico-chemical readings recorded on the 7rd December 2013 in the Klein Brak Estuary (readings taken at 0.5 m depth intervals)

Station	Depth (m)	Temp (°C)	Salinity	DO %	DO Mg/l	pH
1	5	20.17	33.8	100	8.11	8.17
	0	20.39	34.21	109.6	8.1	8.22
2	0	21.87	19.28	101.9	7.81	8.16
	0.5	21.86	19.15	102.2	8.82	8.15
	1	21.71	19.89	101.9	7.96	8.15
	1.5	20.75	30.07	91.6	7.83	8.15
	2	19.58	34	100	7.49	8.19
	3	19.49	34.32	101.2	7.58	8.17
	4	19.49	34.46	99.9	7.38	8.18
3	0	22.76	7.94	84.8	6.97	8.28
	0.5	22.75	7.95	85.1	7	8.19
4	0	24.01	0.52	91.1	7.63	8.6
	0.5	23.92	0.67	91.2	7.65	8.41
	1	23.06	1.09	22.1	1.68	7.63
5	0	23.29	1.02	97.4	8.25	8.16
	0.5	23.29	1.02	97.3	8.2	8.1
	1	23.3	1.02	97.6	8.31	7.95

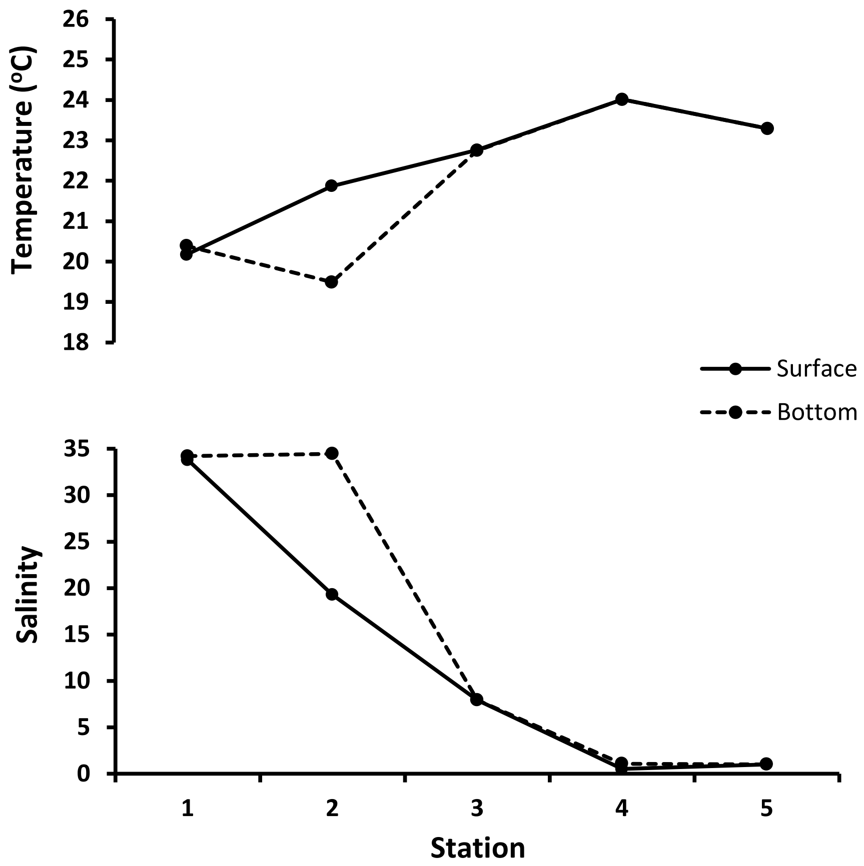


Figure F.3 Temperature and salinity readings measured just below the water surface and near the substrate at five stations in the Klein Brak Estuary (station positions shown in Figure F.2)

Sediment particle size distribution and organic content of the sediment is shown in **Table F.2**. Fine sand dominated the sediment (particle size ranging between 0.125 and 0,065 µm). A small percentage of slightly coarser sand was present at the upper two sites. Organic content of the sediment was generally low, averaging around 2% for all stations.

Table F.2 Sediment particle size distribution at five stations in the Small Brak 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

Station	Sediment particle size distribution (µm)				Organic matter (%)
	> 0.500 µm	< 0.500 – 0.125	< 0.125 – 0.065	0.065	
1	0	0.00	96.96	2.67	1.68
2	0	0.00	98.24	2.24	2.29
3	0	0.00	97.07	2.64	1.58
4	0	0.31	97.07	2.59	1.89
5	0	1.85	95.68	2.70	2.13

F.2.2 Zooplankton

Zooplankton samples were collected after dark at the five sites respectively (refer to **Figure F.2**), using a flat-bottomed boat. Two replicates at each site were taken at mid-depth levels using modified WP2 nets (57 cm diameter and 190 μm mesh) suspended from a boom on either side of the bow of the boat. Approximately 12 – 15 m^3 of water was sampled during tows. Nets were held at the required water depth using a graduated T-pole operated by workers on the boat. Samples were concentrated at the cod-end of the net and washed into labelled plastic bottles. Approximately 5% formaldehyde solution was added to samples. In the laboratory, samples were analysed for species composition and enumerated. Final abundance was expressed as the average number of each species per m^3 of water (ind.m^{-3}) at each site.

Twenty-one taxa were recorded in the zooplankton. Abundance (ind.m^{-3}) was relatively low for most species (refer to **Table F.3**), although the copepod *Pseudodiaptomus hessei* followed a more typical pattern for temperate estuaries. This species is often the numerically dominant taxon in the zooplankton of South African estuaries and the Klein Brak follows this broader pattern. However, abundance was still an order of magnitude lower relative to many other temperate systems.

The zooplankton species present were typical of estuaries along the south coast, with amphipods, mysids, cumaceans and carid shrimps also being numerically important. No distinct difference was observed in species composition and abundance between the two arms of the estuary (Station 4 vs Station 5).

The cumacean *Iphinoe truncata* is a sand-burrower and was particularly abundant at Station 2 where the substrate was composed of fine sand (refer to **Table F.2**).

Table F.3 Abundance of zooplankton (ind. m^{-3}) in the Klein Brak Estuary (data represent mean values of two replicates collected in Dec 2013 at five stations)

Group	Station				
	1	2	3	4	5
Copepoda					
Acartia longipatella	0.0	240.0	0.0	0.0	0.0
Copepod sp.	0.0	2825.0	0.0	0.0	0.0
Oithona sp.	0.0	523.0	0.0	0.0	0.0
Pseudodiaptomus hessei	24.0	351.0	2563.0	2187.0	267.0
Mysidacea					
Mesopodopsis wooldridgei	3.0	36.0	4.0	2.0	8.0
Rhopalophthalmus terranatalis	0.0	0.0	4.0	3.0	8.0
Cumacea					
Iphinoe truncata	1.0	164.0	4.0	0.0	5.0
Cumacean sp.	0.0	0.0	0.0	1.0	0.0
Isopoda					

Group	Station				
	1	2	3	4	5
Cirolana fluviatilis	0.0	0.0	4.0	1.0	4.0
Corallana africana	0.0	0.0	0.0	2.0	0.0
Cyathura estuaria	0.0	0.0	4.0	19.0	43.0
Amphipoda					
Corophium triaenonyx	0.0	0.0	13.0	52.0	31.0
Grandidierella lignorum	0.0	0.0	113.0	73.0	89.0
Caridea					
Palaemon capensis post-larvae	0.0	12.0	13.0	1.0	0.0
Palaemon capensis juvs	0.0	0.0	0.0	1.0	3.0
Brachyura					
Chiromantes eulimine	0.0	56.0	176.0	147.0	120.0
Hymenosoma orbiculare larvae	2.0	228.0	38.0	157.0	70.0
Hymenosoma orbiculare juvs	0.0	0.0	0.0	0.0	1.0
Paratylodiplax edwardsii larvae	0.0	0.0	0.0	0.0	54.0
Zoea larvae	0.0	0.0	0.0	22.0	0.0
Pisces					
Fish eggs	0.0	164.0	0.0	0.0	0.0

Figure F.4 represents the contribution of major taxa to total abundance in the estuary. In the Klein Brak Estuary, the zooplankton was dominated by copepods, with crab larvae ranking second in numerical importance.

F.2.3 Hyperbenthos

Hyperbenthic animals were sampled at the five stations in the estuary (refer to **Figure F.2**) 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 cm 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.

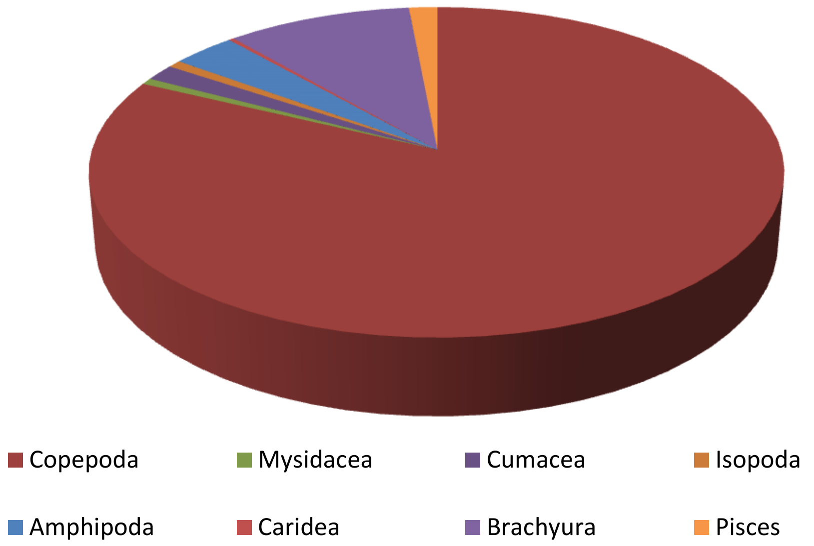


Figure F.4 Pie diagram of the most abundant zooplankton taxa in the Klein Brak Estuary. Values represent their total abundance at all sites in the estuary (see Table F.3) and expressed as percentage contribution of each group

Analysis of biological samples was completed in the laboratory. Final abundance was expressed as the average number of each species per m^{-3} of water at each site (ind.m^{-3}), determined from the two 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.

Sixteen taxa were recorded in the hyperbenthos (refer to **Table F.4**), similar to the number recorded in the Duiwenhoks Estuary (17 taxa). However, abundance (ind.m^{-3}) was also low and probably reflected a response to the oligohaline conditions recorded at most stations in the estuary at the time.

Species present were typical of estuaries along the south coast, with amphipods, mysids and carid shrimps dominating the hyperbenthic community. No adult carid shrimps (*Palaemon capensis*), were record in the estuary, although carid post-larvae were present in relatively high numbers. These post-larvae were considered to be those of *P. capensis* and were the same as those present in the Duivenhoks Estuary where gravid females were collected in the sled. This freshwater shrimp breeds in upper estuarine reaches where salinity values are oligohaline.

Figure F.5 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 mysid *Mesopodopsis wooldridgei* and *Hymenosoma* zoel stages were present in relatively high numbers, particularly at Station 2.

Table F.4 Abundance of hyperbenthic organisms (ind.m^3) in the Klein Brak Estuary (data represent mean values of two replicates collected in Dec 2013 at five stations)

Group	Station				
	1	2	3	4	5
Ostracoda					
Ostracod sp.	0.0	0.0	0.0	15.0	0.0
Copepoda					
Acartia longipatella	0.0	334.0	0.0	0.0	0.0
Copepod sp.	0.0	77.0	0.0	0.0	0.0
Pseudodiaptomus hessei	0.0	0.0	0.0	0.0	1134.0
Mysidacea					
Mesopodopsis wooldridgei	0.0	143.0	9.0	0.0	0.0
Rhopalophthalmus terranatalis	0.0	2.0	7.0	2.0	2.0
Cumacea					
Iphinoe truncata	0.0	0.0	7.0	0.0	0.0
Cumacean *sp.*	0.0	0.0	3.0	0.0	0.0
Amphipoda					
Corophium triaenonyx	0.0	0.0	2.0	25.0	3.0
Grandidierella lignorum	0.0	0.0	5.0	26.0	4.0
Caridea					
Palaemon capensis post larvae	0.0	0.0	2.0	0.0	0.0
Palaemon capensis juvs	0.0	0.0	0.0	2.0	0.0
Brachyura					
Chiromantes eulimine	31.0	0.0	0.0	0.0	0.0
Hymenosoma orbiculare larvae	18.0	4171.0	149.0	22.0	280.0
Hymenosoma juvs	0.0	1.0	2.0	1.0	2.0
Paratylodiplax edwardsii larvae	1.0	0.0	0.0	0.0	0.0

F.2.4 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.

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 (ind.m^{-2}), 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.

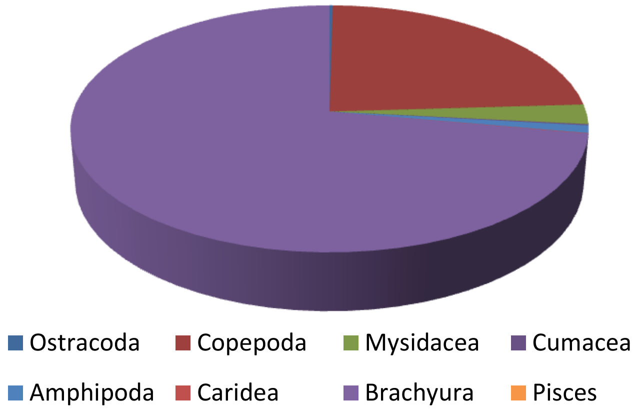


Figure F.5 **Pie diagram of the most abundant hyperbenthic taxa in the Klein Brak Estuary. Values represent their total abundance at all sites in the estuary (see Table F4) and expressed as percentage contribution of each group**

Species present were typical of estuaries along the south and west coast (refer to **Table F.5**), with the community dominated by two species of amphipods (*Corophium triaenonyx* and *Grandidierella lignorum*), The polychaete worm *Prionospio* sp and the Tanaid *Apseudes digitalis* were the only other relatively common species. In terms of biomass, the community was dominated by gastropods and bivalve molluscs. Along the intertidal zone, very high densities of *Upogebia africana* were present along the eastern bank near Station 2.

Figure F.6 summarises **Table F.5** in visual format and emphasises the dominance of amphipods at most stations sampled.

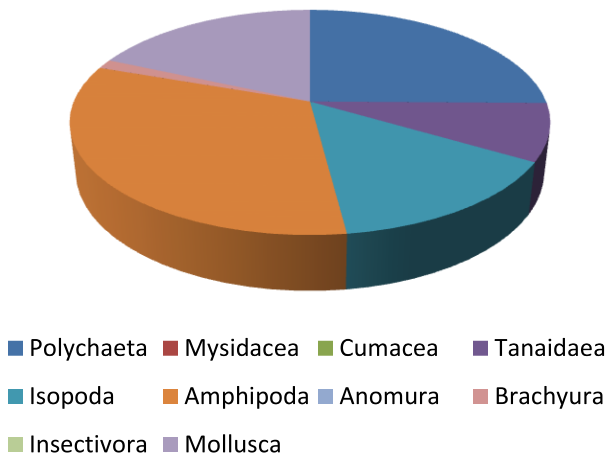


Figure F.6 **Pie diagram of the most abundant macrozoobenthic taxa in the Klein Brak Estuary. Values represent their total abundance at all sites in the estuary (see Table F5) and expressed as percentage contribution of each group**

Table F.5 Abundance of macrozoobenthic organisms (ind.m^2) in the Klein Brak Estuary (data represent mean values of six replicates collected in Dec 2013 at five stations)

Group	Station				
	1	**2**	**3**	**4**	**5**
Polychaeta					
Ceratonereis keiskama	0.0	0.0	3.0	82.7	0.0
Juvenile polychaeta	0.0	0.0	0.0	0.0	3.0
Nephtys sp.	0.0	3.0	0.0	0.0	0.0
Prionospio sp	0.0	499.4	0.0	0.0	14.8
Tanaidacea					
Apseudes digitalis	0.0	0.0	20.9	0.0	177.3
Isopoda					
Corallana africana	0.0	0.0	0.0	160.0	0.0
Cirolana fluviatilis	0.0	0.0	0.0	3.0	3.0
Cyathura estuaria	0.0	0.0	55.4	38.4	88.7
Amphipoda					
Corophium triaenonyx	0.0	17.7	0.5	257.1	5.9
Grandidierella lignorum	56.2	14.8	177.3	183.2	65.0
Brachyura					
Hymenosoma orbiculare	0.0	0.0	0.0	26.6	5.9
Mollusca					
Assiminea bifasciata	17.7	17.7	0.0	0.0	5.9
Nassa kraussianus	20.7	5.9	0.0	0.0	0.0
Modiolus capensis	26.6	20.7	0.0	183.2	8.9
Sanguinolaria capensis	3.0	3.0	0.0	0.0	0.0
Tellina sp.	8.9	8.9	47.3	0.0	62.1

APPENDIX G: DATA SUMMARY REPORT FOR FISH

G.1 AVAILABLE DATA

Historical Klein Brak Estuary fish data are limited to once-off sampling by James & Harrison (2009). Since then, the ichthyofauna of the Klein Brak has been sampled twice annually in spring / summer, autumn winter by DAFF Inshore Fisheries Research since 2011. Until the 1990s, there were beach-seines being used in the Klein Brak but the existence or status of a permitting system is unknown. Currently, recreational angling and small-scale / subsistence fishing effort, including bait collection and cast-netting is extremely high in the Klein Brak. Illegal gillnetting (especially of spotted grunter & dusky kob) has become a problem especially over the past five years. Both legal and illicit fishing peaks during holiday periods and when predictable aggregations of large dusky kob occur in the system. Total annual catch was estimated at 4-5 t by Lamberth and Turpie (2003) but is likely at least twice that now.

G.2 ASSESSMENT OF FISH DATA

South African estuarine fish species may be categorised according to their dependence on estuaries Whitfield (1994), based on life-history characteristics (**Table G.1**).

Table G.1 The five major categories of fish that utilise South African estuaries (adapted after Whitfield 1994)

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

Thirty-five species of fish from 19 families have been recorded in the Klein Brak Estuary which is comparable to that of the adjacent Groot Brak and Gouritz estuaries of equivalent size (refer to **Table G.2**).

Table G.2 A list of all 35 (37 with eels) species and 19 families recorded in the Klein Brak Estuary by Harrison (1999), DAFF (Lamberth 2002 -2015) and during this study. The species are classified into five major categories of estuarine-dependence as suggested by Whitfield 1994

Family name	Species name	Common name	Dependence
OSTEICHTHYES			
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
Carangidae	*Lichia amia*	Leervis	IIa
	Trachurus capensis	Maasbunker	III
Centrarchidae	*Micropterus salmoides*	Largemouth bass	IV
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV
	Tilapia sparrmanii	Banded tilapia	IV
Clinidae	*Clinus superciliosus*	Super klipvis	Ib
Clupeidae	*Gilchristella aestuaria*	Estuarine round herring	Ia
Cyprinidae	*Cyprinus carpio*	Carp	IV
Gobiidae	*Caffrogobius gilchristii*	Prison goby	Ib
	Caffrogobius natalensis	Baldy	Ib
	Caffrogobius nudiceps	Barehead goby	Ib
	Psammogobius knysnaensis	Knysna sandgoby	Ib
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa
	Pomadasys olivaceum	Piggy	III
Hemiramphidae	*Hyporhamphus capensis*	Cape halfbeak	Ia
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa
Mugilidae	*Liza dumerili*	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
	Argyrosomus japonicus	Dusky kob	IIa
Soleidae	*Heteromycterus capensis*	Cape sole	IIb

Family name	Species name	Common name	Dependence
	Solea bleekeri	Blackhand sole	IIb
Sparidae	*Diplodus sargus*	Dassie	IIc
	Lithognathus lithognathus	White steenbras	IIa
	Rhabdosargus globiceps	White stumpnose	IIc
	Rhabdosargus holubi	Cape Stumpnose	IIa
Syngnathidae	*Syngnathus temminckii*	Longsnout pipefish	Ib
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III

Over a 4-year sampling period (twice annually 2010-2014), 32 species were caught in the Klein Brak compared to 26 and 37 in the Groot Brak and Gouritz respectively. Of these, 12 (38%) are entirely dependent on estuaries to complete their life-cycle (Categories Ia and IIa), of which four are estuarine breeders; estuarine round-herring *G. aestuaria*, Cape halfbeak *Hyporhamphus capensis* and river goby *Glossogobius callidus* (Category Ia). Eight species, including Cape stumpnose *Rhabdosargus holubi*, dusky kob *Argyrosomus japonicus*, white steenbras *L. lithognathus*, leervis *Lichia amia* and spotted grunter *Pomadasys commersonnii* are dependent on estuaries as nursery areas for at least their first year (Category IIa). Another 10 species (31%) are at least partially dependent on estuaries, e.g. southern mullet *L. richardsonii*, groovy mullet *Liza dumerilii*, elf *P. saltatrix,* dassie *Diplodus capensis,* white stumpnose *Rhabdosargus globiceps* (Categories IIb and IIc). In all, 69% of the fish species recorded from the Klein Brak Estuary are either partially or completely dependent on estuaries for their survival. Most of the remaining species were marine species (22%), e.g. evil-eye puffer / blaasop *Amblyrhynchotes honckenii*, white-spotted puffer *Arothron hispidus* and Piggy *Pomadasys olivaceum* which occur in estuaries, but are not dependent on estuaries (Category III); three (9%) are alien euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance, namely Carp *Cyprinus carpio,* Banded tilapia *Tilapia sparmanii and* Mozambique tilapia *Oreochromis mossambicus* (Category IV).

Numerically*, G. aestuaria* (39%), *Caffrogobius* spp. (12%), *L. richardsonii* (11%) and *R. holubi* (9%) dominate the Klein Brak fish assemblage providing 71% of sampling catches. *Mugilidae* sp. (6%), *P. knysnaensis* (6%), groovy mullet *Liza dumerili* (4%), piggy *P. olivaceum* (4%) and two sole species namely blackhand sole *Solea turbynei* (3%) and Cape sole *Heteromycteris capensis* (3%) are also important. The remaining species all contributed < 1% to the sampling catch. However, some of these species e.g. dusky kob *Argyrosomus japonicus*, spotted grunter *Pomadasys commersonnii*, elf *Pomatomus saltatrix* and leervis *Lichia amia* are large and species of natural lower abundance. *Caffrogobius* spp. and *P. knysnaensis* occurred in over 70% and *S. bleekeri*, *L. richardsonii* and *R. holubi* in around 50% of sample hauls.

Along-stream distribution was largely a reflection of salinity preferences and the estuary-dependence category to which the fish belonged (refer to **Figure G.3**).

Klein Brak Estuary fish % catch per salinity range

Moordkuils (20-30) | Brandwag (10-20) | Weirs (<10)

	Dependence category S‰	>30	20-30	10-20	<10	**Total**
Ia	Resident breeders	5	14	78	86	71
Ib	Marine & estuarine breeders	26	26	10	4	9
IIa	Obligate dependents	20	16	3	3	5
IIb	Partial dependents	21	9	3	<1	3
IIc	Marine opportunists	29	30	5	6	10
III	Marine vagrants	<1	5	1	1	1
IV	Freshwater	0	1	<1	<1	<1
V	Catadromous	0	<1	<1	<1	<1

Figure G.3 Klein Brak Estuary fish distribution according to four different salinity ranges

The highest densities of the facultative catadromous *Myxus capensis* as well as the opportunistic marine *L. richardsonii* occurred in the < 10 REI zone with peaks in the 20-30 reach as well. However, these high densities may be partly explained by fish backing up against the wiers in the Brandwag and Moordkuil arms. Most individuals (60-100%) of species that have a preference for the < 10 REI zone e.g. *G.aestuaria* and moony *Monodactylus falciformis* were in the “middle reaches” just below either weirs even when salinities were high throughout the system. Numerically, 53% of the fish assemblage was in the REI zone compared to 28%, 14% and 5% in the middle (10-20 & 20-30) and lower (> 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 (22 species) in both parts of the middle reaches (10-30, Brandwag and Moordkuil arms) and lowest in the infrequent & small REI zone (0-10). On the whole, the fish assemblage was dominated by estuarine associated species with very small contributions by both freshwater and marine vagrant species.

APPENDIX H: DATA SUMMARY REPORT FOR BIRDS

H.1 AVAILABLE DATA

Several counts of avifauna populations have been conducted in the Klein Brak Estuary (refer to **Table H.1**). The first as well as the most recent survey have been conducted in the summer, while the CWAC data[1] which also included winter surveys. These counts include all types of birds and the full estuary.

Table H.1 Summary of bird count data available for the Klein Brak Estuary

Date	Type of count	Number of species	Total abundance	Wader abundance	Reference
Summer between 1978-1981	Full	42	1282	813	Underhill & Cooper 1984
February 2006-January 2013	Full	Range 8-19	Range 35-502	Range 13-60	CWAC data
December 2013	Full	32	418	324	This study

H.2 SPECIES RICHNESS AND ABUNDANCE

A total of 60 non-passerine waterbird species have been recorded on Klein Brak Estuary. Of these, 41 species were sighed during Underhill & Cooper 1984, 37 species were sighted in multiple counts between 2006-2013 (29 in summer and 26 in winter) and 31 species were sighted in December 2013 (this study). Counts from Underhill & Cooper 1984, Anchor 2013 as well as the CWAC data mean and maximum counts between 2006 and 2013 are summarised in **Table H.2**.

While it appears that both the Underhill & Cooper 1984 and the Dec 2013 counts were of the entire system, including the floodplain, the CWAC counts have only recorded birds in the lower estuary up to the N2 bridge. As a result, the numbers recorded in the CWAC counts are much lower than in the other two counts. There were 21 species that were recorded in either the Underhill & Cooper 1984 study or during the most recent count (Dec 2013) that were not recorded in the 2006-2013 CWAC data. The majority of these species were migratory waders recorded in large numbers during the Underhill & Cooper 1984 study.

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

Table H.2 Numbers of species recorded on the estuary using Underhill & Cooper 1984, 2006-2013 CWAC data and Anchor 2013 (non-passerine waterbirds, excluding vagrants)

Common name	Underhill & Cooper 1984 Summer	2006-2013 CWAC data (lower estuary only)				Anchor 2013 Summer
		Summer		Winter		
		Average	Max	Average	Max	Estuary
Grebe, Little	2	0	0	2	8	0
Cormorant, White-breasted	1	3	7	14	27	13
Cormorant, Cape	0	0	2	1	6	0
Cormorant, Reed	12	1	7	2	9	4
Darter, African	9	0	1	0	2	0
Heron, Grey	6	2	4	2	5	5
Heron, Black-headed	1	0	0	0	2	0
Heron, Purple	3	0	0	0	0	1
Egret, Great	0	0	1	0	0	0
Egret, Little	14	2	2	2	7	12
Egret, Cattle	3	0	0	0	0	23
Ibis, African Sacred	0	1	3	0	0	37
Ibis, Hadeda	0	0	2	0	0	9
Spoonbill, African	37	0	0	0	0	5
Goose, Egyptian	11	0	0	1	3	5
Duck, Yellow-billed	169	2	12	1	8	3
Goose, Spur-winged	0	0	2	0	0	0
Teal, Cape	41	0	0	0	3	0
Teal, Red-billed	48	0	0	0	0	3
Teal, Hottentot	1	0	0	0	0	0
Shoveler, Cape	79	0	0	1	4	0
Pochard, Southern	5	0	0	0	0	0
Moorhen, Common	1	0	0	0	0	0
Coot, Red-knobbed	71	0	0	0	0	0
Osprey, Osprey	0	1	3	0	0	0
Turnstone, Ruddy	4	0	0	0	0	0
Oystercatcher, African Black	0	3	5	8	16	4
Plover, Common Ringed	18	3	18	0	0	13
Plover, White-fronted	17	6	8	8	36	16
Plover, Kittlitz's	36	0	2	0	0	0
Plover, Grey	2	1	3	0	0	0
Plover, Three-banded	10	0	0	0	0	0

Common name	Underhill & Cooper 1984 Summer	2006-2013 CWAC data (lower estuary only)				Anchor 2013 Summer
		Summer		Winter		
		Average	Max	Average	Max	Estuary
Lapwing, Blacksmith	29	1	3	1	2	23
Sandpiper, Curlew	62	0	0	0	0	2
Stint, Little	118	1	5	0	0	100
Sanderling, Sanderling	6	0	0	0	0	0
Sandpiper, Common	19	0	0	0	0	4
Sandpiper, Wood	71	0	0	0	0	0
Sandpiper, Marsh	27	0	0	0	0	2
Greenshank, Common	19	2	6	0	0	27
Ruff, Ruff	219	0	0	0	0	12
Snipe, African	34	0	0	0	0	0
Godwit, Bar-tailed	0	0	0	0	0	2
Curlew, Eurasian	2	0	0	0	0	0
Whimbrel, Common	0	3	9	1	5	11
Avocet, Pied	0	0	1	0	0	17
Stilt, Black-winged	32	0	0	1	8	11
Thick-knee, Water	0	1	3	1	9	0
Gull, Kelp	7	24	48	21	35	40
Gull, Grey-headed	0	1	2	0	1	0
Gull, Hartlaub's	0	0	0	0	0	13
Tern, Caspian	1	1	4	1	6	2
Tern, Common	0	0	0	1	6	0
Tern, Sandwich	0	0	1	1	8	0
Tern, Swift	0	3	15	119	430	0
Kingfisher, Pied	10	0	1	2	3	6
Kingfisher, Giant	0	0	0	1	2	1
Kingfisher, Malachite	1	0	0	0	0	1
Total	**1258**	**60**	**86**	**193**	**500**	**427**

H.3 BIRD GROUPS AND COMMUNITY COMPOSITION

The CWAC counts have been the only counts to include both summer and winter surveys. In the lower estuary, the avifauna of the Klein Brak Estuary was dominated by piscivorous gulls and terns (65%) in summer (47%) but also especially so in winter (74%; 2006-2013 CWAC data; refer to **Figure H.1**). Most of the birds in the gulls and terns group in summer were Kelp Gulls, whereas in winter the main component was large numbers of Swift Terns (38%). The numbers of cormorants were higher in winter than in summer. Very low numbers of waterfowl, wading birds, birds of prey or kingfishers were recorded in summer and in winter during 2006-2013 CWAC counts.

In the Underhill & Cooper 1984 and Anchor 2013 surveys, the community was dominated by benthivorous waders (58% Underhill & Cooper 1984; 56% this study; refer to **Figure H.2**). However, the proportion of waterfowl, kingfishers and birds of prey was comparatively low in the Anchor 2013 count, which recorded similar numbers to the 2006-2013 CWAC data. This suggests a change in community composition between the early 1980s and 2013.

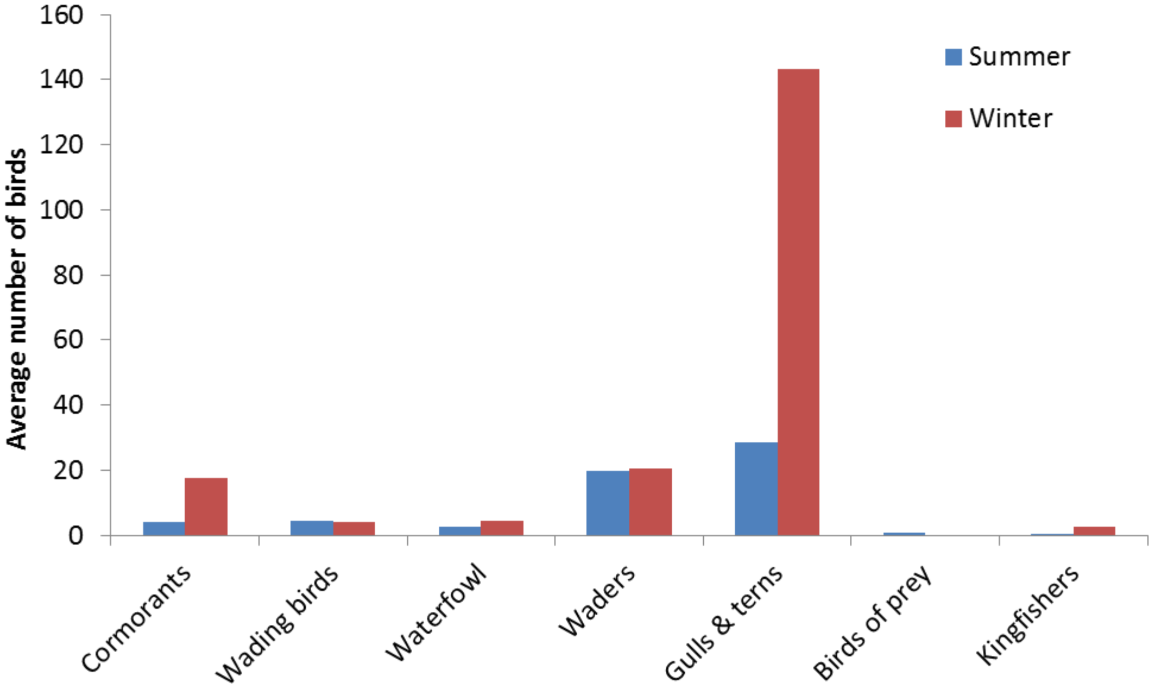


Figure H.1 Average counts of different groups of birds in summer and winter (CWAC data 2006-2013)

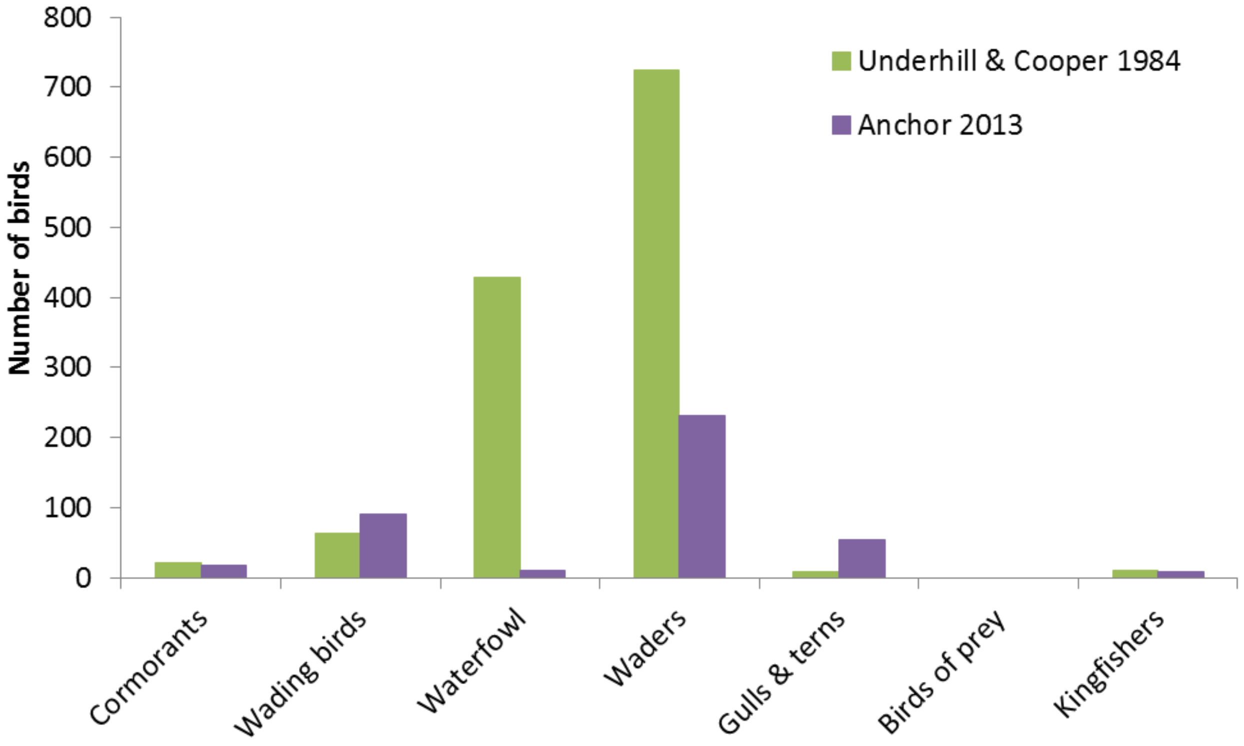


Figure H.2 Counts of different groups of birds in summer using Underhill & Cooper 1984 and Anchor December 2013 surveys

The distribution of birds along the estuary in December 2013 is shown in **Figure H.3**. In the lower estuary, most birds were either at the mouth or on a river bank roost site between the N2 and R102 road bridges, while a small number of birds were in the pans among the salt marshes. The lower estuary area was dominated by gulls, terns and sandy beach waders at the mouth, and gulls and other waders further upstream. The middle reaches, which contained muddy margins and areas of saltmarsh were dominated by waders, gulls and wading birds. A pair of Blue Cranes, not counted among the waterbirds, was using the salt marsh island for breeding. Relatively few birds were counted along the Moordkuil and Brandwag estuarine tributaries, and their communities were quite different. While wading birds and kingfishers were most common along the Moorkuil which was lined with grassy verges and overhanging trees, the Brandwag section had a handful of gulls and wading birds, plus more waterfowl then other stretches. The highest numbers of birds were counted in the marshy floodplain above the weir on the Brandwag tributary (refer to **Figure H.4**). This part of the estuary had high numbers of waders (dominated by Little Stint), wading birds (dominated by Sacred Ibis) and kingfishers compared with the rest of the estuary.

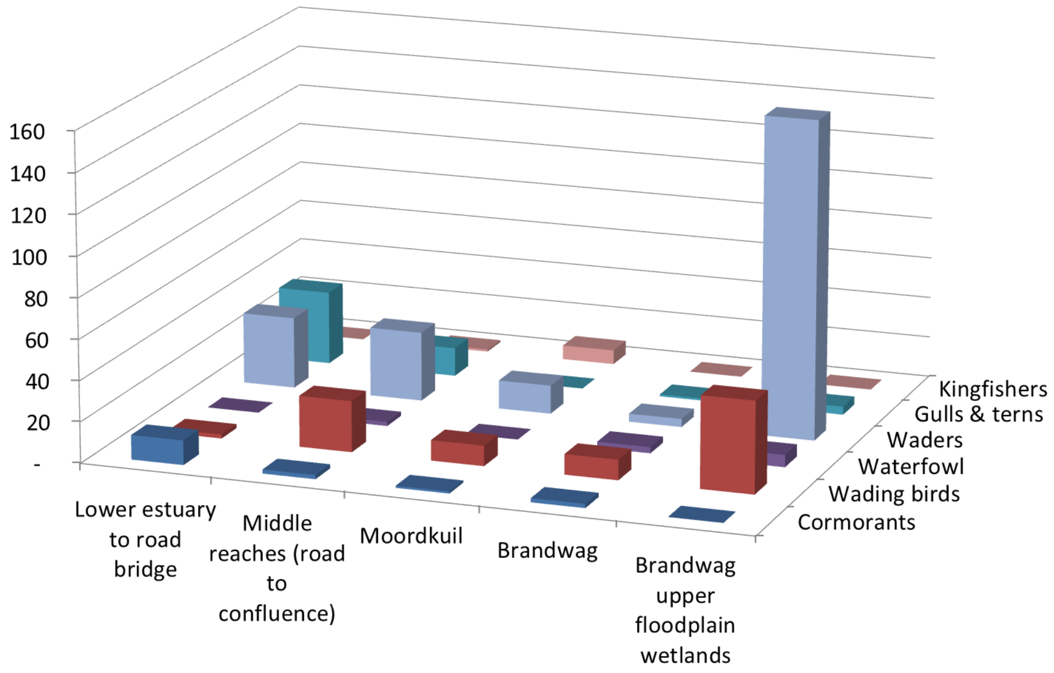


Figure H.3 **Counts of different groups of birds along different stretches of the Klein Brak Estuary during Anchor Dec 2013 surveys**

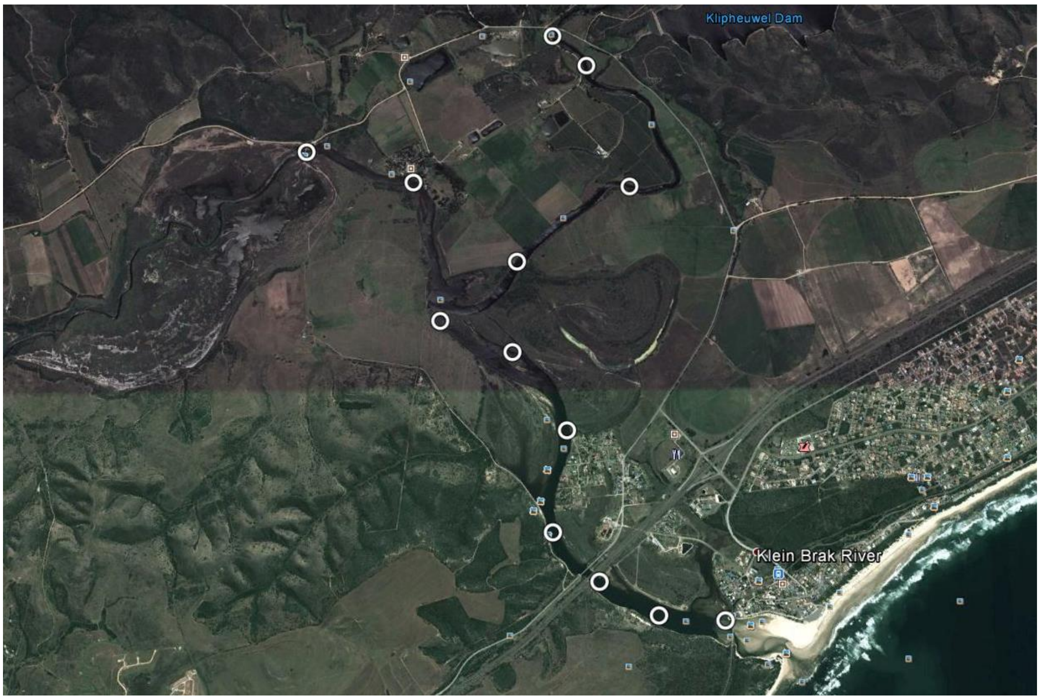


Figure H.4 **Klein Brak Estuary showing the east (Moordkuil) and west (Brandwag) tributaries as well as marsh above the weir on the upper Brandwag**

APPENDIX I: COMMENTS AND RESPONSE REGISTER

Section	Report Statement	Comments	Addressed in Report?	Author Comment
Comments: Dr Andrew Gordon (DWS) dated 12 May 2015				
8.2	EcoSpecs	No EWRs and EcoSpecs have been proposed for alternate Ecological Category scenarios	No	In terms of the Estuary methods (DWAF, 2008) and ToR for this preliminary Reserve study, EcoSpecs will only be provided for REC
8.2	EcoSpecs	Phrase "Resource Quality Objective" is used to describe what I think are actually Ecospecs	Yes	RQOs changed to EcoSpecs throughout report
8.3	Monitoring programme	Recommended monitoring programmes for the estuaries are beyond the current capabilities of the DWS/CMA. Is it possible to suggest a monitoring plan that is phased in over a number of years so that the managing agency has a chance to build capacity	Yes, mostly	Priority components in the monitoring programme has been identified. Also the monitoring was split between baseline surveys and long-term monitoring.
8.2	EcpSpecs: Fish	EcoSpecs for fish need to be more explicit	Yes	Uncertainly in EcoSpecs for fish was changed (see Section 8.2)
Comments: Dr Angus Paterson (external reviewer, SAIAB) dated May 2015				
Entire report	Entire report	Editorial corrections pointed out in his report	Yes	Editorial corrections were made through out report
9	References	Referencing in the report is not comprehensive. In some instances references in main report are listed in Appendices	Yes	References were checked and consolidated (i.e. removed from individual Appendices) in the Reference section (see Section 9)
4 and 7	Colour coding of Abiotic States in Tables and Graphs	A colour legend should be included with each of the figures in these sections for the various abiotic state	Yes, mostly	To include a legend in each of the graphs and figures would result in major repetition. The colour legend is first described in Table 3.1. Therefore in the legend of each table and figure, the reader is referred to Table 3.1 (see Sections

Section	Report Statement	Comments	Addressed in Report?	Author Comment
				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)
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	Yes, mostly	Components with low data availability were highlighted in Section 5.3 on confidence.

Section	Report Statement	Comments	Addressed in Report?	Author Comment
		Sections which end up having a low or Very Low confidence, the low confidence be explained in the narrative on that section and/or specifically discussed . If it is data that was limiting or inconclusive this then needs to be linked to the limitations and assumptions section as per comment 5.6 above.		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 water quality 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-H	Data availability for all Specialist studies	The Specialist reports vary in the manner in which Available information and Data Requirements are reported on. It is important that the reports clearly outline: a) data required for the level of Reserve being undertaken and b) the availability of the prescribed data and if it will be collected in this study. Key missing data should be indicated in Limitations and Assumptions section of the Report.	Yes, mostly	Rapid level assessments do not have data limitation, but avaialbel data sources was discussedin the Specialist summaries.
Appendices A-	Station numbering	Stationing numbering should be distance from	Yes, mostly	As far as possible distance from mouth was

Section	Report Statement	Comments	Addressed in Report?	Author Comment
H		mouth as per methods		provided.
Executive summary	Executive summary	Check for completeness regarding monitoring for Birds and Fish	Yes	Amended
1.1	Method	Check Step 3b, sentence not complete	Yes	Amended
1.4	Limitations and Assumptions	Confidence of Hydrology contradicting	Yes	Amended confidence is score to Low
3.3	Abiotic state	Last sentence incomplete	Yes	Amended
Tables 4.5 7 & 4.7		Low flows: It is indicated that confidence is High but in Executive summary page vi it is indicated as Low.	Yes	Table confidences amended to Low
Table 4.8	Physical habitat	Check bullet numbering and cross-referencing	Yes	Amended
Table 4.9	Spelling	Well mix should be Well Mixed.	Yes	Amended
Table 4.31 & 4.36	Fish and Birds	The rationale around changes in fish biomass (small species) and influence on birds needs to be checked.	Yes	Bird Table amended
5.3	Confidence	Overall Confidence needs to be checked against Section 4.1.2.1	Yes	Checked and amended in Section 4.1.2.1
6.1	Importance	What % estuaries and what Table 1.4. This sentence needs to be checked as it may be a carryover.	Yes	Corrected
6.1	Ecological Importance	The Klein Brak even with a functional Importance score of 100 comes out as of Average Importance. This is then “upgraded” to an Important system which changes the REC. This change is motivated by the importance in terms of fish and the negative trajectory. Is this not a case of double counting as fish has	No	The Klein Brak is in a Category C and the REC should maintain. Section wrongly referred to a Catetory B and this was corrected.

Section	Report Statement	Comments	Addressed in Report?	Author Comment
		already been built into the scoring?		
7.4.1		EHI score is presented in Table 7.22 not 7.21.	Yes	Corrected
8	Recommendations	While the Present flows meet requirements Scenario 1 is recommended to alleviate the loss in base flows and arrest the negative trajectory. This deviation needs to be ratified by DWS.	N/A	Scenario 1 also maintains a Category C. This scenario was selected a one of the major reason for the negative trajectory of change is very low baseflows. This is a recommendation which DWS can override in the sign off templates if not attainable.
8	Recommendations	Is the removal of the weirs a feasible option?	N/A	This is a recooomendation and needs to be futher investigated
Appendix A	Figures	Figure A3. Check Figure is it the right one?	Yes	Figure number amended
Appendix B	Reference	See Breetzke Moore? Incomplete sentence.	Yes	Amended
Appendix C	Figures	Check all Figures as many are out of focus	Yes	That these were at a low resolution in the PDF files reviewed
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 15 January 2015, received 22 September 2015				
Entire report	Entire report	Editorial corrections made in hard copy	Yes	Editorial corrections were made throughout report

Section	Report Statement	Comments	Addressed in Report?	Author Comment
Entire report	Brandwag and Moordkuil arms	Rather use tributaries than arms	No	The areas that we refer to as “arms” are not in the Moordkuil and Brandwag tributaries, but rather in the estuary. Not to confuse these areas in the estuary with the Moordkuil and Brandwag tributaries (flowing into the estuary) we chose to use the terminology “arms”
Section 4.2.1 and 4.2.2	Physical habitat	Combine two section	Yes	Section combined
4.8	Fish	Why romans letter for fish categories?	No	This is the official manner in which these fish categories are referenced in literature
Appendix A	Figure A1	No later mouth survey than 1993?	No	Only these historical data sets are available
Appendix A	Figure A3	No cross-section profiles after 1996?	No	Only these historical data sets are available