



**DEPARTMENT:
DIRECTORATE:**

**WATER AFFAIRS AND FORESTRY
RESOURCE DIRECTED MEASURES**

**OLIFANTS/DORING CATCHMENT
ECOLOGICAL WATER REQUIREMENTS
STUDY**

RDM Report on Estuarine Component

FINAL

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EXECUTIVE SUMMARY

This report outlines results from the Estuarine Component as part of assessing the Ecological Water Requirements the Olifants/Doring River Catchment. The technical component of this study was awarded to Southern Waters Ecological Research and Consulting, and the project management component was awarded to Ninham Shand. The coordination of the estuarine component was awarded to the CSIR (Stellenbosch).

The study is being conducted under the auspices of the Resource Directed Measures (RDM) Directorate of the Department of Water Affairs and Forestry (DWAF). The results of the study are intended to support water allocations planning, in accordance with the requirements of the National Water Act (No. 36 of 1998).

ASSUMPTIONS AND LIMITATIONS

The brief was undertaken based on the following assumptions and limitations:

- Due to budgetary constraints, the complete estuarine field data set, as recommended for a comprehensive ecological reserve determination, could not be collected as part of this project (i.e. only summer and winter surveys instead of quarterly surveys). It, therefore, should be noted that the confidence of the ecological reserve determination may be lower than required for a comprehensive determination (even so, due to the size and complexity of the Olifants Estuary, the generic data requirements recommended for a Comprehensive Ecological Reserve determination may not have given the desired confidence)
- Accurate inflow data on the magnitude and duration of floods in Olifants/Doring System was not available. Flood hydrographs representative of inflows into the Olifants Estuary for both the Reference Condition and Present State were not available. However, as part of the sediment dynamics evaluation some flood hydrographs were generated.
- The overall confidence in the hydrology is **low** as only limited accurate baseflow data was available to base the hydrological and hydrodynamic assessments on. Summer baseflow comprises river flow, leaks from the Bulshoek Weir (though some of this is currently intercepted and pumped back into the irrigation system), return flows from the irrigators, and possibly inflow from springs (e.g. near Kapel). The baseflow is difficult to determine because:
 - The accuracy of the stage measurements at the bridge downstream of Lutzville depends on how well the bridge is cleaned of the debris that blocks the bridge culverts
 - The leaks from Bulshoek Weir have been reduced and were estimated to be about 0.5 m³/s in April 2002 and since then the Lower Olifants River Water User Association (LORWUA) have pumped leakage water back into the canal or into the Bulshoek Weir
 - An unknown proportion of the return flows may have been intercepted by irrigators further downstream
 - There are unconfirmed reports of contributions from springs
 - Flows measurements taken during the summer of 2004/5 at the Lutzville Bridge were made during a drought when the irrigators may have been forced to take additional water from the river to supplement the water from the canal.
- Variable leakage from the Bulshoek Dam also hindered the estimation of flows that reach the estuary. Total leakage of water from Bulshoek Weir was estimated to be 1.2 m³/s

(26 January 1994) of which leakage through the foundation was estimated as about 0.7 m³/s, while the rest was from excessive leakage from the crest gates at the time and leakage from the canal in the immediate vicinity of the wall.

Work done on the foundation of the Bulshoek Weir by DWAF reduced the leakage. The leakage however gradually increased again and on 11 April 2002 it was estimated to be about 0.5 m³/s.

Thereafter DWAF did some major repair work (new concrete apron) to stabilize the foundation. However, the leakage remained the same and some grout work still needs to be done to resolve the problem. In the mean time the LORWUA installed pumps downstream of the dam wall, pump leakage water back into either the irrigation canal or the dam. (Mr F van Heerden, pers comm.).

- The catchment of the Doring River is by far the largest at about 24000 km². The Olifants catchment up to the confluence of the Doring River is much smaller at only about 2900 km². However, the two rivers have approximately the same mean annual runoff under Reference Conditions. The Sout River on the other hand produces very little runoff (approximately 2% of the total mean annual runoff [MAR] of the Olifants), and for this reason, together with the fact that there is very little gauging data, it was decided to exclude this area from the modelling and analysis.
- Water quality data from the DWAF at their routine monitoring station on the Olifants River at Lutzville causeway (E2H016Q01) (representative of the quality of river inflow to the estuary) were only available from December 2002 to January 2005. Reference Conditions were derived from the DWAF routine water quality monitoring station on the Doring River [Melkboom - E2H003] for the years 1980 to 1986.
- Criteria for confidence limits attached to statements in this study were as follows:

LIMIT	DEGREE OF CONFIDENCE
Low	If no data were available for the estuary or similar estuaries (i.e. < 40%)
Medium	If limited data were available for the estuary or other similar estuaries (i.e. 40% – 80%)
High	If sufficient data were available for the estuary (i.e. > 80%)

GEOGRAPHICAL BOUNDARIES

For the purposes of the study, the geographical boundaries for the Olifants Estuary were as follows:

- **Downstream boundary:** Estuary mouth (31° 42.00'S; 18° 11.34'E)
- **Upstream boundary:** Extent of tidal influence, i.e. the causeway at Lutzville - about 36 km from the mouth (31° 33.80'S; 18° 19.78'E)
- **Lateral boundaries:** 5 m contour above MSL along each bank.

The 5 m contour above MSL is indicated on 1:10 000 orthophotos (Olifants River Estuary spans about ten 1:10 000 orthophotos). Although the 1:10 000 orthophotos are electronically available, the 5 m contour above MSL is not yet available on the electronic versions.

PRESENT ECOLOGICAL STATUS (PES)

The Estuarine Health Index scores allocated to the Olifants Estuary (Present State) were:

VARIABLE	WEIGHT	SCORE	WEIGHTED SCORE
Hydrology	25	69	17
Hydrodynamics and mouth condition	25	100	25
Water quality	25	50	13
Physical habitat alteration	25	78	19
Habitat health score			74
Microalgae	20	70	14
Macrophytes	20	58	12
Invertebrates	20	65	13
Fish	20	40	8
Birds	20	95	19
Biotic health score			66
ESTUARINE HEALTH SCORE			70

The EHI score for the Olifants Estuary, based on its Present State, was 70, translating into a Present Ecological Status of C as indicated below:

EHI SCORE	PRESENT ECOLOGICAL STATUS	GENERAL DESCRIPTION
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	C	Moderately modified
41 – 60	D	Largely modified
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

Although the Present State of the Olifants Estuary currently falls within an Ecological Category C, it is likely that the estuary is on a negative trajectory of change, because of the extremely low base flows under the Present State ($< 1 \text{ m}^3/\text{s}$), particularly during the summer months. Maintaining the *status quo* is therefore likely to result in continued modification of the Ecological Status of the estuary.

IMPORTANCE OF THE OLIFANTS ESTUARY

The Estuarine Importance scores allocated to the Olifants Estuary were as follows:

CRITERION	SCORE	WEIGHT	WEIGHTED SCORE
Estuary Size	100	15	15
Zonal Rarity Type	90	10	9
Habitat Diversity	100	25	25
Biodiversity Importance	98	25	25
Functional Importance	100	25	25
ESTUARINE IMPORTANCE SCORE			99

The Estuarine Importance Score for the Olifants Estuary, based on its Present State, is 99, indicating that the estuary is highly important, as indicated below:

IMPORTANCE SCORE	DESCRIPTION
81 – 100	Highly important
61 – 80	Important
0 – 60	Of low to average importance

ECOLOGICAL RESERVE CATEGORY

The recommended Ecological Reserve Category (ERC) represents the level of protection assigned to an estuary.

For estuaries the first step is to determine the 'minimum' ERC, based on its Present Ecological Status (PES). The relationship between EHI Score, PES and minimum ERC is set out in Table 7.

TABLE 7: Relationship between the EHI, PES and minimum ERC

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

NOTE: Should the Present Ecological Status of an estuary be either an E or F, recommendations must be made as to how the status can be elevated to at least achieve a Category D (as indicated above).

PES sets the minimum Ecological Reserve Category. The degree to which Ecological Category needs to be elevated higher than PES depends on the level of **importance** and level of **protection or desired** protection of a particular estuary:

CURRENT/DESIRED PROTECTION STATUS AND ESTUARY IMPORTANCE	RECOMMENDED ECOLOGICAL RESERVE CATEGORY	POLICY BASIS
Protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area (based on complementarity)		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category
Important	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D category

* BAS = Best Attainable State

In addition to being categorised as a 'Highly important estuary' (see above), the Olifants Estuary has also been targeted as a Desired Protected Area (DWAf, 2004a). Therefore, according to the guidelines for assigning a recommended ERC, the estuary needs to be in a Category A or the Best Attainable State (BAS).

At the specialist workshop (held on 25-27 July 2005 in Stellenbosch) it was, however, concluded that with large dam developments already existing in the catchment (e.g. Clanwilliam Dam) it will be difficult to improve the Olifants Estuary to a Category A. The workshop therefore decided to recommend that the Olifants Estuary be improved to the minimum ERC for a 'Highly Important estuary', namely a **Category B**. This also represents

the PES + 1, i.e. the Olifants Estuary is currently a C plus 1 category up takes the estuary to a B category.

QUANTIFICATION OF ECOLOGICAL RESERVE SCENARIOS

A summary of the suite of future runoff scenarios evaluated as part of this project is provided below. Each comprises different inflow scenarios from the Olifants/Doring Catchment, respectively.

SCENARIO	DESCRIPTION	Mean annual runoff (MAR) (million m ³ /year)
Reference	Representative of flows before agricultural developments and impoundments in the catchment	1070.1
Present	Reflects the present agricultural developments and dam developments in the Olifants main stream (Clanwilliam and Bulshoek Dam) - simulated data reflect inflow without Bulshoek leakage	715.0
Scenario 2	Present inflow plus the Ecological Water Requirement releases of the River	800.3
Scenario 7	Raising Clanwilliam wall (15 m) plus the Ecological Water Requirement releases of the River	741.5
Scenario 5	Raising Clanwilliam wall (15 m) with no River EWR releases	605.7
Scenario 17	Brandewyn weir/dam development on the Brandewyn river (a tributary to the Doring River) with a capacity of 5 x 10 ⁶ m ³ , including an abstraction of 5 m ³ /s plus raising the Clanwilliam wall (15 m) with no River EWR releases	529.3
Scenario 10	Maximum development represents the Melkbosrug Dam in the Doring catchment. This development would regulate almost all of the inflows from the Doring River and maximise the yield from the Olifants / Doring River system. This scenario ignores the Ecological Water Requirement of the Doring river (includes 15 m raising of Clanwilliam wall) with no River EWR releases	423.5

The individual EHI scores, as well as the corresponding ERC for the different scenarios were as follows:

VARIABLE	WEIGHT	PRESENT	RUNOFF SCENARIO				
			2	7	5	17	10
Hydrology	25	69	77	74	64	61	38
Hydrodynamics/mouth condition	25	100	100	100	100	100	100
Water quality	25	50	61	56	46	41	34
Physical habitat alteration	25	78	78	75	75	70	50
Habitat health score	50	74	79	76	71	68	47
Microalgae	20	70	80	75	70	50	40
Macrophytes	20	58	70	55	49	47	40
Invertebrates	20	65	75	70	55	45	25
Fish	20	40	50	52	40	30	25
Birds	20	95	94	95	95	90	78
Biotic health score	50	66	74	69	62	52	33
Estuarine Health Index Score		70	76	73	67	60	40
Ecological Reserve Category (ERC)		C	B	C	C	D	E

RECOMMENDED ECOLOGICAL FLOW REQUIREMENT

The evaluation of the simulated runoff scenarios is used to derive the recommended Ecological Flow Requirement. The recommended Ecological Flow Requirements is defined as the runoff scenario (or a slight modification thereof) that represents the highest reduction in river inflow that will still protect the aquatic ecosystem of the estuary and keep it in the recommended ERC.

The Olifants Estuary has been targeted as a Desired Protected Area (DWAF, 2004). According to the guidelines for assigning a recommended ERC the estuary, therefore needs to be in a Category A or the Best Attainable State (BAS). However, with large dam developments already existing in the catchment (e.g. Clanwilliam Dam) it will be difficult to improve the Olifants Estuary to a Category of A. It was therefore recommended that the Olifants Estuary be improved to the minimum ERC for a 'Highly Important estuary', namely a **Category B**.

Following the guideline above, **Scenario 2**, i.e. the Present inflow scenario plus the Ecological Water Requirement releases of the River ($MAR = 800.3 \times 10^6 \text{ m}^3$) is selected as the recommended Ecological Flow Requirement Scenario for the Olifants Estuary. The flow distributions are summarised below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	48.13	32.08	21.50	37.21	24.46	7.77	96.73	194.20	550.92	472.06	230.02	153.70
90%ile	28.90	9.60	7.24	3.64	3.76	3.85	9.62	80.90	151.71	159.08	126.25	65.58
80%ile	16.05	4.30	2.06	1.75	1.68	2.21	4.85	22.01	93.83	104.19	79.44	48.08
70%ile	12.84	2.93	1.68	1.55	1.38	1.81	3.07	11.18	57.99	78.10	66.22	34.22
60%ile	11.49	2.93	1.51	1.51	1.37	1.46	2.88	8.24	42.45	58.26	50.45	25.66
50%ile	10.11	2.93	1.50	1.51	1.34	1.42	2.84	6.19	37.99	51.82	47.54	22.18
40%ile	9.01	2.49	1.50	1.51	1.34	1.42	2.49	3.57	36.22	39.92	44.77	16.34
30%ile	8.32	1.51	1.50	1.51	1.34	1.42	1.76	3.42	24.20	30.79	33.23	14.73
20%ile	6.36	1.43	1.18	1.51	0.91	1.11	1.41	2.05	15.78	21.17	28.07	11.21
10%ile	4.02	0.83	0.58	0.99	0.85	1.00	1.28	1.15	7.44	9.49	17.41	9.66
1%ile	1.01	0.15	0.00	0.99	0.34	0.00	0.04	0.29	0.82	2.07	5.35	4.04

The workshop highlighted that a significant degree of the modification resulting in the Present State Category C is linked to non-flow related anthropogenic activities such as:

- Nutrient inputs from agricultural activities; and
- Over-exploitation of fish resources (gill net fisheries).

It was therefore concluded that should improved management and control of the above-mentioned activities be achieved, Scenario 7 (raising of the Clanwilliam Dam by 15 m plus the Ecological Water Requirement releases of the River - $MAR = 741.5 \times 10^6 \text{ m}^3$) might prove to be sufficient to achieve the recommended Category B. However, this will require cooperation and assistance from the Department of Agriculture and the Department of Environmental Affairs and Tourism (in particular Marine and Coastal Management) (i.e. cooperative governance).

The flow distributions of Scenario 7 are summarised below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	38.67	28.63	21.90	37.61	24.80	7.37	96.27	174.77	456.58	471.55	205.43	148.18
90%ile	16.94	8.24	7.64	4.04	4.13	4.07	9.92	69.28	127.88	158.65	111.97	51.47
80%ile	12.56	4.35	2.46	2.15	2.01	2.37	4.92	21.44	88.02	81.43	73.72	35.30
70%ile	10.61	3.29	2.08	1.91	1.77	1.96	3.25	10.60	57.48	67.52	57.21	26.31
60%ile	9.40	3.29	1.90	1.91	1.71	1.77	3.18	7.67	41.29	54.98	48.28	22.32
50%ile	9.33	3.29	1.90	1.91	1.71	1.77	2.86	5.48	38.23	51.94	47.57	16.21
40%ile	9.33	2.72	1.90	1.91	1.71	1.77	2.53	3.65	37.67	47.54	44.17	14.00
30%ile	7.22	1.87	1.90	1.88	1.30	1.26	1.76	3.41	26.23	29.53	34.55	12.50
20%ile	5.69	1.79	1.43	1.88	1.15	1.00	1.68	1.62	15.69	21.31	28.53	10.87
10%ile	4.34	1.13	0.98	0.99	0.88	1.00	1.00	1.21	6.44	7.88	15.28	8.11
1%ile	1.29	0.03	0.00	0.99	0.44	0.15	0.17	0.40	0.90	1.54	4.80	4.26

Although the Present State of the Olifants Estuary currently falls within an Ecological Category C, the estuary is on a negative trajectory of change, because of the extremely low base flows under the Present State ($< 1 \text{ m}^3/\text{s}$), particularly during the summer months.

It was therefore concluded that to maintain the estuary in the Present State (Ecological Category C) base flows will need to be re-introduced, particularly during the summer period. Scenario 5 showed that by returning some of the base flows during summer, it is possible to maintain the estuary in a Category C, even if the Clanwilliam Dam was raised by 15 m. Scenario 5 was selected as the environmental flow requirements that would maintain the estuary in a Category C:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	42.17	28.76	21.52	37.04	24.33	7.43	95.80	153.56	471.91	470.40	210.01	149.81
90%ile	23.61	7.85	7.27	3.66	3.84	4.07	9.43	66.69	112.14	150.96	116.78	65.34
80%ile	11.33	3.96	2.33	1.62	1.80	2.11	4.34	17.92	72.07	78.37	81.56	40.07
70%ile	7.85	2.16	1.64	1.53	1.46	1.73	2.24	8.84	44.03	53.49	52.19	30.07
60%ile	5.44	1.67	1.52	1.53	1.45	1.39	1.79	4.84	21.61	38.99	33.68	20.61
50%ile	4.36	1.42	1.52	1.53	1.41	1.32	1.23	2.33	14.39	22.60	27.35	13.96
40%ile	3.17	1.36	1.52	1.53	1.41	1.32	1.15	1.65	9.02	12.62	17.14	12.10
30%ile	2.00	1.36	1.52	1.53	1.41	1.32	1.15	0.90	5.01	8.22	11.91	8.78
20%ile	1.70	1.36	1.52	1.53	1.41	1.32	1.15	0.52	2.19	5.28	8.21	5.68
10%ile	1.43	1.36	1.52	1.24	0.95	0.70	0.80	0.43	0.84	2.91	3.92	3.28
1%ile	1.20	1.19	0.89	0.88	0.40	0.22	0.00	0.04	0.32	0.49	0.84	1.59

The consequences of maintaining the Olifants Estuary in an Ecological Category C are considered to be as follows:

- Excessive (or nuisance) macrophyte growth is likely to occur during the late summer months in the upper reaches, particularly if nutrient inputs from agricultural activities continue in the upper reaches. This will have potential negative impacts on water intake systems, recreational usage and aesthetics (i.e. 'loss of value').
- As the flow scenario for an Ecological Category C will result in a reduction of freshwater pulsing to the marine environment (e.g. inflows will be more regulated), this could result in a reduced cueing effect to estuarine dependent invertebrate and fish species.

- Also, more regulated inflow will reduce the variability in abiotic conditions, which in turn may result in changes in community composition (particularly in terms of invertebrates and fish), thus affecting biodiversity.

The above-mentioned are also likely to have a ripple effect on economic good and services provided by the adjacent marine environment, e.g. the marine fisheries. The Olifants Estuary is but one of a few large estuarine systems along the South African west coast where it is considered to play a crucial role in terms of biological functionality to sustain the important fisheries resource. However, the linkages between the estuary, the marine environment and the fisheries resource are still poorly understood. Some of the key aspects that require further research are highlighted later.

It is therefore strongly recommended that decisions regarding the future state of the Olifants Estuary, carefully consider potential impacts on all uses, both land-based and marine-based activities. This will require effective cooperative governance between the Department of Water Affairs and Forestry, Department of Agriculture and the Department of Environmental Affairs and Tourism (particularly Marine and Coastal Management).

ECOLOGICAL SPECIFICATIONS

Ecological Specifications are clear and measurable specifications of ecological attributes (in the case of estuaries - hydrodynamics, sediment dynamics, water quality and different biotic components) that define a specific ecological reserve category, in the case of the Olifants Estuary for a **Category B**. Thresholds of potential concern (TPC) are defined as measurable end points related to specific abiotic or biotic indicators that if reached (or when modelling predicts that such points will be reached) prompts management action. The ecological specifications and associated TPCs are listed below:

COMPONENT	ECOLOGICAL SPECIFICATION/ RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN
Birds	Retain the species richness, abundance and diversity of the bird community, representative of resident and migrant waders, wading birds and water fowl as under the Present State, except for that there would be an higher abundance of water fowl (increasing by about 10% from Present State numbers)	1.1 Community composition or bird numbers deviates by more than 50% of average seasonal baseline counts for two consecutive summer or winter seasons, focusing on waders, wading birds, terns & water fowl (summer and winter), and specifically red data species which are supported by the system (e.g. Pelican, Oyster catchers, Chestnut banded plover) 1.2 In the case of water fowl densities decline by 20% of average seasonal baseline counts for two consecutive summer or winter seasons
Fish	Retain the following fish assemblages in the estuary: estuarine species (35%), partially estuarine dependent species (50-60%), obligate estuarine dependent (e.g. white steenbras) (>1%) and indigenous freshwater species (>1%). Exotic freshwater species (<0.5%)	2.1 Level of estuarine species drop below 30% of total abundance 2.2 Levels of obligate estuarine dependent species drop below 1% of total abundance 2.3 Levels of partially estuarine dependent species drop below 50% or above 60% of total abundance 2.4 Levels of exotic freshwater species above 0.5% (e.g. Mozambique tilapia out-competing resident species) 2.5 Benthic dwellers species drop below 2% of total abundance in estuary above 18 km from the mouth

COMPONENT	ECOLOGICAL SPECIFICATION/ RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN
	Maintain recruitment of adult and juvenile fish at Reference Condition levels. This requires maintaining sufficient flow for freshwater plume (temperature, salinity and oliphactory gradient) entering the sea. This implies that there should be a significant number of 0 -1 year old fish and no missing year classes.	2.6 There are a missing year class within a species
Invertebrates	Retain Present State species richness and mix (low species abundance, high dominance). However, under the present state one or two species are always present at high densities compared to others (e.g. <i>Pseudodiaptomus hessei</i> & <i>Ceratonereis keiskama</i>). For a B Category the higher densities need to be more variable in abundance during the year.	3.1 Species richness is greater than 30 for zooplankton and macroinvertebrates respectively (50% increase)
	Indicator species such as <i>Capitella capitata</i> , should not dominate benthic species at any site	3.2 <i>Capitella capitata</i> exceeds 50% abundance of benthic species at any site
	<i>Calianassa</i> and <i>Upogebia</i> distribution patterns as under Present State	3.3 Abundance levels or areas of distribution decreases by more than 50% (mainly lower sandy reaches)
Macrophytes	Maintain the present distribution (summer 2004) and abundance of the different plant community types (<i>Zostera capensis</i> (48 ha), intertidal salt marsh (92 ha), supratidal salt marsh (143 ha), floodplain salt marsh (797 ha), reeds and sedges (60 ha))	4.1 Greater than 20% change in the area covered by different plant community types
	Reduce the areas covered by water weeds in the upper reaches by 50% compared to the Present State (summer 2004). Therefore area covered by invasive waterweeds (<i>Azolla filiculoides</i>), nuisance filamentous algae (e.g. <i>Enteromorpha</i> , <i>Ulva</i> , <i>Cladophora</i>) and pondweed (<i>Potamogeton pectinatus</i>) should be 30 ha (half of channel)	4.2 Upper 15 km of estuary with greater than 50% of estuary water channel covered by invasive waterweeds (<i>Azolla filiculoides</i>), nuisance filamentous algae (e.g. <i>Enteromorpha</i> , <i>Ulva</i> , <i>Cladophora</i>) and pondweed (<i>Potamogeton pectinatus</i>).
	Control the spread of invasive aliens in the riparian zone (e.g. <i>Sesbania punicea</i> and <i>Eucalyptus</i> spp.).	4.3 Greater than 20 % increase in area covered by invasive plants.
	Maintain reed and sedge areas (60 ha) and brackish salt marsh (~10 ha) as for the Present State (summer 2004) (by preventing salinity of 20 ppt to move further upstream than 8.5 km and remain there for greater than 3 months).	4.4 Dieback of reeds and brackish salt marsh at 8.5 km and further upstream from the mouth.
	Prevent an increase in bareground in the floodplain salt marsh by maintaining groundwater salinity at <70 ppt and depth to the water table at < 1.5 m	4.5 Greater than 20% increase in bare ground in salt marsh.
Microalgae	Maintain a low phytoplankton biomass with a small REI (i.e. 10 ppt to river +1 ppt) zone	5.1 Phytoplankton biomass exceeds 15 µg/l chlorophyll a in summer and 10 ug/l chlorophyll a in winter 5.2 Blue-green algae exceeds 10% of phytoplankton cell counts
	Maintain microalgal group diversity as measured under Present State (2004)	5.3 Flagellates cease to be the dominant group and diatoms become less diverse (<10 taxa per site)
	Maintain intertidal and subtidal microphytobenthic biomass as measured under Present State (2004).	5.4 Benthic microphytobenthic biomass exceeds 40 mg/m ² chlorophyll a
	Maintain a low frequency of dinoflagellates	5.5 The frequency of dinoflagellates exceeds 5% of the total phytoplankton counts

COMPONENT	ECOLOGICAL SPECIFICATION/ RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN
Water quality	Salinity intrusion should not to cause exceedence of TPCs for fish, invertebrates, macrophytes and microalgae (see above)	6.1 Salinity greater than 20 ppt for greater than 3 months at 7 km upstream from the mouth (brackish saltmarsh, reeds and sedges & invertebrates) 6.2 Salinity of groundwater increases to 50 ppt and depth to water table to 1 m. (flood plain salt marsh) 6.3 Total dissolved solids (measure of 'salinity') of river inflow exceeds 3500 mg/l (phytoplankton) 6.4 Salinity in estuary exceeds 35 ppt (prevent hyper-salinity) (for phytoplankton) 6.5 Salinity greater than 10 ppt occurs above 16 km upstream of the mouth (for fish)
	System variables (Temperature, pH, turbidity, dissolved oxygen, suspended solids and turbidity) not to cause exceedence of TPCs for biota (see above)	6.6 River inflow: Summer temp < 20°C pH < 6.5 'Turbid' river inflow (to be determined) Dissolved oxygen < 4 mg/l
		6.7 Secchi disc reading above 8 km from the mouth is greater than 1 m (used as a proxy for turbidity concentrations in estuary)
		6.8 pH > 8.5 or < 6.5 in river inflow or in estuary
		6.9 Water column DO drops below 4 mg/l (1 m above bottom except in deep holes) (need to investigate DO level at night in dense macrophyte beds)
	Inorganic nutrient concentrations not to cause exceedence of TPCs for macrophytes and microalgae (see above).	6.10 When average river inflow is less than 5 m ³ /s and average DIN concentrations exceed 100 µg/l in river inflow and average DIN concentrations in the upper reaches of the estuary (above 16 km from mouth) exceed 100 µg/l.
		6.11 During high flow season (flows > 20 m ³ /s) average DIN concentrations exceed 500 µg/l in river inflow and average DIN concentrations in the upper reaches of the estuary (above 16 km from mouth) exceed 500 µg/l
		6.12 Average DRP concentrations exceed 100 µg/l in river inflow and average DRP concentrations in the upper reaches of the estuary (above 16 km from mouth) exceed 100 µg/l.
	Presence of toxic substances not to cause exceedence of TPCs for biota (see above).	6.13 For pesticides/herbicides baseline studies still need to be undertaken before TPCs can be set (special concern in upper reaches with extensive agricultural activities along banks of estuary)
	Hydrodynamics	7.1 River inflow distribution patterns differ by more than 5% from that of Scenario 2 (i.e. recommended flow scenario for the Olifants)
		7.2 River inflow decreases to below 1.5 m ³ /s at any time
		7.3 River inflow below 2 m ³ /s persists for longer than 4 months
Sediment dynamics	Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) so as not to exceed TPCs for biota (see above)	8.1 River inflow distribution patterns (flood components) differ by more than 10% (in terms of magnitude, timing and variability) from that of the Present State (2004)
		8.2 Suspended sediment concentration from river inflow deviates by more than 10% of the sediment load discharge relationship to be determine as part of baseline studies (Present State 2004)

COMPONENT	ECOLOGICAL SPECIFICATION/ RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN
	Changes in sediment grain size distribution patterns not to cause exceedance of TPCs in benthic invertebrates (see above).	8.3 The median bed sediment diameter deviates by more than a factor of two from levels to be determined as part of baseline studies (Present State). 8.4 Sand/mud distribution in middle reaches (8-20 km) change by more than 20% from Present State (2004) 8.5 Changes in the channel bathymetry in the upper reaches (above 20 km upstream of the mouth) change by more than 20% from Present State (2004) 8.6 Changes in tidal amplitude below the Lutzville causeway of more than 20% from Present State (2004)

RESOURCE MONITORING PROGRAMME

The status of baseline studies currently available for the Olifants Estuary are summarised in this report. However, although this Ecological Reserve determination study did include a summer (March 2004) and winter (August 2004) sampling surveys, these surveys were actually representative of drought conditions (even the winter sampling still reflected the influence of a drought year). The 2004 sampling survey did therefore not capture typical seasonal responses as required for an Ecological reserve determination – not even for a typical summer/winter situation (although it did provide valuable information on the system's response during drought periods).

The Olifants Estuary, being a complex system, does require (consecutive) seasonal surveys to improve the confidence of the Reserve, as well as to set a suitable and reliable baseline (high confidence) for the different abiotic and biotic components in a long-term monitoring programme.

As a result quite extensive baseline surveys still need to be undertaken to achieve this goal for the Olifants Estuary (see following pages). The additional baseline surveys were prioritised according to the criteria provided below.

	High priority, considered as a minimum list of indicators to sufficiently monitor the effectiveness of the Reserve
	Medium Priority, will improve the confidence of the auditing process and should be added to the process if funding is available
	Low priority, will add to the overall confidence of the auditing process, but not considered to be a critical indicator in the case of the Olifants Estuary

However, for baseline surveys the quantification of linkages between different abiotic and biotic components is very important, and exclusion of certain components is likely to result in only incremental gain in confidence which may not warrant the effort.

A proposed long-term resource monitoring programme for the Olifants Estuary is also provided below. Should the components within the programme need to be prioritised prior to the completion of the baseline studies (when higher confidence will allow for a sensible prioritisation), it was concluded that the emphasis should be placed on monitoring of the abiotic 'driver' components.

Additional baseline studies to improve confidence of Reserve and to set baseline for long-term monitoring in Olifants Estuary are as follows:

	High priority
	Medium Priority
	Low priority

ECOLOGICAL COMPONENT	MONITORING ACTION	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
BIRDS	Undertake counts of all water associated birds. All birds should be identified to species level and total number of each counted.	Monthly surveys during a normal flow year	Entire estuary
FISH	Conduct fish surveys using both seine and gill nets as primary gear.	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season	Entire estuary (15-20 stns)
	Collect samples for larval recruitment.	Summer and winter survey	At mouth
INVERTEBRATES	Zooplankton: Collect quantitative samples using a flow meter <u>after dark</u> , preferably during neap tides (mid to high tide) because currents are less strong and zooplankton will be more active in water column. Sampling to be done at mid- water level, i.e. not surface. (Include chlorophyll a measurements on benthic microalgae and water column chlorophyll as to establish feeding links)	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season	Entire estuary (10-15 stns)
	Benthic invertebrates: Collect (subtidal) samples using a Zabalocki-type Eckman grab sampler with 5-9 randomly placed grabs (replicates) at each station. Collect intertidal samples at spring low tide using core sampling.	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season	Entire estuary (10-15 stns)
	Macrocrustaceans: Collect quantitative samples during neap tides (mid to high tide), at the same stations used for zooplankton, using a benthic sled with flow meter.	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season	Entire estuary (10-15 stns)
	Collect samples for larval recruitment (zooplankton can supplement fish surveys).	Summer and winter survey	At mouth
MACROPHYTES	No additional baseline are data required.	-	-
MICROALGAE	Phytoplankton: Conduct counts of dominant phytoplankton group.	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season.	Entire estuary (8 stns)
	Benthic microalgae: No additional baseline data are required.	-	-

	High priority
	Medium Priority
	Low priority

Additional baseline studies (cont...):

ECOLOGICAL COMPONENT	MONITORING ACTION	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
WATER QUALITY	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow.	At least monthly for 3 additional years	At Lutzville causeway
	Water quality measurements of seawater (No additional measurements required - consult available literature on marine water quality in the area).	-	-
	Collected longitudinal salinity & temperature profiles (in situ).	Quarterly for 1 year, coinciding with biotic sampling	Entire estuary (10-15 stns)
	Water quality measurements taken along the length of the estuary (surface and bottom samples) for pH, dissolved oxygen, suspended solids/turbidity and inorganic nutrients.	Quarterly for 1 year, coinciding with phytoplankton and other biotic surveys	Entire estuary (10-15 stns)
	Temperature recordings - large portions of recruitment and behavioural aspects of fish and invertebrates are probably temperature driven on the west coast. Knowledge gained can also be extrapolated to other systems (as this is not considered to be a very costly exercise it is listed here)	Continuous for 1 year	At mouth and 3-5 stns along estuary
	Baseline data set for pesticides/herbicides accumulation in sediments	Once, at end of low flow period also taking into consideration when spraying occurred	Focus on depositional areas
HYDRODYNAMIC	Water level recordings	Continuous	Near mouth 15 km from mouth 36 km from mouth
	Flow gauging	Continuous	Near Lutzville causeway
	Aerial photographs of estuary (recent photograph at spring low tide)	Once-off	Entire estuary
	Water level recordings along the length of the estuary (done at the same time as cross section profile survey) (if the additional water level recorders cannot be installed)	Once of during a spring and neap tidal cycle (2 wks each)	Near mouth 15 km from mouth 36 km from mouth
	Near-shore wave data records (only if available)	-	-
SEDIMENT DYNAMICS	Bathymetric survey: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but more detailed in the mouth (vertical accuracy better than 300 mm)	Once-off (to define Present State)	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	Once off	Entire estuary 200 m to 2 km intervals
	Series of sediment core (3 m) samples for the analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) along the length of estuary (200 m to 2 km intervals). Recommend that isotope analysis in carried out on selected sample to determine the age of sediments	Once-off	Entire estuary 200 m to 2 km intervals
	Velocity cross section data during a neap and spring tide (the same period as the cross section profiles)	Once-off	200 m from mouth
	Daily sampling of suspended sediment (and organic matter) - Required to quantify actual sediment and organic yield and variability entering the estuary from the catchment. (Although sampling of organic input to the estuary from the catchment is not included in current estuarine protocol it is important and this means of quantifying it)	Daily for 5 years	DWAF monitoring station at Sishen-Saldanha train bridge

Proposed long-term resource monitoring programme for the Olifants Estuary are as follows:

	High priority
	Medium Priority
	Low priority

ECOLOGICAL COMPONENT	MONITORING ACTION	RELATED TPC (see above)	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
BIRDS	Undertake counts of all water associated birds. All birds should be identified to species level and total number of each counted.	1.1 – 1.2	Winter and summer survey, yearly	Entire estuary
FISH	Conduct fish surveys using both seine and gill nets as primary gear.	2.1 – 2.6	Two years after implementation conduct summer and winter survey, followed by summer and winter survey every 3 years thereafter	Entire estuary (10-15 stns)
INVERTEBRATES	Zooplankton: Collect quantitative samples using a flow meter <u>after dark</u> , preferably during neap tides (mid to high tide). Sampling to be done at mid- water level, i.e. not surface. (Include chlorophyll a measurements on benthic microalgae and water column chlorophyll a to establish feeding links)	3.1	Same as for fish	Entire estuary (10-15 stns)
	Benthic invertebrates: Collect (subtidal) samples using a Zabalocki-type Eckman grab sampler with 5-9 randomly placed grabs (replicates) at each station. Collect intertidal samples at spring low tide using core sampling.	3.2	Same as for fish	Entire estuary (10-15 stns)
	Macrocrustaceans: Collected quantitative samples during neap tides (mid to high tide), at the same stations used for zooplankton, using a benthic sled with flow meter.	3.3	Same as for fish	Entire estuary (10-15 stns)
MACROPHYTES	Use aerial photographs to quantify area covered by different plant community types and produce a vegetation map. Conduct ground survey to: 1) verify areas covered by different plant community types, 2) check the spread of alien vegetation, 3) check the spread of aquatic weeds and algae in the upper estuarine reaches 4) check the extent of bareground in the floodplain salt marsh, depth to groundwater and groundwater salinity. 5) check the distribution of reeds, sedges and brackish salt marsh up the length of the estuary in relation to the longitudinal salinity gradient.	4.1 – 4.5	Same as for fish	Entire estuary
MICROALGAE	Phytoplankton: Conduct water column chlorophyll a measurements and counts of dominant phytoplankton group.	5.1 – 5.3, 5.5	Same as for fish	Entire estuary (8 stns)
	Benthic microalgae: Conduct benthic chlorophyll a measurements	5.4	Same as for fish	Entire estuary (8 stns)

Proposed long-term resource monitoring programme (cont...):

	High priority
	Medium Priority
	Low priority

ECOLOGICAL COMPONENT	MONITORING ACTION	RELATED TPC (see above)	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
WATER QUALITY	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow	6.6, 6.7 & 6.8	At least monthly	At Lutzville causeway
	Monitor inorganic nutrient inflow from agricultural return flow in upper reaches (e.g. bore hole sampling)	6.6, 6.7 & 6.8	At least monthly	3-5 stns along upper banks
	Collected longitudinal salinity & temperature profiles (<i>in situ</i>)	6.1 – 6.5	To be measured when biotic surveys require information for interpretation	Entire estuary (10-15 stns)
	Water quality measurements taken along the length of the estuary (surface and bottom samples) for pH, dissolved oxygen, suspended solids/turbidity and inorganic nutrients.	6.7 – 6.9		Entire estuary (10-15 stns)
	Baseline data set for pesticides/herbicides accumulation in sediments	6.13	Every 3 – 6 years	Focus on depositional areas
HYDRODYNAMICS	Water level recordings	8.6	Continuous	Near mouth
	Flow gauging	7.1 – 7.3 & 8.1	Continuous	Near Lutzville causeway
	Aerial photographs of estuary (spring low tide)	4.1 – 4.4 & 8.5	Annually	Entire estuary
SEDIMENT DYNAMICS	Bathymetric survey: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but more detailed in the mouth (vertical accuracy better than 300 mm)	8.5	Every 3-6 years, depending on time scale of dominant	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	8.3 - 8.4	sedimentation/erosion processes in estuary, as well as after flood events	Entire estuary
	Daily sampling of suspended sediment (and organic matter)	8.2	Daily	Sishen-Saldanha train bridge

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

BAS	Best Attainable State
CERM	Consortium for Estuarine Research and Management
cpue	Catch per unit effort
DEAT	Department of Environmental Affairs and Tourism
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DRP	Dissolved Reactive Phosphate
DRS	Dissolved Reactive Silicate
DWAF	Department of Water Affairs and Forestry
ERC	Ecological Reserve Category
EHI	Estuarine Health Index
EWR	Ecological Water Requirement
NRF	National Research Foundation
NWA	National Water Act
MAR	Mean Annual Runoff
MSL	Mean Sea Level
PES	Present Ecological Status
RDM	Resource Directed Measures
REI	River-Estuary-Interface
RSA	Republic of South Africa
RQO	Resource Quality Objectives
TPC	Threshold of Potential Concern
WRC	Water Research Commission

1. INTRODUCTION

1.1 Background

The National Water Act (Act No. 36 of 1998) (NWA) is founded on the principle that National Government has overall responsibility for, and authority over, water resource management for the benefit of the public without seriously affecting the functioning of the natural environment. In order to achieve this objective, Chapter 3 of the NWA provides for the protection of water resources through the Reserve.

The Directorate: Resource Directed Measures (D:RDM) is tasked with the responsibility of ensuring that the Reserve requirements, which have priority over other uses in terms of the Act, are determined before license applications are to be processed, particularly in stressed catchments. The Olifants/Doring River Catchment is deemed to be one such catchment and a comprehensive determination of the Reserve is therefore needed.

This report outlines results from the Estuarine Component as part of assessing the Ecological Water Requirements the Olifants/Doring River Catchment. The technical component of this study was awarded to Southern Waters Ecological Research and Consulting, and the project management component was awarded to Ninham Shand. The coordination of the estuarine component was awarded to the CSIR (Stellenbosch).

The study is being conducted under the auspices of the Resource Directed Measures (RDM) Directorate of the Department of Water Affairs and Forestry (DWAF). The results of the study are intended to support water allocations planning, in accordance with the requirements of the National Water Act (No. 36 of 1998).

1.2 Project Team

The core specialist team appointed for this project was as follows:

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The following persons formed part of the project team to support capacity building in the application of Ecological Reserve determinations on Estuaries or attended the workshop as a learning opportunity (* attended the specialist workshop from 25 – 28 July 2005 in Stellenbosch):

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Other parties that attended the Estuarine Specialist Workshop, held in Stellenbosch, for one or more days were:

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1.3 Overview of Determination of Ecological Reserve for Estuaries: Process

The preliminary determination of the Ecological Reserve can be conducted on different levels, namely:

- Comprehensive level
- Intermediate level
- Rapid level.

The procedures are discussed in detail in *Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAF, 2004a). A summary of the procedures for the determination of the comprehensive preliminary Ecological Reserve determination for estuaries, in the context of the larger process, are illustrated in Figure 1.

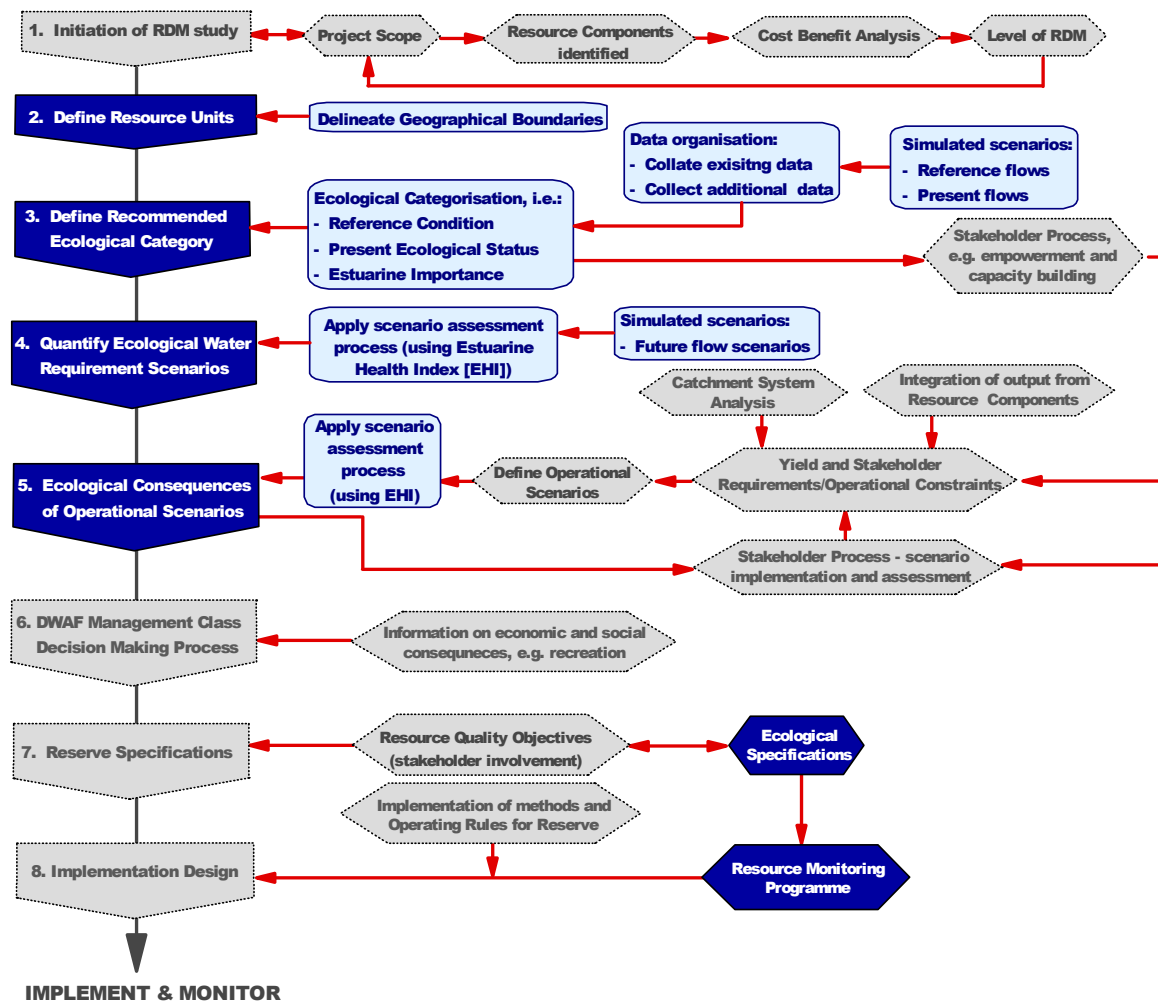


Figure 1: Procedures for a Comprehensive Ecological Reserve determination on estuaries, in context of the broader RDM process (components not addressed as part of the Ecological Reserve determination process are indicated by non-solid line boxes) (DWAF, 2004a)

A summary of the human resources required to conduct a Comprehensive level determination of the preliminary Ecological Reserve for estuaries are illustrated in Figure 2.

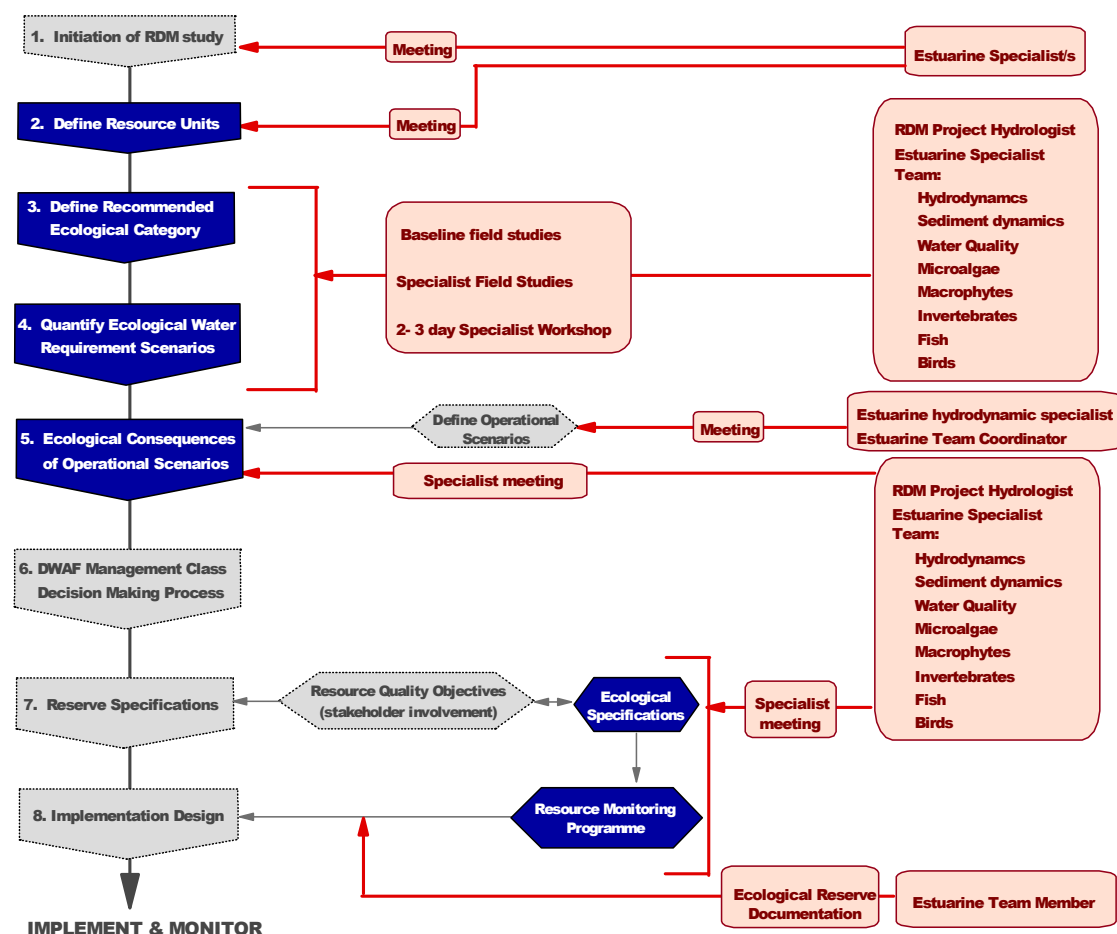


Figure 2: Indication of human resource requirements for a comprehensive Ecological Reserve determination on estuaries (DWAF, 2004a)

1.4 Assumptions and Limitation for this Study

The brief was undertaken based on the following assumptions and limitations:

- Due to budgetary constraints, the complete estuarine field data set, as recommended for a comprehensive ecological reserve determination, could not be collected as part of this project (i.e. only summer and winter surveys instead of quarterly surveys). It, therefore, should be noted that the confidence of the ecological reserve determination may be lower than required for a comprehensive determination (even so, due to the size and complexity of the Olifants Estuary, the generic data requirements recommended for a Comprehensive Ecological Reserve determination may not have given the desired confidence)
- Accurate inflow data on the magnitude and duration of floods in Olifants/Doring System was not available. Flood hydrographs representative of inflows into the Olifants Estuary for both the Reference Condition and Present State were not available. However, as part of the sediment dynamics evaluation some flood hydrographs were generated.

- The overall confidence in the hydrology is **low** as only limited accurate baseflow data was available to base the hydrological and hydrodynamic assessments on. Summer baseflow comprises river flow, leaks from the Bulshoek Weir (though some of this is currently intercepted and pumped back into the irrigation system), return flows from the irrigators, and possibly inflow from springs (e.g. near Kapel). The baseflow is difficult to determine because:
 - The accuracy of the stage measurements at the bridge downstream of Lutzville depends on how well the bridge is cleaned of the debris that blocks the bridge culverts
 - The leaks from Bulshoek Weir have been reduced and were estimated to be about 0.5 m³/s in April 2002 and since then the Lower Olifants River Water User Association (LORWUA) have pumped leakage water back into the canal or into the Bulshoek Weir
 - An unknown proportion of the return flows may have been intercepted by irrigators further downstream
 - There are unconfirmed reports of contributions from springs
 - Flows measurements taken during the summer of 2004/5 at the Lutzville Bridge were made during a drought when the irrigators may have been forced to take additional water from the river to supplement the water from the canal.
- Variable leakage from the Bulshoek Dam also hindered the estimation of flows that reach the estuary. Total leakage of water from Bulshoek Weir was estimated to be 1.2 m³/s (26 January 1994) of which leakage through the foundation was estimated as about 0.7 m³/s, while the rest was from excessive leakage from the crest gates at the time and leakage from the canal in the immediate vicinity of the wall.

Work done on the foundation of the Bulshoek Weir by DWAF reduced the leakage. The leakage however gradually increased again and on 11 April 2002 it was estimated to be about 0.5 m³/s.

Thereafter DWAF did some major repair work (new concrete apron) to stabilize the foundation. However, the leakage remained the same and some grout work still needs to be done to resolve the problem. In the mean time the LORWUA installed pumps downstream of the dam wall, pump leakage water back into either the irrigation canal or the dam. (Mr F van Heerden, pers comm.).

- The catchment of the Doring River is by far the largest at about 24000 km². The Olifants catchment up to the confluence of the Doring River is much smaller at only about 2900 km². However, the two rivers have approximately the same mean annual runoff under Reference Conditions. The Sout River on the other hand produces very little runoff (approximately 2% of the total mean annual runoff [MAR] of the Olifants), and for this reason, together with the fact that there is very little gauging data, it was decided to exclude this area from the modelling and analysis.
- Water quality data from the DWAF at their routine monitoring station on the Olifants River at Lutzville causeway (E2H016Q01) (representative of the quality of river inflow to the estuary) were only available from December 2002 to January 2005. Reference Conditions were derived from the DWAF routine water quality monitoring station on the Doring River [Melkboom - E2H003] for the years 1980 to 1986.
- Criteria for confidence limits attached to statements in this study were as follows:

LIMIT	DEGREE OF CONFIDENCE
Low	If no data were available for the estuary or similar estuaries (i.e. < 40%)
Medium	If limited data were available for the estuary or other similar estuaries (i.e. 40% – 80%)
High	If sufficient data were available for the estuary (i.e. > 80%)

2. DEFINITION OF RESOURCE UNIT

The Olifants Estuary is approximately 250 km north of Cape Town and forms the generally accepted southern boundary of Namaqualand (Morant, 1984).

The estuary receives freshwater inflow from the Olifants/Doring system which has a catchment of approximately 49 000 km², making it one of the largest catchments in South Africa. The naturalised MAR of 1070 x 10⁶ m³, however, only contributes about 2% to the country's MAR. The Olifants River is approximately 250 km long and arises in the Agter Witzenberg, which is a winter rainfall area. The area drains hard, well-leached sandstone and quartzites of the Table Mountain Group. The Doring River drains the eastern slopes of the Cedarberg, the Swartruggens and the western Roggeveldberge. This sub-catchment lies in the more arid Ceres Karoo. It drains mainly soft, leachable shales and thus has a different chemical characteristics to those of the main stem. The Doring River joins the Olifants River near Klawer. The Doring River, as it nears the confluence flows strong enough during winter to support a white-water rafting industry, but is reduced to a series of pools in summer (low flow period) (DWAF, 1997).

At present the main stem of the Olifants River has two major dams, namely the Clanwilliam Dam (with a capacity of 127 x 10⁶ m³) and the Bulshoek Dam (with a capacity of 7.5 x 10⁶ m³).

The Olifants Estuary is a permanently open system. The mouth is situated between a large sand spit on the south and a rocky bluff on the northern side. The position is fixed in the north by a reef (Morant, 1984). Just upstream of the mouth the estuary widens to about 400 m with water depths in a typical range of between 3 – 5 m. Prior to 1925, the lower reaches of the Olifants Estuary comprised a large swampy island encompassed by two channels which combined to form a common mouth. However, after a violent storm in 1925 the southern channel became blocked with marine sand (Morant, 1984). From about 15 km upstream of the mouth the estuary becomes narrower (100 – 200 m) and shallower with water depths of around 2 – 3 m. The head of tidal intrusion is approximately 36 km upstream at a low water bridge/causeway near Lutzville. Although the causeway has been constructed over a natural rocky obstruction in the system, tidal intrusion under Reference Conditions probably extended further upstream.

For the purposes of the study, the geographical boundaries for the Olifants Estuary are as follows (Figure 3):

- **Downstream boundary:** Estuary mouth (31° 42.00'S; 18° 11.34'E)
- **Upstream boundary:** Extent of tidal influence, i.e. the causeway at Lutzville - about 36 km from the mouth (31° 33.80'S; 18° 19.78'E)
- **Lateral boundaries:** 5 m contour above MSL along each bank.

The 5 m contour above MSL is indicated on 1:10 000 orthophotos (Olifants River Estuary spans about ten 1:10 000 orthophotos). Although the 1:10 000 orthophotos are electronically available, the 5 m contour above MSL is not yet available on the electronic versions.

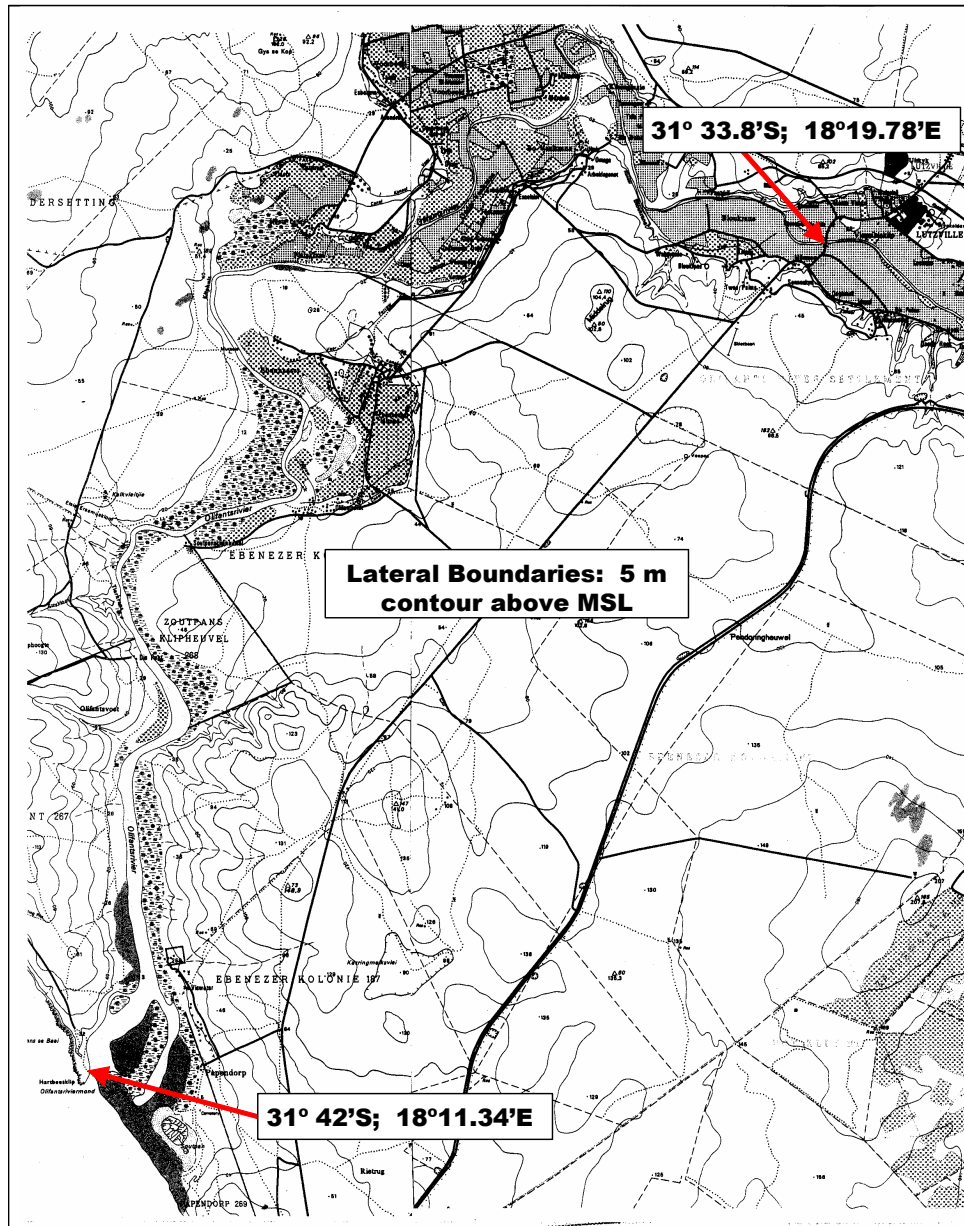


Figure 3: Geographical boundaries for the Olifants Estuary

3. ECOLOGICAL RESERVE CATEGORISATION

3.1 Typical Abiotic States

Based on the assessments and evaluations conducted for this specialist report, four Abiotic States were derived for the Olifants Estuary, of which the occurrence and duration varies depending on river inflow rate. These states are:

State 1: Marine dominated	< 2 m ³ /s
State 2: Saline penetration extended to middle reaches	2 – 5 m ³ /s
State 3: Saline penetration limited to lower reaches	5 – 20 m ³ /s
State 4: Freshwater dominated	> 20 m ³ /s

Note: The overall confidence in the hydrology is **low** as only limited and inaccurate baseflow data were available to base the hydrological and hydrodynamic assessment on (refer to *Assumptions and Limitations*).

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, including:

- Colour coding was used for the full tables of simulated monthly river flow reaching the estuary for the each scenario to highlight the occurrences of the different Abiotic States related to the different flow ranges.
- Summary tables of the occurrences of different flows at increments of 10%ile are listed separately to provide a quick comprehensive overview
- To provide a conceptual overview of the annual distribution of Abiotic States under the different scenarios, median (50%ile) monthly flows were used. The occurrence of different Abiotic States is indicated on the median concentrations. In this instance, the 75%ile and the 25%ile flows are also indicated to illustrate variability in monthly flows (shaded area). Regulating catchments through impoundments reduces the variability in river inflow, this reduction is the most notable during the higher flow periods. Maintaining such variability is often important as it represents the natural stresses (extremes) under which a particular ecosystem evolved, e.g. regulated inflows has been shown to result in a loss of diversity.

ABIOTIC STATE 1: Marine dominated

Typical flow patterns: River flows are usually less than 2 m³/s and occur during the summer months. Under the Reference Condition this state sometimes occurred, and if so, only for short periods during droughts. However, under the Present State, and some of the Future Runoff Scenarios, it now typically occurs from November to April.

Confidence: Low

State of the mouth: The mouth is permanently open

Confidence: High

Flood plain inundation patterns: At these flows inundation of the flood plain will be limited, probably on spring high tides.

Confidence: High

Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide): During neap tides the vertical water level variations is approximately 0.3 m. This variation is very similar throughout the estuary to the top at the Lutzville low water bridge. During spring tides, the tidal variation increases to about 1.30 m at the mouth and reduces upstream to almost 1.0 m just upstream of the low water bridge at Lutzville.

Confidence: High

Residence times of water masses: The residence time in the lower estuary is estimated to be 1 - 10 days, depending on the distance from the mouth. The closer to the mouth, the more effective tidal flushing will be and the less the residence time. Most of the lower estuary will be flushed during a spring-neap tidal cycle from the marine side, so retention is not expected to be more than 2 weeks in the lower reaches.

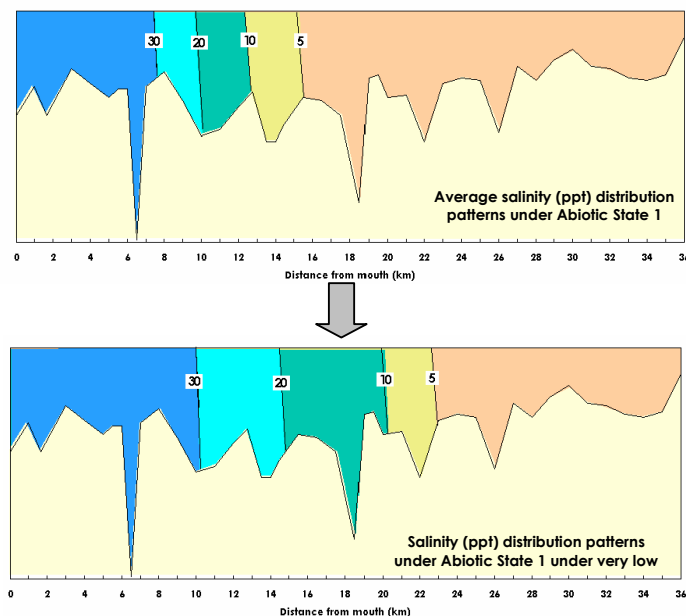
In the middle to upper reaches the residence time is expected to be longer than 4 weeks. In sections where the estuarine bathymetry is deeper than -2.0 m MSL, retention time is expected to be longer (> 6 weeks) as flushing is less effective in these deeper areas.

Confidence: Low

Estimated (maximum) tidal velocities along the estuary: Approximately 1 m/s at springtide near the mouth and gradually reduced velocities further upstream. The tidal velocities are 0 m/s at the causeway at Lutzville.

Confidence: Medium

Salinity distributions in the estuary: The average salinity distribution under State 1 is illustrated below. However, in instances where flows of < 2 m³/s persist for more than 5 months or when flow decreases to <1 m³/s, marked saline penetration can occur even further upstream (as illustrated):



Under State 1, during the average low flow conditions, saline intrusion occurs in the lower 15 – 18 km of the estuary. During period of extended low flows, the salinity intrusion can extend more than 30 km upstream from the mouth.

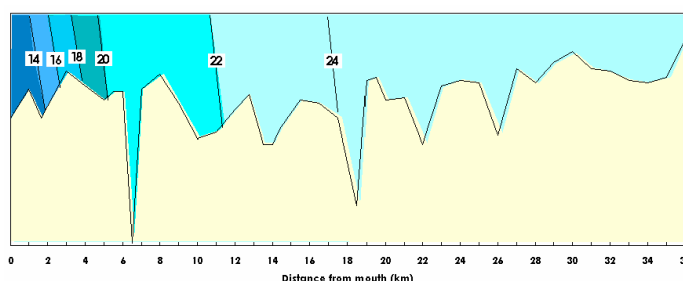
Confidence: Medium

Total volume per salinity ranges:

Salinity zone	Average low flows (~ 3 months)		Extended periods of low flow	
	Distance form mouth (km)	Volume (m ³)	Distance form mouth (km)	Volume (m ³)
30 ppt	7.0	2 921 000	10.0	3 612 200
20 ppt	10.0	691 100	15.0	908 400
10 ppt	13.0	562 800	20.0	696 800
5 ppt	15.0	345 500	23.0	306 900
0.5 ppt	20.0	696 800	32.0	667 400

Confidence: Medium

Temperatures: As State 1 occurs during summer the temperature distribution along the estuary is as follows:



Confidence: High

pH: Levels are likely to range between 7.3 and 8.5 throughout the system

Confidence: High

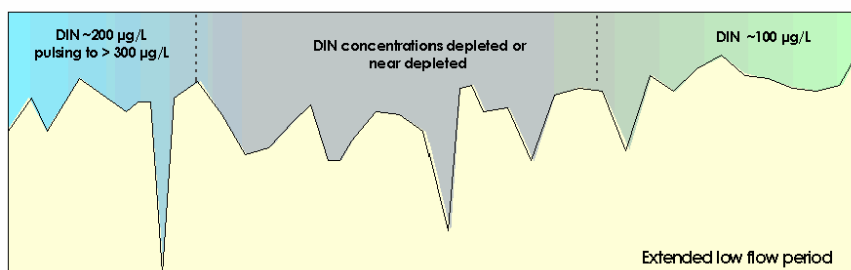
Dissolved oxygen: During State 1 (low flow period in summer), residence time of water in the estuary will be longer and dissolved oxygen concentrations in bottom waters (below 3 m water depths) of the middle, and possibly also the upper reaches, could drop below 4 mg/l. Wind mixing should sustain well-oxygenated conditions (above 6 mg/l) in surface waters (above 3 m water depths). In the lower reaches, strong tidal flushing is expected to sustain well-oxygenated conditions throughout the water column (up to about 8 km from the mouth).

Confidence: Medium

Turbidity/Suspended solids: During State 1 (low flow period in summer) turbidity levels in the estuary will probably remain low, with Secchi disc depths greater than 1 m, and even more, moving towards the lower reaches where the influence of clear seawater becomes more pronounced. However, limited river inflow may still result in relatively turbid waters in the upper reaches. Wind mixing in the shallower reaches of the lower estuary may also increase turbidity levels at times.

Confidence: Low/Medium

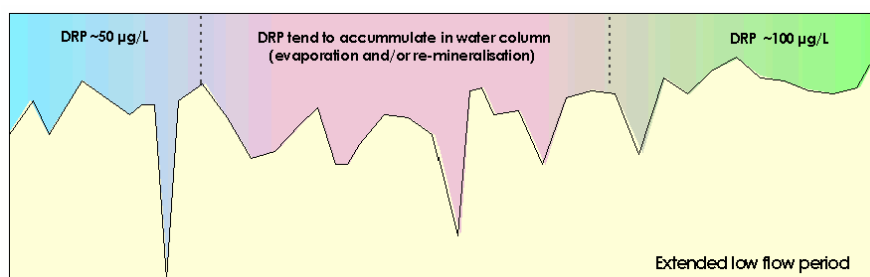
Dissolved Inorganic Nitrogen (DIN): The distribution of DIN concentration in the estuary during State 1, in particular when the state occurs for extended periods or flow becomes very low, is follows:



In future scenarios where agricultural return flows are expected to increase, it is likely that DIN concentrations entering the estuary in the upper reaches will also increase (>100 µg/l) under State 1.

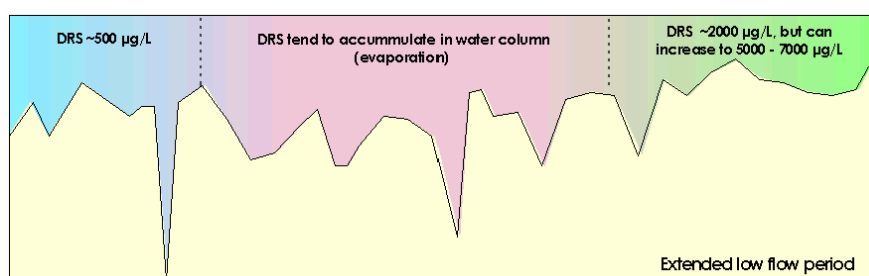
Confidence: Medium

Dissolved Reactive P (DRP): The distribution of DRP concentrations in the estuary during State 1, in particular when the state occurs for extended periods or flow becomes very low, is follows:



Confidence: Medium

Dissolved Reactive Silicate (DRS): The distribution of DRS concentrations in the estuary during State 1, in particular when the state occurs for extended periods or flow becomes very low, is follows:



Confidence: Medium

ABIOTIC STATE 2: Saline penetration to middle reaches

Typical flow patterns: River flows range between 2 and 5 m³/s. This flow range typically occurs in summer (December to March). However, under the Present State and some of the Future Runoff Scenarios, it could extend into autumn (April to May).

Confidence: Low

State of the mouth: The mouth is permanently open

Confidence: High

Flood plain inundation patterns: At these flows inundation of the flood plain will be limited, probably on spring high tides.

Confidence: High

Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide): During neap tides the vertical water level variations is approximately 0.3 m. This variation is very similar throughout the estuary to the top at the Lutzville causeway. During spring tides, the tidal variation increases to about 1.30 m at the mouth and reduces upstream to almost 1.0 m just upstream of the low water bridge at Lutzville.

Confidence: High

Retention times of water masses: The residence time in the lower estuary is estimated to be 1 - 5 days, depending on the distance from the mouth. The closer to the mouth the more effective tidal flushing will be.

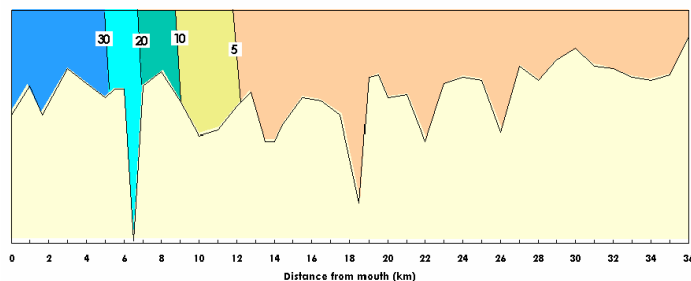
In the middle to upper reaches the residence time can vary between 1 and 4 weeks. In sections where the estuarine bathymetry is deeper than -2.0 m MSL, retention time is expected to be longer (> 4 weeks) as flushing is less effective in these deeper areas.

Confidence: Low

Estimated (maximum) tidal velocity along the estuary: Approximately 1 m/s at springtide near the mouth and gradually reduced velocities further upstream. The tidal velocity is 0 m/s at the Lutzville causeway.

Confidence: Medium

Salinity distributions in the estuary: The average salinity distribution (ppt) under State 2 is illustrated below:



Under State 2 saline intrusion occurs in the lower 10 – 17.5 km of the estuary.

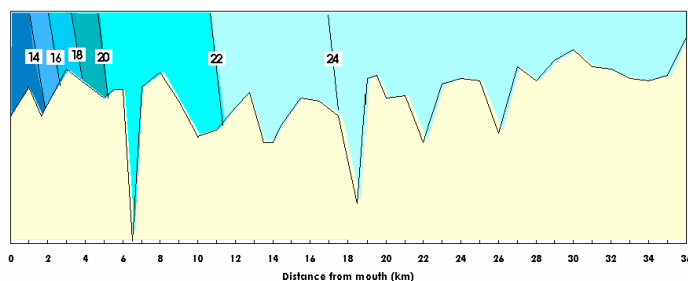
Confidence: Medium

Total volume per salinity ranges:

Salinity zone	Distance form mouth (km)	Volume (m ³)
30 ppt	5.8	2 290 600
20 ppt	7	630 500
10 ppt	9	446 500
5 ppt	13	807 500
0.5 ppt	16	488 700

Confidence: Medium

Temperatures: As State 2 occurs mainly during summer the temperature distribution along the estuary is as follows:



Confidence: High

pH: Levels are likely to range between 7.3 and 8.5 throughout the system

Confidence: High

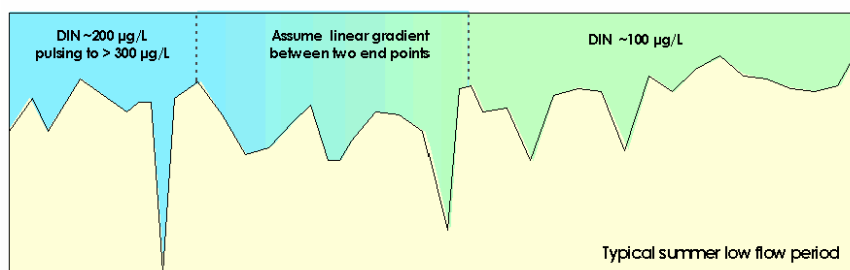
Dissolved oxygen: During State 2 (also considered a low flow period), residence time of water in the estuary will be longer and dissolved oxygen concentrations in bottom waters (below 3 m water depths) of the middle, and possibly also the upper reaches, could drop below 4 mg/l. Wind mixing should sustain well-oxygenated conditions (above 6 mg/l) in surface waters (above 3 m water depths). In the lower reaches, strong tidal flushing is expected to sustain well-oxygenated conditions throughout the water column (up to about 8 km from the mouth).

Confidence: Medium

Turbidity/Suspended solids: During State 2 (also considered a low flow period) turbidity levels in the estuary will probably remain low, with Secchi disc depths greater than 1 m, and even more, moving towards the lower reaches where the influence of clear seawater becomes more pronounced. However, limited river inflow may still result in relatively turbid waters in the upper reaches. Wind mixing in the shallower reaches of the lower estuary may also increase turbidity levels at times.

Confidence: Low/Medium

Dissolved Inorganic Nitrogen (DIN): The distribution of DIN concentrations in the estuary during State 2 is estimated as follows:

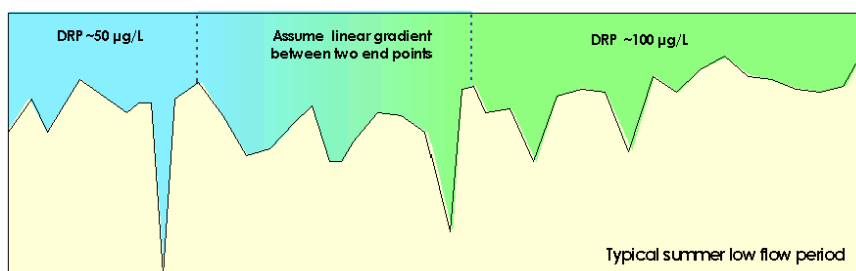


Where State 2 occurred under the Reference Condition, the DIN concentrations in the upper reaches were probably markedly lower (~50 µg/L), based on the predicted Reference Condition for DIN in river inflow. As a result DIN concentrations in the estuary showed a linear gradient between that present in the upper reaches (~50 µg/L) and that typically measured in lower reaches – characteristics of seawater (50-300 µg/L).

In future scenarios where agricultural return flows are expected to increase, it is likely that DIN concentrations entering the estuary in the upper reaches will also increase (>100 µg/L) under State 2.

Confidence: Medium

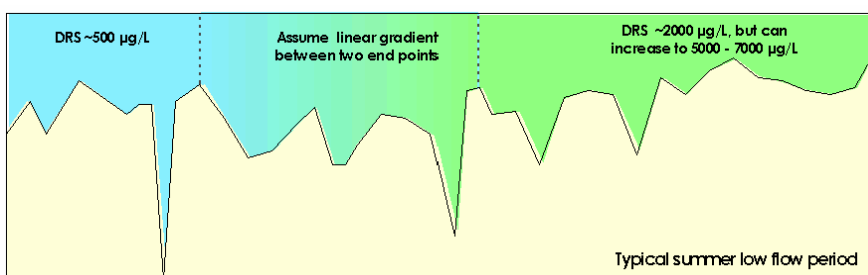
Dissolved Reactive P (DRP): The distribution of DRP concentrations in the estuary during State 2 is estimated as follows:



Where State 2 occurred under the Reference Condition, the DRP concentrations in the upper reaches were probably markedly lower ($<20 \mu\text{g/L}$), based on the predicted Reference Condition for DRP in river inflow. As a result DRP concentrations in the estuary showed a linear gradient between that present in the upper reaches ($<20 \mu\text{g/L}$) and that typically measured in lower reaches – characteristics of seawater ($\sim 50 \mu\text{g/L}$).

Confidence: Medium

Dissolved Reactive Silicate (DRS): The distribution of DRS concentrations in the estuary during State 2 is estimated as follows:



Where State 2 occurred under the Reference Condition, the DRS concentrations in the upper reaches probably remained in the $2000 \mu\text{g/L}$ range based on the predicted Reference Condition for DRS in river inflow.

Confidence: Medium

ABIOTIC STATE 3: Saline penetration limited to lower reaches

Typical flow patterns: River flows are usually between 5 - 20 m³/s. These flow ranges usually only occur for relatively short periods (e.g. a few weeks to a month) during the transition periods between summer and winter, i.e. autumn (April - May) and spring (October to December).

Confidence: Medium

State of the mouth: The mouth is permanently open

Confidence: High

Flood plain inundation patterns: At these flows inundation of the flood plain will be limited, probably on spring high tides.

Confidence: High

Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide): During neap tides the vertical water level variations is approximately 0.3 m. This variation is very similar throughout the estuary to the top at the Lutzville bridge. During spring tides, the tidal variation increases to about 1.30 m at the mouth and reduces upstream to almost 1.0 m just upstream of the low water bridge at Lutzville.

Confidence: High

Residence times of water masses: The residence time in the lower estuary is estimated to be 1- 3 days. In the middle to upper reaches the retention time can be a few days to about a week.

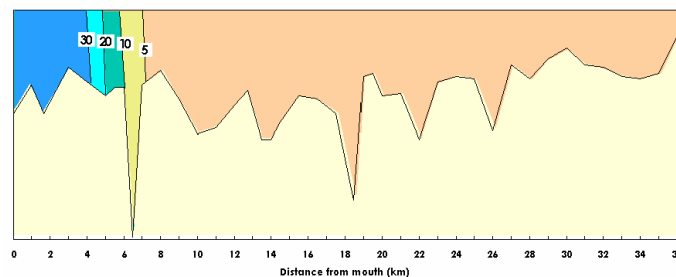
In sections where the estuarine bathymetry is deeper than -2.0 m MSL, residence time is expected to be longer (1 - 2 weeks) as the estuary often stratifies during this transition state especially in the case of Autumn flow following protracted low flow in summer.

Confidence: Low

Estimated (maximum) tidal velocity along the estuary: Approximately 1 m/s at springtide near the mouth and gradually reduced velocity further upstream. The tidal velocity is 0 m/s at the causeway at Lutzville.

Confidence: Medium

Salinity distributions in the estuary: The average salinity distribution under State 3 is illustrated below:



Under State 3 saline intrusion occurs in the lower 10 km of the estuary during high tides. During low tides, the salinity intrusion is restricted to the lower 6.5 km of the estuary. This salinity intrusion is also representative of what occurs during flood conditions.

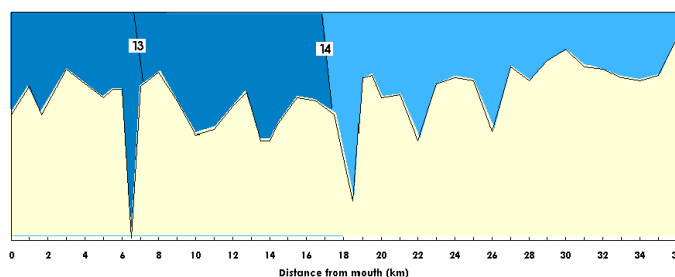
Confidence: Medium

Total volume per salinity ranges:

Salinity zone	High tides		Low tides	
	Distance form mouth (km)	Volume (m ³)	Distance form mouth (km)	Volume (m ³)
30 ppt	4	2 083 800	-	-
20 ppt	5.25	349 400	-	-
10 ppt	6	215 300	1.0	631 100
5 ppt	6.8	195 400	3.0	1 154 300
0.5 ppt	9.0	523 500	5.0	576 300

Confidence: Medium

Temperature: As State 3 will predominantly occur during the wetter, colder months of the year the temperature distribution along the estuary is estimated as follows:



Confidence: High

pH: Levels are likely to range between 7.3 and 8.5 throughout the system

Confidence: High

Dissolved oxygen: Under State 3 (moving into higher flow periods), freshwater flushing together with tidal exchange is expected to maintain well oxygenated conditions throughout the estuary (above 6 mg/l).

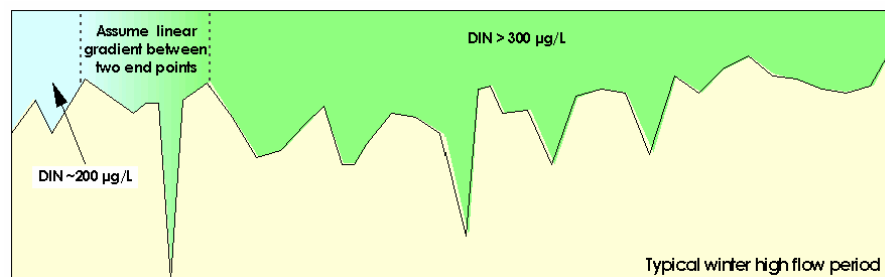
Confidence: Medium

Turbidity/Suspended solids: Under State 3 (moving into higher river flow periods) the estuary starts to become more turbid, particularly when inflow originates from the Doring River and other tributaries draining the soft leachable shales (Karoo formation). As tidal intrusion still introduce clearer seawater into the lower reaches, a strong horizontal gradient can be expected, ranging from between 25-50 NTU (Secchi disc depth typically less than 1 m) in the upper reaches to <15 NTU (Secchi disc depth typically greater than 1 m) near the mouth.

Where future scenarios include damming of the Doring River, it may result in a decrease in the turbidity of water that enters the estuary in the upper reaches during State 3.

Confidence: Low/Medium

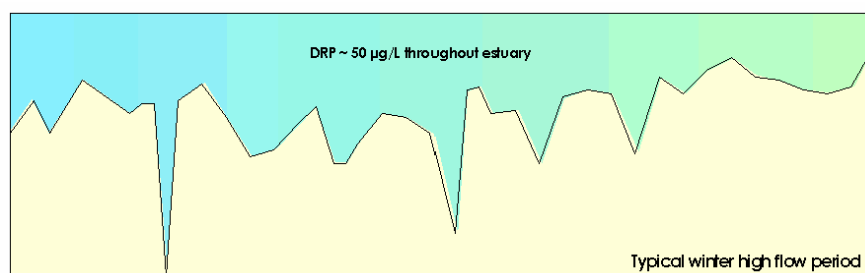
Dissolved Inorganic Nitrogen (DIN): The distribution of DIN concentrations in the estuary during State 3 is estimated as follows:



Where State 3 occur under the Reference Condition, the DIN concentrations in the upper reaches were probably markedly lower (<100 µg/L), based on the predicted Reference Condition for DIN in river inflow.

Confidence: Medium

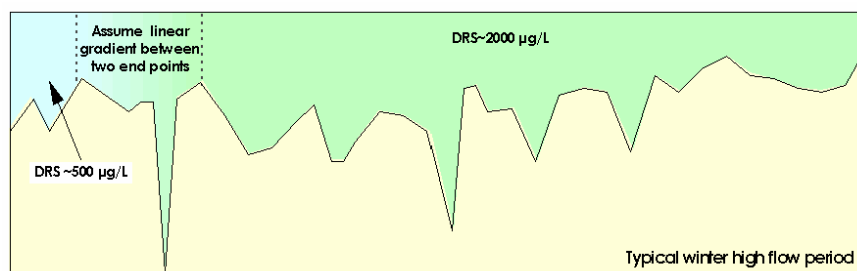
Dissolved Reactive P (DRP): The distribution of DRP concentrations in the estuary during State 3 is estimated as follows:



Where State 3 occurred under the Reference Condition, the DRP concentrations in the upper reaches were probably markedly lower ($<20 \mu\text{g/L}$), based on the predicted Reference Condition for DRP in river inflow. As a result DRP concentrations in the estuary showed a linear gradient between that present in the upper reaches ($<20 \mu\text{g/L}$) and that typically measured in lower reaches – characteristics of seawater ($\sim 50 \mu\text{g/L}$).

Confidence: Medium

Dissolved Reactive Silicate (DRS): The distribution of DRS concentrations in the estuary during State 3 is estimated as follows:



Confidence: Medium

ABIOTIC STATE 4: Freshwater dominated

Typical flow patterns: River flows are usually $> 20 \text{ m}^3/\text{s}$. This range is typical of winter high flow conditions (June to September).

Confidence: High

State of the mouth: The mouth is permanently open

Confidence: High

Flood plain inundation patterns: At these flows inundation of the flood plain will be limited, probably on spring high tides. However, during much higher flows at river floods inundation of the flood plain will occur. Such flooding may be essential for the ecological processes on the flood plains.

Confidence: High

Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide): During neap tides the vertical water level variations are approximately 0.3 m at the mouth and during spring tides they are approximately 1.30 m at the mouth. This variation is, contrary to States 1 to 3, reduced further upstream and there is probably no tidal variation at the top at the Lutzville bridge.

Confidence: High

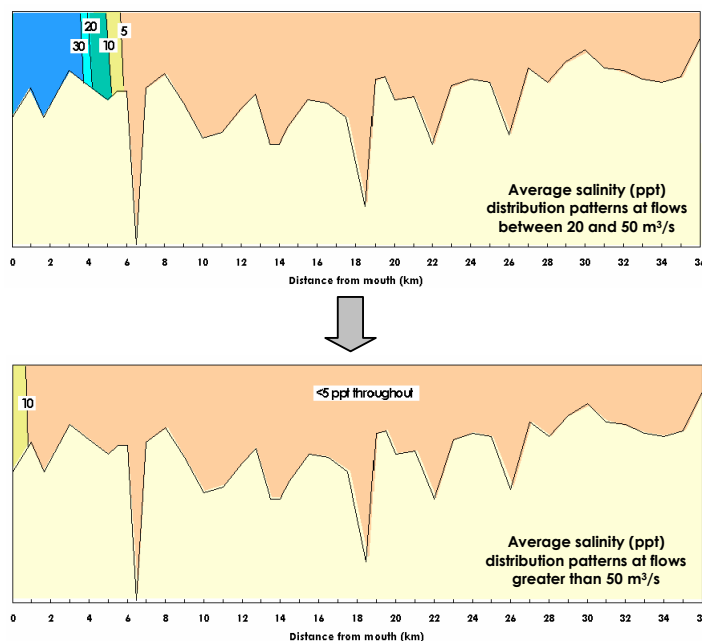
Residence times of water masses: At flow of more than $20 \text{ m}^3/\text{s}$ the residence time is estimated to be less than a day in the lower, middle and upper reaches respectively. Due to some stratification in the bottom water in areas deeper than 2.0 m MSL, residence time is expected to be slightly more (about 1 – 3 days in these areas). For the entire estuary, water residence time is expected to vary between < 1 day to 4 days at flows of $> 20 \text{ m}^3/\text{s}$.

Confidence: Low

Estimated (maximum) tidal velocities along the estuary: Approximately 1 m/s at springtide near the mouth and these are strongly reduced further upstream because of the strong river flow.

Confidence: Medium

Salinity distributions in the estuary: The average salinity distribution under State 3 is illustrated below:



During the lower flow ranges ($20 - 50 \text{ m}^3/\text{s}$) under State 4, some saline intrusion occurs in the lower 7.0 km of the estuary during high tides. During lower tides, the salinity intrusion is restricted to the lower 2.2 km of the estuary. At higher flows (also representative of what occurs during flood conditions) the estuary becomes almost fresh.

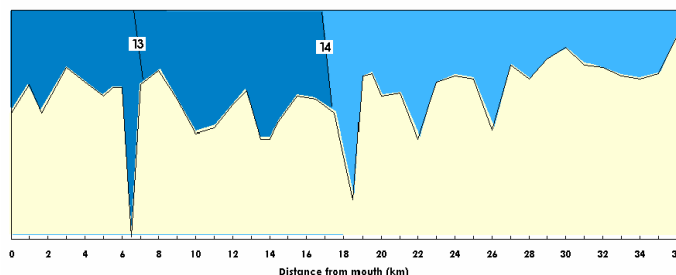
Confidence: Medium

Total volume per salinity ranges:

Salinity zone	High tides		Low tides	
	Distance form mouth (km)	Volume (m ³)	Distance form mouth (km)	Volume (m ³)
30 ppt	3.5	1 995 000	-	-
20 ppt	4.5	284 300	-	-
10 ppt	5.4	283 600	-	-
5 ppt	6	144 300	0.25	268 300
0.5 ppt	7.3	337 600	2.2	1 119 000

Confidence: Medium

Temperatures: As State 4 will predominantly occur during the wet winter months when the temperature distribution along the estuary is estimated as follows:



Confidence: High

pH: Levels are likely to range between 7.3 and 8.5 throughout the system

Confidence: High

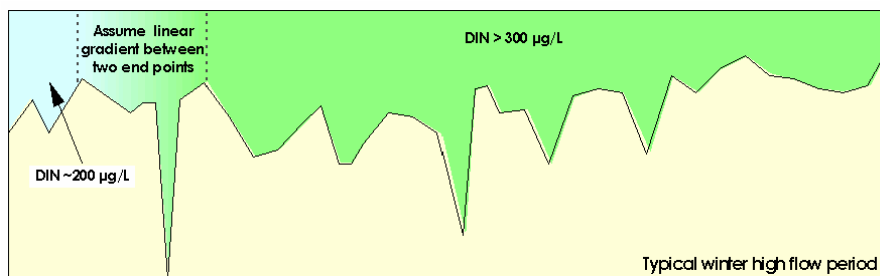
Dissolved oxygen: Under State 4 (high flow period), freshwater flushing together with tidal exchange is expected to maintain well oxygenated conditions throughout the estuary (above 6 mg/l).

Confidence: Medium

Turbidity/Suspended solids: Under State 4 (high river inflows) the estuary starts to become more turbid, particularly when inflow originates from the Doring River and other tributaries draining the soft leachable shales (Karoo formation). As tidal intrusion will introduce clearer seawater into the lower reaches, a strong horizontal gradient can be expected, ranging from between 25-50 NTU (Secchi disc depth typically less than 1 m) in the upper reaches to <15 NTU (Secchi disc depth typically greater than 1 m) near the mouth.

Confidence: Low/Medium

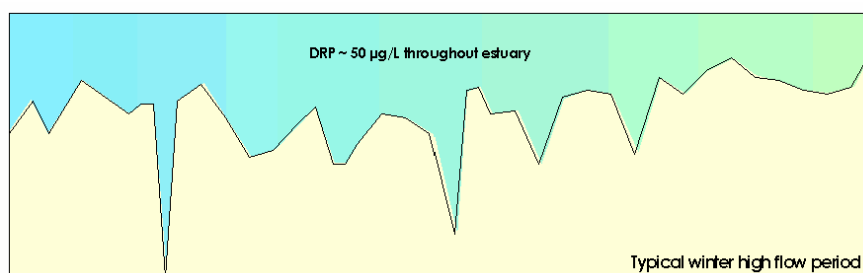
Dissolved Inorganic Nitrogen (DIN): The distribution of DIN concentrations in the estuary during State 4 is estimated as follows:



Where State 4 occurred under the Reference Condition, the DIN concentrations in the upper reaches were probably markedly lower (<100 µg/l), based on the predicted Reference Condition for DIN in river inflow.

Confidence: Medium

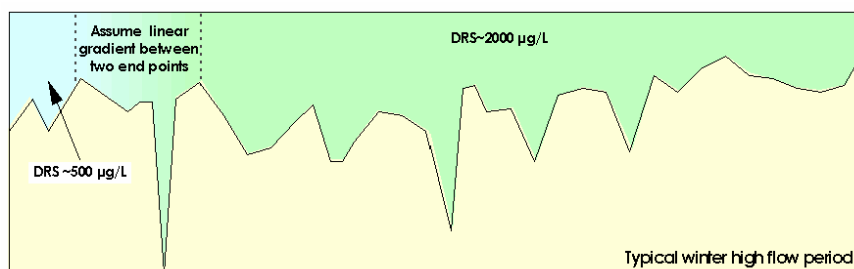
Dissolved Reactive P (DRP): The distribution of DRP concentrations in the estuary during State 4 is estimated as follows:



Where State 4 occurred under the Reference Condition, the DRP concentrations in the upper reaches were probably markedly lower ($<20 \mu\text{g/L}$), based on the predicted Reference Condition for DRP in river inflow. As a result DRP concentrations in the estuary showed a linear gradient between that present in the upper reaches ($<20 \mu\text{g/L}$) and that typically measured in lower reaches – characteristics of seawater ($\sim 50 \mu\text{g/L}$).

Confidence: Medium

Dissolved Reactive Silicate (DRS): The distribution of DRS concentrations in the estuary during State 4 is estimated as follows:



Confidence: Medium

3.2 Description of Present State

3.2.1 Abiotic components

The characteristics and functioning of the different abiotic components of the Olifants Estuary is discussed in detail in each of the individual specialist reports provided as appendices to this report, (Appendix C: Hydrodynamics, Sediment Dynamics and Water Quality).

The main purpose of this report is the use the information as provided in the specialist reports to determine, for example the present ecological status and the implication of future runoff scenarios using the Estuarine Health Index (EHI). To provide the rationale for the scores allocated to different abiotic components, key information derived from the specialist assessments is re-captured in this main report.

i. Seasonal variability in river inflow

Monthly simulated runoff data for the Present State is provided in Table 1. The mean annual runoff (MAR) is 715 Million m³ for this scenario. A summary of flow distribution (mean monthly flows in m³/s) for the Present State of the Olifants Estuary derived from the 70-year simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	45.03	31.25	20.88	36.75	26.64	6.99	98.47	186.79	567.98	471.28	231.59	157.39
90%ile	27.01	7.60	6.52	2.88	3.34	3.41	9.19	74.42	160.84	158.30	126.90	76.10
80%ile	14.47	4.36	1.56	0.94	1.09	1.47	4.05	17.74	96.43	105.84	100.55	56.23
70%ile	11.17	1.50	0.93	0.76	0.76	1.06	1.77	8.69	48.30	81.22	69.26	42.07
60%ile	8.29	0.99	0.74	0.75	0.72	0.64	1.05	4.69	30.91	56.77	56.64	32.23
50%ile	6.49	0.76	0.74	0.75	0.70	0.57	0.51	2.19	21.22	40.66	43.61	24.82
40%ile	4.18	0.68	0.74	0.75	0.68	0.57	0.26	1.52	10.31	23.13	32.19	19.97
30%ile	2.72	0.68	0.74	0.75	0.66	0.57	0.19	0.77	5.06	13.84	23.71	15.68
20%ile	1.34	0.68	0.74	0.73	0.66	0.49	0.07	0.40	2.15	6.32	18.26	12.32
10%ile	1.06	0.68	0.74	0.73	0.66	0.28	0.00	0.21	0.74	2.72	5.31	8.01
1%ile	0.59	0.68	0.72	0.73	0.46	0.00	0.00	0.00	0.19	0.30	0.60	1.46

TABLE 1: Monthly simulated runoff data in m³/s (70-year period) under the Present State

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	7.45	0.68	1.06	1.12	9.53	10.83	2.55	0.02	566.13	496.14	105.01	24.52
1921	2.77	0.68	8.59	3.98	0.68	0.29	0.00	0.40	24.88	32.54	107.91	64.37
1922	1.06	0.68	0.74	0.73	0.66	0.00	1.33	2.58	160.84	109.48	31.71	16.00
1923	1.64	0.70	0.74	0.73	0.68	0.36	0.00	0.00	7.61	11.26	56.64	28.30
1924	6.76	1.06	0.74	0.75	1.17	0.57	0.07	1.10	572.29	460.62	46.49	8.10
1925	13.59	2.74	0.74	0.75	0.71	0.57	0.08	4.91	4.47	21.36	24.76	5.46
1926	24.41	5.81	0.74	0.75	0.72	0.57	1.77	2.07	0.66	0.56	8.26	14.62
1927	0.64	0.78	0.74	0.73	0.68	0.62	0.00	0.00	14.03	19.77	15.10	9.67
1928	1.34	0.68	0.74	0.73	0.66	0.00	0.58	0.85	15.01	62.28	41.79	29.11
1929	11.27	0.68	0.74	0.73	5.39	2.03	0.00	0.62	0.74	0.33	4.51	45.07
1930	32.00	0.68	0.74	0.79	0.72	0.51	4.03	4.01	2.31	6.16	80.31	62.09
1931	10.25	0.68	0.74	0.75	5.94	3.56	0.26	2.86	43.86	41.18	19.67	16.50
1932	2.90	0.94	0.93	0.73	0.66	0.23	0.00	1.87	37.56	121.30	57.40	12.07
1933	1.64	0.99	0.83	0.73	0.66	4.04	2.46	0.73	1.27	2.73	2.47	7.09
1934	14.47	29.81	12.71	0.75	0.76	0.64	1.88	4.26	8.40	9.93	66.26	46.65
1935	6.21	0.68	0.74	0.75	0.68	0.61	0.00	1.48	1.02	5.05	20.52	62.49
1936	12.60	7.60	6.28	0.82	0.66	0.68	0.13	0.97	44.48	102.75	41.24	10.66
1937	1.20	0.68	6.67	11.42	0.66	0.28	1.05	5.83	5.83	3.40	13.47	34.85
1938	9.07	0.68	0.74	0.73	1.92	1.14	0.00	17.74	19.92	2.72	90.31	83.95
1939	1.59	0.68	0.72	0.73	5.58	1.77	1.61	1.52	4.07	5.44	5.31	8.01
1940	1.17	0.86	0.78	0.80	0.66	0.05	6.01	55.80	191.19	102.43	103.26	144.25
1941	28.26	2.02	0.74	0.75	0.66	0.57	0.35	2.19	197.04	109.73	34.35	15.09
1942	12.40	9.18	5.18	4.98	0.66	0.68	0.00	0.29	4.65	27.55	114.08	33.77
1943	8.76	9.79	6.52	0.75	0.78	1.47	1.18	8.69	55.35	81.22	65.09	39.76
1944	14.40	1.50	0.74	0.75	0.72	0.61	0.19	15.73	124.12	158.30	125.22	20.83
1945	8.24	1.01	0.74	0.75	0.66	0.51	0.59	0.64	0.21	0.34	0.51	94.08
1946	42.75	0.68	0.74	0.75	0.66	1.42	0.29	6.86	7.87	47.95	44.47	16.07
1947	3.49	0.68	0.74	0.75	0.76	5.34	7.93	4.69	5.06	35.36	27.86	47.23
1948	14.89	0.73	0.74	0.75	0.66	0.49	0.02	0.37	0.51	1.00	20.41	24.82
1949	6.01	27.62	6.49	0.75	0.76	0.57	9.82	9.21	2.15	70.42	40.59	27.02
1950	21.24	5.11	1.79	0.75	0.68	0.57	0.26	0.43	46.16	104.39	43.61	32.23
1951	8.29	4.36	0.74	0.75	1.72	0.87	0.26	7.72	9.20	48.08	141.54	61.53
1952	12.55	26.72	19.00	0.75	1.09	0.98	25.24	48.08	24.51	83.33	99.43	22.94
1953	0.91	1.40	1.56	1.31	0.66	1.27	1.66	92.11	96.43	192.62	143.84	56.23
1954	11.05	0.68	0.74	0.75	2.12	1.18	1.41	0.99	30.91	107.54	197.96	88.27
1955	27.01	7.52	1.30	0.79	0.78	1.02	0.78	0.77	22.88	75.05	69.26	22.44
1956	1.36	0.68	0.74	0.73	3.34	2.53	0.26	19.35	122.79	158.33	126.90	48.09
1957	36.38	3.36	1.16	1.16	0.70	0.57	0.24	14.31	21.22	5.11	7.97	15.85
1958	1.16	0.68	0.74	0.73	0.66	0.45	0.90	248.80	238.46	15.35	44.93	17.22
1959	5.08	1.09	0.74	0.75	0.73	0.57	0.26	1.60	12.00	10.54	4.98	1.68
1960	0.59	0.68	1.18	1.24	0.70	2.34	98.72	86.26	57.98	67.76	34.74	48.45
1961	7.54	0.68	0.74	0.73	0.66	0.34	0.08	0.29	309.18	260.77	156.20	76.10
1962	42.12	5.63	0.78	0.76	0.78	0.57	0.30	0.21	4.44	11.88	168.74	53.42
1963	2.70	0.76	0.74	0.75	0.72	0.57	0.23	0.21	55.81	56.77	23.08	20.63
1964	2.72	2.82	1.30	0.75	0.66	1.06	7.63	7.03	1.66	1.68	3.34	5.80
1965	0.59	0.68	0.74	0.73	0.66	0.36	0.14	0.20	2.01	13.84	19.26	11.08
1966	0.99	0.68	0.73	0.73	0.66	0.54	7.85	12.36	152.67	95.78	32.19	19.97
1967	4.18	0.72	0.74	0.75	0.68	0.57	0.26	26.49	25.64	44.60	46.52	15.68
1968	32.26	4.68	0.74	0.75	0.66	0.51	0.45	0.76	0.24	0.33	0.64	0.96
1969	3.01	1.25	0.72	0.73	0.00	0.00	0.00	2.76	19.34	40.66	59.64	28.78
1970	4.58	0.68	0.74	0.73	0.66	0.43	0.00	0.21	1.70	36.76	62.25	12.32
1971	0.77	0.68	0.74	1.33	0.89	0.21	0.18	1.11	2.08	6.32	3.68	7.87
1972	1.19	0.68	0.74	0.73	0.66	4.23	2.85	0.21	0.16	23.60	29.12	23.62
1973	3.32	0.68	0.91	0.89	1.94	1.68	0.00	1.83	48.30	61.85	310.06	188.05
1974	7.47	1.54	0.74	0.94	1.09	0.64	0.58	74.42	78.95	23.13	32.87	15.35
1975	6.49	0.99	1.71	5.97	7.44	1.34	4.60	3.82	132.97	151.96	43.82	15.71
1976	1.13	34.61	25.26	0.88	0.76	0.64	4.37	160.22	217.75	167.53	135.09	41.10
1977	11.17	0.68	2.28	2.88	0.76	0.60	0.51	0.32	0.23	0.23	12.05	12.84
1978	2.05	0.68	0.74	0.75	0.66	0.57	0.00	0.64	23.00	25.79	22.61	13.43
1979	14.54	0.68	0.74	0.75	0.68	0.57	0.07	1.69	12.01	10.27	18.26	13.66
1980	1.15	27.76	12.64	81.25	43.09	2.41	2.28	0.21	0.21	20.93	111.13	85.39
1981	10.50	0.71	0.74	0.75	0.71	0.57	9.19	9.93	4.80	7.89	10.01	1.89
1982	8.08	3.10	0.74	0.75	0.66	0.54	0.00	77.51	130.60	104.61	31.77	30.52
1983	10.16	0.68	0.74	0.75	0.68	3.49	1.36	79.12	61.62	48.13	23.71	69.90
1984	50.35	5.11	0.86	17.68	19.58	4.39	4.05	5.67	48.80	77.36	76.38	27.33
1985	5.12	0.92	17.18	10.83	0.66	0.57	0.26	0.34	106.79	105.84	93.92	40.76
1986	3.61	0.68	0.74	0.75	0.66	0.57	25.19	31.80	21.28	47.59	48.96	42.07
1987	14.48	0.68	0.74	0.75	0.68	3.41	17.68	13.22	10.31	14.50	24.48	39.05
1988	5.69	0.68	0.75	0.75	0.70	1.08	26.54	22.05	9.88	19.14	76.79	85.51
1989	17.07	1.30	0.74	0.75	0.72	0.64	98.37	104.53	41.60	154.72	59.89	9.87
1990	0.91	0.95	0.99	1.14	1.17	0.11	0.61	2.01	38.21	192.06	100.55	71.57
Median	6.49	0.76	0.74	0.75	0.70	0.57	0.51	2.19	21.22	40.66	43.61	24.82
Average	9.93	3.75	2.52	2.67	2.11	1.22	5.49	18.59	61.53	68.22	58.69	35.88

<2.0
 02.0-5.0
 5.0-20.0
 >20.0

ii. Present flood regime

The Clanwilliam and Bulshoek Dams have limited impact on the present flood regime. Most of the medium to large floods still reach the estuary. Some return period flood peaks are listed below.

Return Period (yrs)	Flood Peak (m ³ /s)
2	355
5	470
10	525

Confidence: Medium

iii. Present sediment processes compared to Reference Condition

The annual sediment yield from the catchment is relatively low (6 ton/km² per annum). The lower part of the estuary up to about 20 km from the mouth depth remains relatively unaffected.

Sediment deposition occurs in the upper 15 km, but on a small scale. The median size of the sediment in the estuary is 0.3 mm. Closer to the mouth the sediment is coarser with a median sediment size of 0.4 mm. In the middle reaches finer sediment can be found.

Confidence: Medium

iv. Occurrence and duration of different abiotic states under Present State

The occurrence and duration of the different Abiotic States during the Present State are illustrated in the simulated monthly river flow table (Table 1).

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under the Reference Condition, median (50%ile) monthly flows are displayed in Figure 4. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

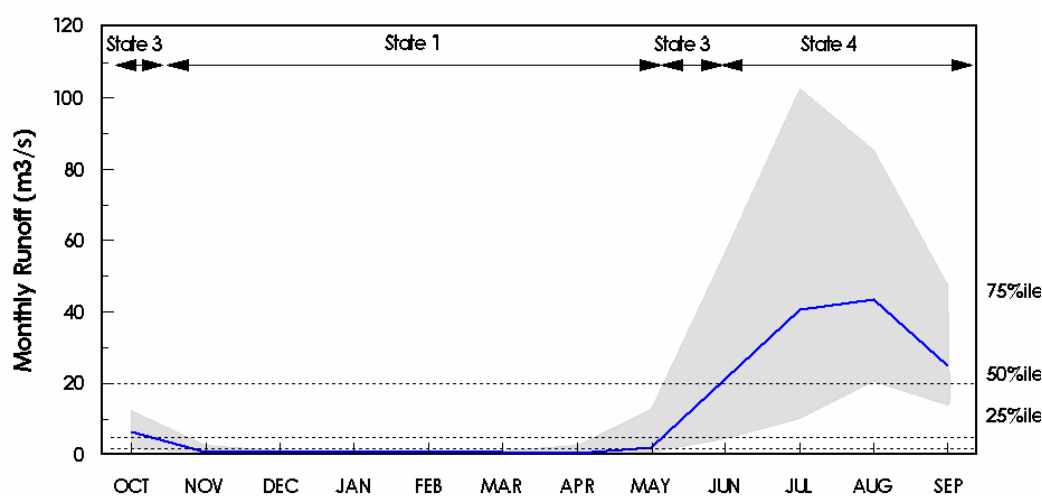


Figure 4: Predicted distribution of Abiotic States under the Present State for the Olifants Estuary, based on median monthly flows (blue line). The 75%ile and the 25%ile (shaded area) are used to illustrate variability in monthly flows

v. Anthropogenic influences, other than modification of river inflow, presently affecting abiotic characteristics

STRUCTURES (e.g. WEIRS, BRIDGES, MOUTH STABILIZATION)

The tidal variation is still strong below the low water bridge at Lutzville, which is at present the head of tidal influence. Under reference conditions the head of tidal influence could therefore have been further upstream, dependent on the effect of the rocky sill underneath the low water bridge.

Confidence: Medium

DISCHARGES INTO ESTUARY AFFECTING WATER QUALITY

Inorganic nutrients inputs (in particular DIN) introduced to the upper reaches of the Olifants Estuary are influenced by agricultural activities in the catchment and along the banks of the upper reaches. In this area drip irrigation is widely used. Although this technique results in substantial water saving per unit area, it tends to build up levels of inorganic nutrients and other fertilizers due to irregular 'flushing' (unlike overhead sprinklers systems). As a result these substances accumulate in soils and are flushed into the river during rains, in particular the DIN.

Confidence: Medium

3.2.1 Biotic components

The characteristics and functioning of the different biotic components of the Olifants Estuary are discussed in detail in each of the individual specialist reports provided as appendices to this report, namely:

- Appendix D: Microalgae
- Appendix E: Macrophytes
- Appendix F: Invertebrates
- Appendix G: Fish
- Appendix H: Birds.

The main purpose of this report is to use the information as provided in the specialist reports to determine, for example the present ecological status and the implication of future runoff scenarios using the Estuarine Health Index (EHI). To provide the rationale for the scores allocated to different components, key information derived from the specialists assessments are re-captured in this main report.

i. Description of the Present State of biotic components

MICROALGAE

***Phytoplankton** biomass levels as determined by chlorophyll-a concentrations lie within the range measured in other estuaries around RSA. However, the indications are that the levels measured were on the low side of the average during 2004, indicating a relatively low macro-nutrient concentration in the water. The high numbers of flagellates in the middle of the estuary is possibly unusual in that it has not been specifically noted before. Unfortunately the numbers of flagellates, their types and their position in estuaries has not been the subject of sufficient study in RSA to be able to use the data as a diagnostic tool.*

***Phytomicrobenthic** communities in RSA have been studied almost exclusively as diatoms. The data for the Olifants Estuary are the result of three surveys (June 2001, March 2004 and August 2004). The data show that there were no special differences in the taxa found by comparison with other estuaries. There were some species not found before in RSA and there were some that could not be identified with reference to the available international literature. These findings are similar to most other estuaries in RSA considering the potential total number of extant species (~100 000).*

The biomass estimates showed that the summer values were lower on average than the winter values where water flow was higher. The range of 1-15 µg chlorophyll-a per gram dry mass of sediment in the March 2004 study are very representative of other well functioning estuaries. The August (winter) values from the Olifants of 0.4 – 27 µg chlorophyll-a per gram dry mass of sediment are quite high. There is no reason to consider the data for these measurements as out of the normal range.

Confidence: Medium

MACROPHYTES

Biomass distribution: The salt marsh vegetation in the Olifants Estuary was distributed in three distinct zones, i.e. intertidal, supratidal and floodplain. The Olifants Estuary has the largest salt marsh areas in South Africa that occupy 91.94, 143 and 797.1 ha respectively. The floodplain (1.34 m above MSL) is the area adjacent to the supratidal area (0.53 m MSL) and is normally elevated above the rest of the estuary. As its name suggests, this area is only covered with water during large floods (Bornman, 2002). *Sarcocornia pillansii* was the dominant species in both the supratidal and the floodplain areas. *Phragmites australis*, *Juncus kraussii* and *Sporobolus virginicus* were recorded along the banks of the middle-upper reaches of the estuary. The reeds start occurring from 8.5 km upstream from the mouth where the salinity of the estuarine water remains below 20 ppt. During the low flow summer survey macroalgae were also a dominant feature of the estuary. The submerged macrophytes were distributed along the salinity gradient with pondweed *Potamogeton pectinatus* forming dense beds in the upper reaches and eelgrass *Zostera capensis* (47.72 ha) distributed in the lower and middle reaches of the estuary. The largest community type was salt marsh, followed by reeds and sedges (60.05 ha) and submerged macrophytes. The floating aquatic weed *Azolla filiculoides* was found in the upper reaches of the estuary.

Species diversity, richness and rarity: The Olifants is a large permanently open estuary and therefore the species richness is greater than most other estuaries. Seven of the nine possible plant community types occur here; only the subtropical swamp forest and mangrove communities are absent. The large intertidal saltmarsh areas are important, as only 18% of South African estuaries are permanently open with intertidal saltmarsh, they can thus be considered rare. The floodplain areas had a high species richness of more terrestrial type species. Overall the salt marsh had naturally low species diversity as these highly saline areas generally have few competitors. Macroalgal richness was high with 12 dominant species. However some of these were washed in from the sea and were not resident in the estuary.

Seasonal and inter-annual variability, as well as flood situations and drought conditions: Large floods can uproot the submerged macrophytes e.g. *Zostera capensis* and *Potamogeton pectinatus* and thus influence the distribution and abundance of these species. Floods can also deposit sediments which smother these plants. High flow during winter can result in flushing of filamentous macroalgal species from the middle and upper reaches where they form dense accumulations during low flow.

During drought the cover/abundance of supratidal and floodplain marsh would be reduced, as these plants are dependent on rain as a source of freshwater. No germination would take place and there would be an increase in bare areas as the salinity of the surface sediment increases. The supratidal and floodplain plants utilise the saline groundwater which is influenced by the salinity of the estuary water column. Any increase in water column salinity would have a negative effect on these plants.

Confidence: High

INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macro crustaceans)

Zooplankton

Biomass distribution: Only three species of copepoda dominated the zooplankton numerically (over 99%). Other groups such as mysid shrimps, crab and fish larvae were relatively rare. The most abundant copepod *Pseudodiaptomus hessei* attained summer densities of ca 40000 m³ at Stations 5-6. During winter, abundance levels peaked at 28500 m³ at Station 5. *Acartia longipatella* was also relatively abundant in the Olifants, peaking nearer the mouth. The abundance levels of *P. hessei* are in accordance with other freshwater rich estuaries in South Africa.

Species richness: The Olifants Estuary supports low zooplankton species richness. In summer, 20 species were present in the estuary and in winter 18. These levels are low in relation to open tidal estuaries having strong marine dominance, but similar to those estuaries that are fresh water dominated (e.g. Great Fish and Keiskamma estuaries). The low numbers of mysid shrimps is unexpected.

Seasonal variability: The change in the number of species between summer and winter is low, although different species may replace others between seasons. *Acartia longipatella* appeared in very low numbers and winter, probably due to freshwater influence.

In summary, the Olifants Estuary supports hardy euryhaline zooplankters that are able to tolerate variable and reduced salinity values. Salinity was identified as the prime factor determining community structure along the estuary, with distinct marine, estuarine and brackish water communities along the gradient. In winter, the same communities were identified, but a downstream shift was apparent for the three groups. Temperature is also considered to be a significant factor, with warmer fresh and estuarine water providing a buffer against cold Atlantic water.

Benthic invertebrates (hyper benthos)

Biomass distribution: Biomass of the hyperbenthos is very low in the Olifants estuary, with the highest abundance of any species (the amphipod *Melita zeylanica*) of only 48 m³ at the uppermost station. Mysid abundance was again extremely low. In winter, the hyperbenthos was insignificant with respect to biomass.

INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macro crustaceans)

Species richness: Only 12 and ten species were present in summer and winter respectively. All species are euryhaline and are therefore able to tolerate wide fluctuations in salinity.

Seasonal variability: Numbers of species and individuals was too low to establish seasonal patterns.

Macro crustaceans (Benthos)

Biomass distribution: Polychaete worms and amphipods dominated subtidal benthic biomass. *Ceratonereis keiskama* and the amphipod *Corophium triaenonyx* attained very high abundance levels and in summer, peaking at the uppermost station. In August, the peak in biomass shifted downstream, peaking at Station 6 (polychaetes) and at Station 4 (amphipods). The sandprawn *Callinassa kraussi* is relatively abundant and extends up to about Station 6. It was particularly abundant in summer at Stations 4 and 6. The mudprawn *Upogebia africana* is described as abundant in muddy reaches of the estuary.

Species richness: As in the case of the other two invertebrate groups, the number of species in the subtidal benthos was relatively low. Twenty-two species were recorded in summer and 23 in winter. Again, species richness is low relative to tidal estuaries having distinct marine conditions in the lower estuary. In the Olifants Estuary, salinity variability is relatively high and only hardy estuarine species survive.

Seasonal variability: Spatially, peaks in abundance shifted significantly between seasons. In addition, the species mix changed significantly. *Ceratonereis keiskama* and *Corophium triaenonyx* attained very high levels in summer at Station 10, but the centre of polychaete abundance shifted downstream in winter to Station 6 (*Ceratonereis keiskama* and *Desdomona ornata*). Amphipod abundance peaked at Station 3 (*Grandidierella lutosa* and *Melita zeylanica*). Salinity was identified as the prime factor determining community structure along the estuary, with distinct marine, estuarine and brackish water communities along the gradient. In winter, the same communities occupied the same reaches of the estuary, although species composition within communities changed. Temperature is also considered to be a significant factor, with warmer fresh and estuarine water providing a buffer against cold Atlantic water.

Confidence: Medium

FISH

Biomass distribution: In the Present State the system is progressing from a low diversity high biomass freshwater dominated system towards a high biomass medium diversity marine dominated system. Category IIc species that occur in equal abundance in the marine & estuarine environments, (mostly *Liza richardsonii*), dominate numerically (52 %) and contribute > 80% of the biomass. Estuarine (*Gilchristella aestuaria*), facultative catadromous (*Mugil cephalus*) and freshwater species (*Barbus serra*) contribute much less to overall biomass than they did historically. Overall abundance (and biomass) is 120 % of that under reference conditions.

Species richness: Thirty-eight species have been recorded from the Olifants Estuary comparing well with the Berg and Orange with 37 and 32 species respectively. Excluding freshwater species, there have been 31 marine and estuarine species recorded from the Olifants. The endemic freshwater fish assemblage (e.g. *B. serra*) has mostly been replaced by introduced species such as bluegill (*Lepomis macrochirus*) and smallmouth bass (*Micropterus dolomieu*). Consequently, the freshwater component has undergone a greater change than that purely influenced by a reduction in flow. In turn, the gillnet fishery has been in existence for eighty years or more and is likely to have had a major impact on the abundance and occurrence of large bodied estuarine dependent species such as white steenbras (*Lithognathus lithognathus*) and white stumprnose (*Rhabdosargus globiceps*). Overall, although species richness has remained fairly stable, the fish assemblage has undergone a drastic change with an order of magnitude change in the frequency of occurrence of some species.

Seasonal variability: The fish assemblage is strongly seasonal with the most species and highest catches in the gillnet fishery occurring during autumn (April, 11 species) and spring / early summer (Sept – Dec, 9 species). Juvenile recruits occurred in both the summer and winter (2004) and all previous surveys but with a peak in spring and early summer (September – December). Total catch and effort in the gillnet fishery is lowest in the winter months largely due to increased flow making fishing difficult rather than a decrease in the abundance of the target species *L. richardsonii*. Interestingly, catch per unit effort (cpue) of *L. richardsonii* remains fairly high in the winter months. This is largely due to there being a strong negative correlation between effort and cpue and less fishers sharing the available fish during the winter months.

During the low flow summer months, most estuarine, estuarine dependent and marine species extend their range upstream, some (*L. richardsonii*, *Pomatomus saltatrix* & *M. cephalus*), 20 - 36 km to the Lutzville causeway. During winter and high flows there is a marked drop in abundance (or catchability) of these species and most appear to be confined to the lower 16 km of the estuary. However, the bulk of the fish assemblage seems to occur 4-12 km from the mouth throughout the year. This is likely to be temperature related as the lower 4 km are usually 5 to 10 degrees cooler than the rest of the estuary during the winter and summer respectively.

Confidence: Medium

BIRDS

Species richness: The Olifants Estuary is a particularly rich estuary in terms of avifauna, this being largely ascribed to its size, diversity of habitats and productivity. It also has a range of bird habitats from relatively fresh to marine. A total of 73 waterbird species have been recorded on the estuary, with about 52 species recorded in single summer and winter counts of the whole estuary.

Most estuarine waterbird species occur in this system, thus the full range of taxonomic groups is found. Species are dominated by waders (25), and there is also a high diversity of ducks (12), terns (7), ciconiiformes (8) and pelicaniformes (5). The latter group includes two marine cormorant species that are largely confined to the rocky point at the mouth, and which are excluded from later analyses.

Biomass distribution: Bird numbers are highest in the northern arm and blind arm of the estuary. About 80% of birds are found in this area, with bird densities decreasing progressively upstream. The density gradient is much steeper in summer than in winter, since most migratory waders and terns occur in the lower estuary. Very low densities of waders occur in the saltpan and supratidal marshes.

Seasonal variability: While species richness is similar in summer and winter, there are marked changes in community composition and numbers. Excluding the large number of marine cormorants at the mouth, the avifauna in summer is numerically dominated by waders (about 36%) and terns (about 45%), the majority of which are long-distance migrants. In winter, there is a very even spread in terms of community composition. While waders and terns make up about 32% of birds, waterfowl (ducks, rails and grebes) make up about 35% of birds, pelicaniformes (pelicans, cormorants and darters) and ciconiiformes (herons, egrets etc) make up about 4% of birds. The numbers of waders and terns vary considerably between years, as do numbers of flamingos. Kingfishers and birds of prey are present in small numbers.

Confidence: Medium

ii. Effect of abiotic characteristics and processes, as well as other biotic components on estuarine biota

MOUTH CONDITION

Microalgae: The mouth appears unlikely to close under any water flow scenario, however if it were to close due to a drop in freshwater input, this is most likely to be in the summer months. The effect of this is that water movement and mixing would become wind dependent. As a result, deep stagnant pools would develop. The stillness of the water would mean that there would be little suspended material in the water column. This in turn would produce clear water that would allow light transmission to greater depths than at present. Under such a scenario, the phytoplankton community would comprise a high proportion of green algae and dinoflagellates (i.e. flagellates that are able to remain in the water column), and a lower proportion of diatoms. The biomass would depend on the extent of grazing and remineralisation. The microphytobenthos would be largely unaffected in terms of biomass because it would depend on mineralization and light intensity at the sediment level. The foregoing comments are likely whether the salinity rises or falls as a result of mouth closure.

(Note: This comment represents a shift from previous opinion and is the result of data emanating from a study in St Lucia that is still ongoing).

Confidence: Medium

Macrophytes: An open mouth is important as it maintains the intertidal plant community types i.e. intertidal salt marsh and *Zostera* beds. Salt marsh plants occur in distinct zones along a tidal inundation gradient. If the mouth closes the plants found in these zones would die. Marine macroalgae are washed in through the open mouth and represent a significant allochthonous organic load particularly in the lower reaches of the estuary.

Confidence: High

Invertebrates: Although the mouth is unlikely to close, such a scenario would induce changes in the invertebrate community. Marine zooplankton would no longer move in and out of the estuary with the tides and species richness would decrease further. There is also likely to be a shift towards larger species such as mysid shrimps. Stagnation of bottom waters would also reduce oxygen values, and this would favour some of the benthic species such as *Capitella capitata*. Overall, there would also be a significant decrease in benthic species abundance.

Confidence: Medium

MOUTH CONDITION

Fish: The mouth is unlikely to close but two non-flow-related developments may inhibit the migration of fish into and out of the system. The Hartebees Kanaal, a shallow rocky channel bisecting the northern headland is likely to be the path through which fish enter from the north. This channel has occasionally been filled in by mining activities and is likely to have impacted the number of fish entering the system. Possible beach open cast mining activities on the southern shore are likely to have a high impact on the sandy spit at the mouth as well as extend the shoreline. Plumes from water pumped out of the mining pits may provide confusing cues for fish attempting to enter the estuary.

If mouth closure did occur, the impact on juvenile recruitment would depend on duration and whether it was over the main recruitment period. However, the strong relationship between effort and cpue suggests that recruitment of adult *L. richardsonii* into the estuary is low and that the gillnet fishery relies on constant replenishment. Consequently, mouth closure would result in collapse of the fishery within the space of a month as the fish are quickly mined out

Confidence: Low

Birds: No scenarios lead to mouth closure, and the dramatic effects this would have are thus not considered here. However, it is worth noting that the closure of the 'central channel' (sensu Morant 1984) or 'blind arm' has had a major impact on the system in terms of its value as bird habitat. The blind arm provides particularly important shallow water and intertidal feeding habitat, as well as substantially increasing the availability of saltmarsh in the lower estuary. The latter is extremely important as a roosting area. On the other hand, the closure of the blind arm has connected "Die Eiland" to the mainland, and has thus reduced the attractiveness of the island as a safe roosting area. The island may have thus provided a more important roosting habitat for gulls and waders when the blind arm was open.

Confidence: High

EXPOSURE OF INTER-TIDAL AREAS DURING LOW TIDE

Microalgae: The exposure of intertidal areas at low tide would not affect the benthic microalgal flora. The non-exposure of intertidal sites as a result of mouth closure would result in a decrease in diversity because the intertidal species would not be present. The long-term exposure of sites that are normally intertidal would result in a decrease in biomass and a loss of diversity.

Confidence: Medium

Macrophytes: Tidal flushing is important for salt marsh nutrient exchanges and for maintaining the zonation and diversity of salt marsh plants.

Confidence: High

Invertebrates: Intertidal areas support a different mix of benthic organisms and any change in exposure of this area would influence the community. *Callinasa kraussi* is widespread along the estuary (Stations 2-6) and is probably the most important anomuran in the estuary. The zooplankton and hyperbenthos would be unaffected.

Confidence: Medium

Fish: Detritus, bird faecal material & benthic microalgae re-suspended during the incoming tide may provide a food source for detritivores such as *L. richardsonii*.

Confidence: Low

Birds: Intertidal areas in the lower estuary provide the main foraging habitat for waders, and an increase would be expected to lead to an increase in wader numbers. In the middle reaches, the narrow but substantial intertidal areas are somewhat drier and are important habitat for a different suite of waders (mostly resident) and are vital 'loafing' habitat for waterfowl. Thus availability of intertidal area in the middle to upper reaches will affect these species.

Confidence: High

SEDIMENT PROCESSES AND CHARACTERISTICS

Microalgae: Phytomicrobenthic algae respond very quickly to sediment changes.

Confidence: Medium

Macrophytes: Reduced flooding and a decrease in sediment disturbance can encourage growth of macrophytes. Sediment input from agricultural activities and a decrease in water depth can encourage the growth of reeds into the main water channel.

Confidence: High

Invertebrates: The benthic community in particular is strongly influenced by sediment characteristics (for example, sand and mud associated communities). If sediment characteristics change, there will be a shift in species distribution. Some species could disappear, particularly if species become exposed to unfavourable salinity regimes.

Confidence: High

SEDIMENT PROCESSES AND CHARACTERISTICS

Fish: Sedimentation and the formation of sheltered backwater habitats such as has occurred with the second channel, provide shallow refuge for juveniles & small species. Wind mixing and high turbidity in these shallow areas reduce the risk of predation from piscivorous birds and fish. A high detrital load in the sediment would favour the detritivores *M. cephalus* and *L. richardsonii*. An increase in mud favours the goby *Caffrogobius nudiceps* whereas sandy areas are favourable for foraging *L. lithognathus*.

Confidence: Low

Birds: Sediment size and distribution are important in determining suitability of feeding and roosting areas for different species. The formation of sandbanks in the mouth area is important roosting habitat for terns, whereas muddier sediments are preferable for waders. Fine silts are less suitable in terms of availability of suitable food. Different waders have finer scale preferences in terms of the spectrum of particle size and organic content. This is due to types of food available as well as penetrability of sediment.

Confidence: High

RETENTION TIMES OF WATER MASSES

Microalgae: Moving water results in a higher number of microalgae in the phytoplankton than in still water. At the interface where fresh and seawater mix, biological processes occur that encourage the development of phytoplankton. There is an optimum flow rate for the maximal development of phytoplankton at the River-Estuarine-Interface (REI). In the Olifants Estuary, the flow rate for maximal REI development is $\sim 2 \text{ m}^3/\text{s}$.

Confidence: Medium

Macrophytes: Increased retention of the water body and decreased flow encourages growth of submerged and floating aquatic macrophytes.

Confidence: High

Invertebrates: Zooplankton would respond directly and positively to food availability (phytoplankton). If the food source changes (decrease because of changes to the REI zone – see comments above) biomass of the zooplankton would also decrease. A similar response would occur in the hyperbenthos.

The benthic community would probably be less affected, provided the retention time of water masses does not change significantly. However, if there is a significant change to the biomass of submerged macrophytes, species such as *Melita zeylanica* would respond as macrophyte biomass changed (habitat availability)

Confidence: Medium

Fish: High retention time, high phytoplankton & zooplankton biomass explain the relatively high abundance of *Gilchristella aestuaria* and *Atherina breviceps* within the system. Low phytoplankton production would favour *G. aestuaria*, which depending on food availability, switches from filter to selective feeding. Low food availability would exclude the less behaviourally plastic *A. breviceps*. Increased retention time is likely to favour the eggs and larvae of both these estuarine breeders. High retention times & biomass of rooted submerged macrophytes such as *Zostera* spp., explain the relatively high abundance of gobies, pipefish and other species that favour these habitats.

Confidence: Medium

Birds: This does not impact on birds directly, but has indirect impacts due to its impact on the productivity of the system.

Confidence: High

FLOW VELOCITIES

Microalgae: Flow velocity has been shown in KZN estuaries to reduce all microalgae to very low levels during flood conditions. Under zero flow, the benthic microalgae biomass is highest but when flow moves the sediment, the benthic biomass drops to almost zero. For phytoplankton biomass, see “Retention times of water masses”

Confidence: Medium

Macrophytes: Reduced flow velocity can increase macrophyte growth e.g. submerged macrophytes *Potamogeton pectinatus* and *Zostera capensis*, macroalgae, and reeds and sedges.

Confidence: High

Invertebrates: Response to flow velocity – see comments under ‘Retention times of water masses’.

Confidence: Medium

FLOW VELOCITIES

Fish: Under high flow velocities, juveniles, larvae & eggs have a greater chance of being swept out of the system but tend to either actively or passively find refuge in eddies, macrophyte beds and backwaters. Increased flow velocities may provide the cue for some species such as *L. richardsonii* & *M. cephalus* to migrate further upstream during the summer months or out of the system during the winter. Piscivorous predators e.g. *Lichia amia* tend to maintain position in eddies and ambush prey being swept past or moving out of the shallows on a receding tide. In all, most species benefit by having food / prey carried toward them and shorter less energy expensive foraging times. In the Olifants, high velocities also benefit fish by reducing the capture efficiency of the gillnet fishery.

Confidence: Low

Birds: This does not have much direct impact, except possibly for a short period during floods when some birds would be unable to use the system, and some waterfowl prefer stiller waters than others (but velocities at margins are usually low enough to accommodate these).

Confidence: High

VOLUME OF WATER IN ESTUARY

Microalgae: The volume of water in the estuary does not as a factor influence unit processes with respect to microalgae.

Confidence: Medium

Macrophytes: Groundwater is an important source of moisture to salt marsh plants in semi-arid environments. In the Olifants salt marsh there is an increase in soil moisture and decrease in soil electrical conductivity with depth indicating the presence of a less saline water table below the surface. The dominant plant *Sarcocornia pillansii* was shown to utilise this water. Vegetation cover was reduced where the water table was deeper than 1.5 m.

Confidence: High

Invertebrates: Zooplankton and hyperbenthic biomass will shift as the volume of water in the estuary changes, mainly because of changes in available habitat. Little change is expected to the subtidal benthic community, provided the change in volume does not affect other abiotic drivers.

Confidence: Medium

Fish: Large volumes are likely to be associated with winter floods or spring tides. Both lead to inundation of the saltmarsh, marginal area sand and shallow channels increasing foraging habitat and refuge for most fish species. Freshwater fish will also move down into the estuary under these conditions. The greater the volume, the bigger the search area for piscivorous predators and the lesser the chance that small and juvenile fish will be eaten. In turn, greater volume entering the sea and in the estuary may facilitate the recruitment of higher numbers of fish into the system, especially estuarine dependent species such as *L. lithognathus*.

Confidence: Low

Birds: This affects the amount of habitat available for birds that feed in the water column (e.g. piscivores). In particular, water volume affects the availability of habitats of different depths, which are favoured by different species. In the case of the Olifants Estuary, water depth does not vary significantly under different scenarios.

Confidence: High

SALINITIES

Microalgae: Changes in salinity results in changes in species. There are no known statistically significant relationships between salinity and the number of taxa either in the water column or on the sediment (diversity). Species change in response to salinity level and changes in biomass appear more related to mineral nutrient level (or remineralisation) than salinity level.

Confidence: Medium

Macrophytes: The estuary is characterized by a salinity gradient along which different plants are distributed. Eelgrass, *Zostera capensis* is found in the saline lower and middle reaches of the estuary and pondweed, *Potamogeton pectinatus* occurs in the upper reaches. Intertidal salt marsh is found in the lower and middle estuary reaches and reeds and sedges characterize the middle and upper reaches of the estuary. The intertidal salt marsh in the middle reaches is characterised by brackish species such as *Juncus kraussii* and *Cotula coronopifolia*.

Salinity is the most important factor controlling the growth and distribution of the large supratidal and floodplain salt marsh. Bornman (2002) showed that vegetation cover was reduced where the electrical conductivity of the groundwater was greater than 80 mS cm⁻¹. Floods are necessary as they lower the salinity of the groundwater. The lower water column salinity in winter was responsible for lush growth of intertidal salt marsh. The dominant plant *Sarcocornia pillansii* cannot grow in the hypersaline surface soils characteristic of the Olifants Estuary during the dry period of the year (> 8 months) and is dependent on the saline groundwater (Bornman 2002).

Rainwater in winter is available to the adult plants and also stimulates seedling growth. Ponding of rainwater (0.73 mS cm⁻¹) reduced the surface soil salinity through leaching and dilution and provided an important habitat for seed germination.

Confidence: High

Invertebrates: Salinity was shown to be the most important factor influencing invertebrate distribution, composition and abundance. Any change to the salinity pattern will directly affect invertebrates. Some species may also disappear while other species may colonize the estuary.

Confidence: High

Fish: Estuarine fish are largely distributed according to their salinity preferences and the estuarine dependence category to which they belong. Under the Present State overall fish abundance has increased by 20 % from reference conditions. This is largely due to the reduction in flow, increased saline penetration and the increase in available habitat (10-20 ppt) for category IIc species, namely *L.richardsonii*, which are equally at home in both the estuarine and marine environment. Conversely, category Ia estuarine breeding species such as *G.aestuaria* have declined in abundance as their preferred REI zone (0-10 ppt), has shrunk considerably. Obligate estuarine dependent category IIa species (refer to Appendix G) such as *L. lithognathus* have also undergone substantial decline.

A further increase in salinity levels is likely to see an increase in the number of non-estuarine-dependent marine species e.g. *Sardinops sagax*, that enter the system. Flocculation and lower turbidity may favour visual predators such as *L. amia* but discourage *A. inodorous* which prefers murky waters.

Historically, endemic freshwater species such as *B. serra* and *Labeobarbus capensis* would have moved downstream during the winter months but have since been usurped by introduced species such as *Micropterus dolomieu* and *Oreochromis mossambicus*. Increased saline penetration may be preventing some of the introduced species from spreading downstream. This does not hold for *O. mossambicus* which can tolerate salinities in excess of 60 ppt.

Confidence: Medium

Birds: The distributions of certain waterfowl and some wading birds and other waterbirds are correlated with salinity, although the relationship is probably largely indirect, through the impact of salinity on the distribution of certain habitats (e.g. reeds) and food sources (e.g. *potamogeton*).

Confidence: High

OTHER WATER QUALITY VARIABLES

Microalgae: Water with high levels of dissolved minerals is known to result in changes in dominant and associated species. Biomass and pollution has not been studied specifically in RSA. No information available on the effects of herbicides, fungicides or insecticides.

Confidence: Low

Macrophytes: Nutrient enrichment can increase growth and biomass of submerged macrophytes and macroalgae. A number of macroalgal species were present that indicated enriched conditions. *Enteromorpha* sp. (possibly *prolifera*) occurred throughout the estuary in summer. It forms large biomass accumulations under increased nutrient loads. The blue-green algae *Oscillatoria* found in the upper reaches in summer are considered important indicators of organically polluted stagnant water. Some species are able to produce toxins that may be harmful to animals or humans. *Spirogyra* was found at the same site. It is a common fresh water macroalgae that occurs in moderately polluted water. *Azolla filiculoides* an invasive aquatic waterweed was present in the upper reaches in both winter and summer.

Overgrazing in the Doring catchment has increased the sediment load carried by the Doring River. In earlier reports (Morant, 1984) it was reported that the high turbidity limits the distribution of submerged macrophytes such as *Potamogeton pectinatus*.

Confidence: High

Invertebrates: pH remains a relatively unknown factor. However, should the water in the estuary become more acidic (the two major tributaries of the Olifants River are likely to have different pH values because of differences in the underlying geological characteristics), biomass of all invertebrates is likely to drop. Damming of the Doring tributary is likely to remove the buffering capacity against pH presently provided by the tributary – The other main tributary (Olifants River) flows over a TMS base.

Confidence: Low

Fish: High turbidity and higher temperatures than the marine environment during upwelling events are the likely reasons for *A. inodorus*, *Rhinobatos blochii* and other marine species being common in the Olifants Estuary. Occasional low oxygen events in the marine environment may also influence the movement of estuarine associated species into the system.

A surprisingly low abundance of species such as *Caffrogobius nudiceps* and *Psammogobius knynaensis* in the upper reaches may be a result of toxins from crop spraying and the frequent dumping of used pesticide containers into the system. Bulldozing of the banks may also be a contributing factor.

The formation of a warm, low oxygen plug of water during mid summer is a common feature of arid zone estuaries such as the Olifants and Berg. This is a possible explanation for the low abundances observed in the middle reaches (8-12 km) during March 1994. If this does occur, it may be a limiting factor in fish recruitment and their movement upstream. Depending on the strength and duration of this event, it may reduce the recruitment window for some species.

Confidence: Low

Birds: These do not have direct effects, but are indirectly important through impacts on habitat and food. Turbidity may have an impact on the abundance of certain piscivores, but this relationship is not well understood.

Confidence: Low

OTHER BIOTIC COMPONENTS

Microalgae: Microalgae respond to grazing by utilising the remineralised products. High/low biomass levels may be due to nutrient availability or grazing. Very high biomass levels in St Lucia appear to be the result of reduced grazing pressure at high salinity when the fauna are unable to survive. Oil pollution from outboard motors has been shown to have no detrimental on phytoplankton.

Confidence: Low

Macrophytes: Grazing of macrophytes is limited and most of the plant material enters the detrital food chain.

Confidence: High

Fish: The fish community is dominated by the small-bodied *L. richardsonii* which suggests ample food for piscivorous birds, mammals and fish. Introduced species such as *M. dolomieu* have almost completely usurped indigenous species from the upper reaches of the estuary, probably through predation of young and larvae whereas adults of the translocated *Oreochromis mossambicus* may have displaced some estuarine species such as *L. lithognathus* through aggressive territorial behaviour. *O. mossambicus* is also known to be tolerant of extremely high salinities and poor water quality often colonising river or estuarine reaches when conditions deteriorate.

Confidence: Low

OTHER BIOTIC COMPONENTS

Birds: Food and habitat are the main drivers of the abundance of all groups of birds. Apart from intertidal mud/sandflats, biotic habitats that affect bird abundance include reedmarsh, saltmarsh and riparian vegetation. Most of the biotic components are a food source for bird species, e.g. phytoplankton, benthic microalgae, macrophytes, zooplankton, benthic macrofauna, and fish. The productivity of each of these groups and biomass distribution among size classes is an important factor.

Confidence: High

iii. **Anthropogenic influences, other than modification of river inflow, presently directly affecting biotic characteristics**

STRUCTURES (E.G. WEIRS, BRIDGES, JETTIES)

Microalgae: No known or likely adverse effects

Confidence: Medium

Macrophytes: The Lutzville causeway would reduce current velocities thus influencing the flushing of macrophytes from the upper reaches of the estuary.

Confidence: Medium

Invertebrates: No known factors.

Confidence: Medium

Fish: The Lutzville Causeway inhibits the upstream movement of *L. richardsonii* and the facultative catadromous *M. cephalus*. However, a shoal of the latter species was observed upstream of the causeway during March 1994.

Infilling of the Hartebees Kanaal through the rocky headland at the mouth may inhibit fish recruitment from the north. In turn, proposed open cast diamond mining on the southern beaches may either obstruct passage or provide confusing cues for fish recruiting from the south.

Confidence: Low

Birds: No significant influences on the estuary itself.

Confidence: Medium

HUMAN EXPLOITATION (CONSUMPTIVE AND NON-CONSUMPTIVE)

Microalgae: Insignificant effect

Confidence: Medium

Macrophytes: In the lower reaches the salt marsh is used for grazing sheep. In the middle reaches both cattle and sheep graze the salt marsh.

Confidence: High

Invertebrates: Heavy exploitation of fish in the estuary probably influences the grazing pressure on invertebrates, particularly the benthos. Although reduced grazing of invertebrates will favour an increase in invertebrate biomass, foraging at the sediment-water interface probably plays an important role in influencing the physico-chemical habitat. However, the effect of sediment disturbance on invertebrates remains unknown.

Confidence: Low

HUMAN EXPLOITATION (CONSUMPTIVE AND NON-CONSUMPTIVE)

Fish: There are currently 45 (reduced from 120) commercial gillnet permit holders in the Olifants Estuary. The fishery targets harders (*L. richardsonii*) of which approximately 120 t are landed each year. A further 20 t of bycatch, mostly elf (*P. saltatrix*) are also caught. The fishery has had a major impact on the occurrence and abundance of large bodied fish species in the estuary, most being caught once they reach 48-50 mm body depth. This contributes to recruitment fishing in the estuary and elsewhere on the West Coast. In turn, sampling is biased by the relative abundance of each species being lower than it would have been in the absence of the gillnet fishery.

Bird bycatch is rare as most piscivorous birds such as Cape & white breasted cormorants have become habituated and have learnt to avoid, as well as remove fish from, the nets. An unknown number of darters are netted in the upper reaches. Seals are a problem to the fishers, removing fish and damaging the nets. "Problem" seals are occasionally shot by Nature Conservation or Fisheries Compliance officers.

Recreational angling is limited with approximately 1 t landed per annum, mostly *A. inodorus*, *A. coronus*, *L. lithognathus* & *L. aureti* over a short time period. Elf (*P. saltatrix*) are caught throughout the year but mostly during the summer months. Castnetting lands approximately 0.1 t of *L. richardsonii* per annum. There is also limited angling for the introduced freshwater species *M. dolomieu* and *O. mossambicus* towards the Lutzville causeway.

Confidence: Low

Birds: Fishing activity on the estuary may have a disturbance impact on birds, however, this is relatively minor. There is very little recreational disturbance. Overall disturbance is very low for an estuary of this size. However, there is some disturbance of birds in the saltpan.

Confidence: Medium

FLOOD PLAIN DEVELOPMENTS

Microalgae: No likely effect

Confidence: Medium

Macrophytes: The saltpan in the mouth area has removed 56.79 ha of salt marsh. In the middle/upper reaches a large area of supratidal and floodplain salt marsh was removed when a dam was constructed. The Ebenhaeser settlement has also resulted in the loss of some riparian vegetation most likely reeds and sedges. Alien invasive plants e.g. *Sesbania punicea* are common in the riparian zone indicating disturbance. However compared to other South African estuaries the Olifants Estuary is largely natural with little of the floodplain and salt marsh vegetation disturbed over time.

Confidence: High

Invertebrates: Saltpan development at the mouth and the construction of the offstream dam will indirectly affect intertidal organisms, particularly the larger organisms such as crabs. This is due to habitat destruction, particularly saltmarsh that was destroyed.

Confidence: Medium

Fish: Saltpan development and access roads have removed some of the shallow water habitat available to fish. Bulldozing of banks in the upper reaches has narrowed the channel and smothered reed beds thus removing refuge for fish.

Confidence: Low

Birds: The construction of dams adjacent to the estuary has created a major attraction for waterfowl in the area. The artificial manipulation of water in the saltpan near the mouth affects the quality of this habitat for resident waders.

Confidence: Medium

Other...

Microalgae: None known

Confidence: Medium

Macrophytes: None known

Confidence: Medium

Invertebrates: None known

Confidence: Medium

Fish: Prospecting trenches on the northern bank are eroding and may lead to localised increases in turbidity during rainfall. Impact on fish likely to be minimal.

Confidence: Low

Birds: The increase in artificial water bodies and alien trees in the region has facilitated the range expansion of certain species into this estuary.

Confidence: Medium

3.3 Reference Conditions

3.3.1 Abiotic components

i. Seasonal variability in river inflow

Monthly simulated runoff data for the Olifants Estuary Reference Condition is provided in Table 2. The mean annual runoff (MAR) is 1070.1 million m³ for this state. A summary of flow distribution (mean monthly flows in m³/s) for the Reference Condition, derived from the 70-year simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	59.99	56.18	35.98	50.57	37.62	22.26	119.78	247.81	654.34	472.73	238.15	164.98
90%ile	38.04	21.79	16.20	10.93	11.71	10.30	31.94	122.39	199.34	162.39	130.56	91.05
80%ile	26.35	16.89	9.18	4.36	4.09	6.12	16.66	48.16	106.52	114.31	108.26	69.91
70%ile	22.92	12.23	6.34	3.62	3.01	4.03	10.22	34.65	99.38	98.30	80.86	50.88
60%ile	20.42	10.10	5.33	2.76	2.75	3.54	6.71	25.20	67.59	81.73	63.77	42.32
50%ile	17.21	9.06	4.36	2.27	2.41	2.76	5.51	19.34	57.95	63.32	50.62	34.87
40%ile	15.75	7.94	3.77	1.71	1.80	2.24	4.67	14.86	34.80	46.07	45.50	28.74
30%ile	13.36	7.13	3.21	1.53	1.40	1.49	3.20	8.70	24.19	31.02	36.01	24.03
20%ile	10.23	5.59	2.42	1.08	1.14	1.04	2.00	6.72	18.90	19.45	30.61	21.41
10%ile	8.25	4.43	1.90	0.78	0.82	0.78	1.46	3.84	11.96	16.43	23.86	17.78
1%ile	6.83	3.06	1.19	0.29	0.28	0.36	0.36	1.10	4.92	7.60	11.25	9.56

ii. Flood regime for the reference condition

The floods from the Doring River would be very much the same as at present. Without the Bulshoek and Clanwilliam Dams, the flood peaks from the Olifants River would be higher than at present. Typical return period floods for the reference condition are listed below:

Return Period (yrs)	Reference
2	435
5	565
10	640

Confidence: Medium

iii. Changes in sediment processes

The upper estuary would have been about 0.5 m shallower under reference conditions compared to present. It could also have been 10% wider.

The sediment loads coming into the estuary would have been higher, since the floods and the total effective catchment area would have been larger. However, the total annual catchment sediment yield (6 ton/km² per annum) was assumed to be more or less the same. The upper reaches of the estuary would have had slightly more fine material.

Confidence: Medium

TABLE 2: Monthly simulated runoff data in m³/s (70-year period) under the Reference Condition

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	16.16	8.21	6.34	3.99	25.97	21.35	7.91	1.98	649.88	497.14	108.26	32.29
1921	12.24	4.97	15.15	12.61	3.80	0.85	3.78	6.76	87.34	41.52	115.16	73.29
1922	8.17	4.55	1.26	1.79	0.86	0.37	10.22	48.16	195.88	113.48	35.28	24.03
1923	11.87	7.36	2.39	0.70	0.29	0.52	1.46	1.38	60.18	31.02	65.78	36.34
1924	17.17	12.30	3.36	0.82	3.15	1.34	0.31	6.42	664.72	462.27	50.62	16.35
1925	23.89	15.66	3.69	0.70	1.35	0.56	0.38	39.65	21.68	41.37	32.93	13.35
1926	38.04	21.79	2.39	0.67	1.72	0.59	6.29	10.56	12.31	9.63	47.97	28.74
1927	6.87	9.18	3.95	1.34	0.50	2.72	1.08	0.45	73.15	37.26	20.68	17.24
1928	8.66	4.55	1.60	0.29	0.24	0.59	14.50	30.43	43.25	84.38	55.03	38.46
1929	23.74	4.43	2.87	1.53	11.71	6.08	1.23	6.20	5.82	11.24	19.71	91.05
1930	47.97	7.94	2.68	0.93	0.82	0.33	15.70	29.61	14.20	19.45	111.89	71.49
1931	21.31	7.52	1.90	1.38	32.16	12.47	0.84	37.52	67.59	46.07	23.86	23.61
1932	13.36	6.01	2.35	0.67	0.90	1.98	0.92	17.14	99.38	129.77	63.77	20.37
1933	12.35	5.90	5.37	2.31	1.80	10.64	6.71	14.11	20.37	17.62	15.90	25.58
1934	29.57	55.51	25.12	0.78	0.53	1.42	10.53	27.89	32.79	29.94	73.10	55.35
1935	18.37	8.52	2.42	2.39	1.40	1.26	1.69	11.61	11.96	25.57	58.28	73.72
1936	23.63	17.67	16.20	4.36	1.14	4.03	6.25	19.94	95.41	109.58	45.50	18.40
1937	9.67	5.01	19.56	19.90	1.06	1.38	10.92	37.71	18.52	16.43	29.87	43.32
1938	20.42	5.59	1.60	0.89	5.48	3.39	2.16	47.30	33.68	10.19	119.44	96.56
1939	8.32	3.08	1.00	0.29	9.42	5.33	11.88	15.72	34.80	21.54	16.91	17.20
1940	7.61	6.94	3.65	4.59	2.86	1.00	22.91	122.39	199.34	105.06	107.03	151.50
1941	39.16	12.03	4.36	2.95	2.41	2.98	1.58	18.59	262.86	114.31	38.15	23.07
1942	29.16	18.63	8.28	9.63	2.45	3.73	3.62	3.84	21.68	81.91	121.45	42.32
1943	20.16	27.35	13.55	0.93	0.72	3.95	5.32	35.13	101.81	87.55	69.22	47.76
1944	26.35	12.84	6.72	1.64	1.26	0.93	4.01	62.13	156.09	164.81	129.10	29.47
1945	19.86	9.22	1.79	1.64	2.90	1.04	6.90	8.70	10.07	12.09	26.39	128.62
1946	58.95	7.13	2.42	1.08	0.98	6.16	4.47	23.67	20.45	97.82	53.80	23.49
1947	14.00	8.14	2.53	0.63	1.14	17.10	17.82	22.44	30.21	62.65	33.30	54.24
1948	26.35	8.48	2.31	0.78	0.94	0.85	4.67	8.33	14.81	18.70	50.85	36.49
1949	17.47	55.63	17.69	1.60	0.69	0.78	31.94	16.61	8.49	113.96	46.67	34.06
1950	33.97	17.24	11.46	2.76	1.96	5.33	1.23	8.51	106.52	116.04	47.27	39.54
1951	19.75	21.72	6.08	1.38	2.54	1.49	2.00	34.65	24.73	75.83	160.33	69.91
1952	24.30	40.66	26.88	1.30	2.45	2.39	79.40	73.10	27.70	88.86	103.46	31.67
1953	9.37	11.45	7.58	4.25	1.18	2.39	11.34	167.20	100.94	195.94	146.33	64.59
1954	22.14	9.80	9.18	3.09	15.85	7.46	8.18	6.72	64.81	140.20	203.51	96.64
1955	37.74	26.54	11.64	4.51	3.01	4.25	3.85	12.06	70.41	91.92	74.52	30.47
1956	11.98	5.55	3.21	1.64	20.36	10.64	4.51	51.78	165.85	162.39	130.56	56.49
1957	46.44	16.89	6.30	3.62	4.05	3.10	3.20	39.09	51.27	17.88	20.98	25.38
1958	10.97	7.36	2.61	1.45	2.86	2.83	9.83	328.42	242.98	18.14	48.68	25.31
1959	16.12	13.00	5.48	2.01	2.67	2.65	5.32	25.20	52.81	16.69	9.89	9.18
1960	6.75	3.01	4.51	3.88	2.78	6.12	116.08	96.81	105.62	75.44	44.74	62.81
1961	21.46	5.47	2.31	1.60	1.67	2.16	5.44	5.15	391.89	264.50	159.81	84.77
1962	52.90	20.87	6.01	3.62	2.62	1.90	2.97	3.17	20.79	43.84	200.29	62.46
1963	13.51	10.14	6.38	2.61	3.60	2.27	3.01	6.16	105.82	78.25	37.04	28.66
1964	14.00	13.00	4.40	2.27	2.74	7.72	22.22	24.86	13.54	12.54	27.03	13.69
1965	10.23	4.32	3.54	2.05	1.51	3.88	5.44	3.25	18.90	63.32	30.69	20.21
1966	7.76	3.55	1.86	2.01	1.96	2.24	17.24	21.65	230.31	105.80	35.65	27.23
1967	15.12	8.83	4.07	3.24	2.75	2.91	6.09	64.33	57.95	56.00	55.09	24.01
1968	42.86	15.12	1.56	0.85	0.82	0.59	5.63	4.89	6.56	9.11	11.83	21.14
1969	22.81	9.06	3.21	2.39	2.21	1.82	1.66	14.86	62.19	69.89	65.52	37.23
1970	15.64	6.71	3.99	3.09	2.13	2.05	2.04	4.37	13.69	98.30	81.13	20.95
1971	8.06	3.97	3.24	4.55	4.58	3.54	5.51	19.34	24.19	18.70	23.93	17.78
1972	8.25	3.66	4.85	1.49	1.02	10.30	7.09	3.73	3.90	81.73	49.92	31.75
1973	8.77	9.10	6.83	1.71	4.83	4.40	1.62	18.70	106.45	74.71	318.99	196.43
1974	15.75	12.23	5.07	15.97	3.35	0.97	5.82	141.61	88.66	26.06	36.70	23.69
1975	16.91	10.45	7.35	12.35	13.83	3.88	33.60	13.37	182.01	154.62	47.99	23.34
1976	10.56	53.74	43.19	10.93	5.73	3.36	17.63	213.26	221.64	168.68	137.37	49.73
1977	22.58	10.10	14.37	9.18	3.15	3.62	5.71	7.17	5.36	4.07	41.59	44.13
1978	16.35	6.71	4.96	3.84	2.99	2.76	1.93	8.03	76.12	50.40	31.10	21.41
1979	26.13	9.49	3.77	3.95	1.31	0.97	3.12	15.08	39.81	25.20	39.01	27.16
1980	9.22	57.48	32.89	90.87	50.35	6.57	5.17	3.02	6.21	62.87	125.63	93.12
1981	22.62	9.06	5.63	5.19	4.09	4.74	30.05	24.30	19.02	30.17	26.13	9.72
1982	20.12	11.26	4.21	3.17	4.26	4.03	1.93	130.86	158.87	109.31	36.01	38.81
1983	22.92	6.52	4.10	1.68	1.40	13.55	9.02	150.87	65.47	52.45	27.48	77.54
1984	62.42	18.24	12.09	33.30	28.47	24.38	16.66	26.17	65.01	81.06	80.86	34.87
1985	17.17	8.41	28.44	16.12	1.63	2.72	4.67	7.50	144.52	137.79	103.92	49.19
1986	14.59	7.75	2.50	1.90	1.76	1.34	41.01	62.91	55.29	58.58	54.21	50.88
1987	28.11	7.64	5.33	2.05	1.69	9.52	38.07	25.69	45.25	32.41	30.61	48.34
1988	17.21	7.75	4.66	2.39	1.92	8.88	48.30	34.35	33.37	45.66	84.60	94.19
1989	28.45	10.68	3.84	2.27	2.21	1.79	128.39	145.16	59.64	162.26	64.21	17.92
1990	7.46	3.51	2.39	3.54	2.99	1.42	2.08	9.05	102.04	212.47	105.34	77.91
Median	17.21	9.06	4.36	2.27	2.41	2.76	5.51	19.34	57.95	63.32	50.62	34.87
Average	20.71	12.96	7.27	5.13	4.84	4.29	13.27	39.28	91.65	84.57	69.66	46.03

<2.0

02.0-5.0

5.0-20.0

>20.0

iv. Occurrence and duration of different abiotic states during the Reference Condition

The occurrence and duration of the different Abiotic States during the Reference Condition for the Olifants Estuary are illustrated in the simulated monthly river flow table (Table 2).

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under the Reference Condition, median (50thile) monthly flows are displayed in Figure 5. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75thile and the 25thile flows are also indicated to illustrate variability in the monthly flows (shaded area).

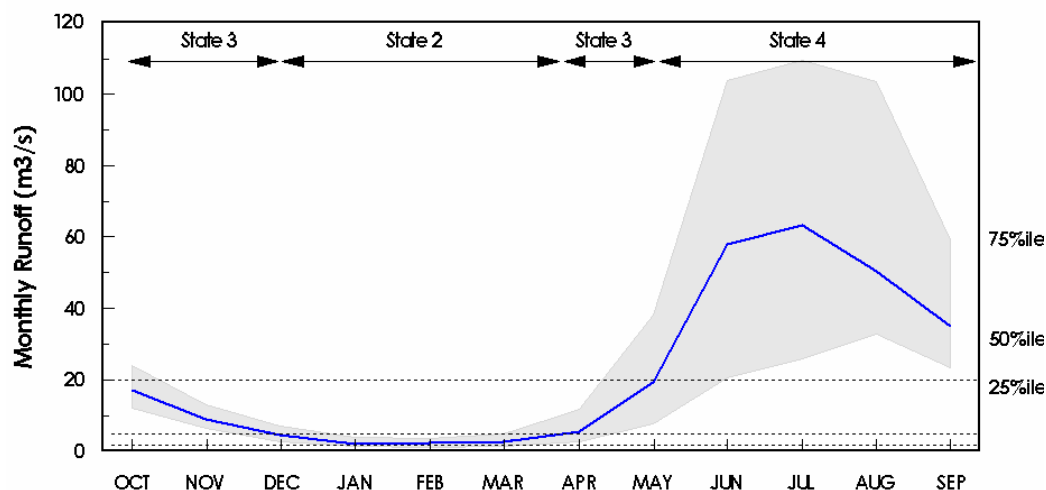


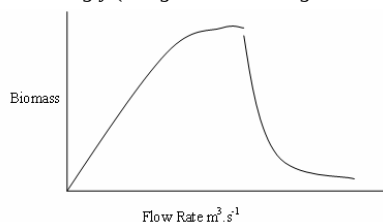
Figure 5: Predicted distribution of Abiotic States under the Reference Condition for the Olifants Estuary, based on median monthly flows (blue line). The 75thile and the 25thile (shaded area) are used to illustrate variability in monthly flows

3.3.2 Biotic components

The predicted change in biotic characteristics from the Reference Condition to the Present State, as well as motivations for the cause of such changes:

MICROALGAE

In the Reference Condition, the REI would likely have been at sea for much of the winter (June – August). As the flow decreased in spring a REI would appear in the estuary, near the mouth, but it would be weak. As the flow decreased, the REI would have developed more strongly (See generalised diagram taken from Snow et al. 2000).



However, because of the low DIN & DRP supply, the biomass in the phytoplankton would have been low ~ 5 µg Chl-a .l⁻¹. In the present condition. The REI region would likely have been slightly higher up the estuary than at present, but the biomass would have been lower by ~ 25% because of the slightly higher flow rates in winter and the water which had a lower mineral content (esp DIN:P). No significant difference in the benthic diversity is likely to have occurred. This is because the flow rates of ~ 2 m³.s⁻¹ were still present under reference conditions.

Confidence: Medium

MACROPHYTES

Species diversity, richness and rarity: There has been an increase in colonization of the upper reaches of the estuary by macroalgae. These plants grow rapidly in response to increased nutrient inputs. Agricultural activities in the catchment and along the banks of the estuary have resulted in nutrient enrichment. Invasive plants have colonized the riparian zone in some disturbed areas. Aquatic waterweeds such as *Azolla filiculoides* occur in the upper reaches.

Biomass distribution: The reduction in freshwater inflow has resulted in stagnant waters in the upper reaches of the estuary. Agricultural activities have resulted in nutrient enrichment. This has increased the biomass and aerial distribution of *Potamogeton pectinatus* and the macroalgae. During summer in 2004 pondweed filled the water column. This increase in organic load has the potential to cause anoxic conditions during decomposition.

There has been an increase in salinity from the reference to the natural condition that may have decreased the distribution of brackish reeds and sedges. This change over time is difficult to determine from aerial photographs as distribution is very patchy in the middle reaches of the estuary. This patchy distribution may be as a result of high salinity during summer but low salinity during winter. In the upper reaches where salinity is lower (<15 ppt) then a continuous reed fringe is found. An increase in salinity will decrease the distribution and growth of salt marsh plants. The supratidal and floodplain plants utilise the saline groundwater during the dry 8 months of the year. Any change in water column salinity will influence the salinity of the groundwater.

Seasonal variability and community composition: Because of the harsh environment a single salt marsh species *Sarcocornia pilansii* is dominant in the supratidal and floodplain areas. No change is expected in the composition of this community. Macroalgae were probably always present in the Olifants Estuary, however nuisance bloom forming species have become more abundant. These could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches. There was however no indication of this during the field survey. The increase in saline intrusion upstream may have decreased the size and extent of brackish salt marsh dominated by *Cotula coronopifolia* and *Juncus kraussii*.

Confidence: High

INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macro crustaceans)

Zooplankton

Biomass: Average annual biomass is likely to have been less under the Reference Condition compared to the Present State. This is because of greater river dominance and very low salinity values over much of the estuary. In addition, residence time of the water was relatively low under the Reference Condition. Salinity only increased in the lower estuary during the dry season (4 months), and during this time zooplankton biomass would have increased, probably to relatively high levels.

Species richness: The number of species present in the estuary would have been similar compared to the present state – some marine species may only have penetrated the estuary on a flood tide during the dry season. Marine associated species would have been absent for most of the year because of stronger river dominance. The estuarine copepod *Acartia longipatella* would also appear in very low numbers for brief periods when salinity values increased above about 20 ppt.

Seasonal variability: Biomass and species are likely to have changed significantly between seasons. This is in contrast to the present condition where variations, although present, are less dramatic. In addition, large spatial shifts would have occurred between seasons. Variation in freshwater flow pattern is the main driver.

Benthic Invertebrates (Hyperbenthos)

As described for the zooplankton.

Macro crustaceans (Benthos)

Biomass: Because of the change in submerged macrophyte biomass in the upper estuary, the biomass of benthic organisms associated with macrophytes would have been significantly lower (lack of habitat) in these reaches compared to Present State. Only hardy euryhaline or brackish water species are present in these upper reaches. Under the Reference Condition biomass of sandprawn (*Callinasa kraussi*) and mudprawn (*Upogebia africana*) would have been less compared to Present State because of strong river dominance (although adults are able to tolerate reduced salinities, larval development requires salinity values of >17-2- ppt).

Species richness: The number of species present in the estuary would have been slightly less compared to the Present State. Marine associated species would also be absent for most of the year, although they probably penetrated the mouth area for brief periods during the dry season.

Seasonal variability: Biomass and species are likely to have changed significantly between seasons. This is in contrast to the Present State where variations, although present, are less dramatic. For example, although sandy sediment may have been present near the mouth, low salinity values in this region would have excluded many species for about 8 months of the year. Similarly, the variation in salinity between high and low tide would also have excluded species.

Confidence: Medium

FISH

Biomass: Under Reference Conditions the ichthyofauna would have been dominated numerically (63 % vs 42 % under the Present State) by category Ia estuarine species, mostly *G.aestuaria*. The facultative catadromous *Mugil cephalus* (IIa) would have been twice as abundant in the upper reaches as under the Present State. Similar to the summer high flows in the Orange Estuary, during the winter wet season, indigenous freshwater species (e.g. *B.serra* & *L. capensis*) in the Olifants Estuary would have dispersed throughout the estuary right up to the mouth. These species are almost absent in the Present State. In the absence of fishing, obligate estuarine dependent marine species (e.g. *L. lithognathus*) would have been 10 % less abundant under reference conditions. However, the Present State stock status suggests that they would have actually been more abundant under reference conditions than under Present State. Similarly, ignoring Present State fishing effects, Category IIc species (e.g. *L. richardsonii*), which are equally at home in the estuarine and marine environment would have been half their Present State abundance.

Species richness: Species richness would have been similar to the Present State with the exception that the 4 introduced freshwater species would not have occurred. Instead, there would have been 4-5 indigenous freshwater species. Estuarine and estuarine dependent species would have been as common as they were in the Present State. Marine species may have been absent in the winter months, but certainly present during summer and cold upwelling events in the sea. Again, in the absence of fishing, more species may have entered and persisted in the system under reference conditions.

Seasonal variability: Seasonal changes in abundance & species composition are likely to have been more marked than under Present State and highest during autumn and spring / early summer when marine, estuarine and freshwater species occurred simultaneously in the same estuarine reach. Abundance would also have been influenced by fish shoaling before they left the system during the first winter spates (e.g. *M. cephalus*) or recruiting to the estuary during spring and early summer (e.g. *L. richardsonii* & *L. lithognathus*). Nowadays, the gillnet fishery is likely to either disrupt or arrest these events.

Upstream (>16 km) penetration of marine, estuarine and estuarine dependent species is likely to have been of shorter duration under reference conditions and confined to the summer months. However, the bulk of the biomass is likely to have been confined to the lower 4-12 km throughout the year as it is under the Present State. A possible exception to this is that a small proportion of some fish populations tend to swim upstream in response to high flow. *Liza richardsonii* and *P.saltatrix* have been found more than 100 km upstream in the Orange Estuary during high flow whereas dusky kob (*Argyrosomus japonicus*) and spotted grunter (*Pomadasys emmersonii*) only move > 50 km upstream in the Olifants Estuary under high flow.

Confidence: Medium

BIRDS

Biomass: In the reference state, the estuary would have been somewhat less productive overall, because nutrient inputs and retention times would have been lower. This has implications all the way up the food chain. In addition, the intertidal area would have been 10% greater in the upper estuary and 20% smaller in the lower estuary, due to the central arm having been open. There would have been more freshwater habitat in the estuary than in the present condition, due to higher base flows in summer.

Invertebrate feeders (such as the waders) are expected to be less abundant due to less habitat and lower densities of invertebrates in the estuary. However, since the changes are lowest in the lower estuary, where most birds occur, it is unlikely that there has been a major change. Moreover, the waders, which dominate the invertebrate feeders and avifauna in general, depend mostly on polychaetes and other small benthic invertebrates, which are thought to have changed relatively little (perhaps having increased by only 10-20% - Wooldridge, pers. comm)

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) would be affected by the change in fish availability. Although the productivity of the fish component would have been lower in the reference state, the fish are expected to have been more abundant than at present, since they would not have been subject to the fishing pressure which keeps abundance down in the present state. Piscivorous birds would thus be more abundant in the reference state, and their composition would have been different, since some species have only colonised the estuary relatively recently. Among piscivores, terns, which are the most numerous, may be least affected, since they feed in the mouth of the estuary.

Waterfowl may have been more abundant in the reference state when there was more freshwater habitat in the estuary and more intertidal area in the middle to upper reaches. However, the freshwater habitat would not have been as productive as in the present state, offsetting the above to some degree.

Species richness: At least five species have colonised the estuary since the reference state. This is due to range expansions of species due to increases in artificial water bodies and alien trees. There is no reason to believe that any species have been lost.

Seasonal variability: There would not have been any significant changes in seasonal patterns of bird numbers.

Confidence: Medium

3.4 Present Ecological Status of the Olifants Estuary

The Present Ecological Status is determined using the Estuarine Health Index (EHI) described in detail in Appendix C of the *Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAf, 2004a). Details regarding the individual scoring systems are included in that report.

The EHI is sub-divided into:

- The Habitat Health score determined by Abiotic variables (hydrology, hydrodynamics and mouth condition, water quality, physical habitat alteration and human disturbance of habitat and biota)
- The Biological Health score determined by Biotic variables (microalgae, macrophytes, invertebrates, fish and birds)

The scores are 'percentage deviation' of the Present State from the Reference Condition, e.g. if the Present State is still the same as the Reference Condition, then the score is 100.

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	60	For the Olifants Estuary low flows are defined as flows associated with the State 1: Marine dominated and State 2: Saline penetration into middle reaches (i.e. flows $<5\text{m}^3/\text{s}$). Months with median low flows $<2\text{m}^3/\text{s}$ increased from 0 months under reference conditions to 6 months under present conditions, Months with median low flows of $<5\text{m}^3/\text{s}$ increased from 4 months (Dec - Mar under the Reference Condition to 7 months (Nov - May) under the Present State. This translates to a score of 75. Due to the introduction of State 1 and the occurrence of <u>very low baseflows</u> simulated ($0.5 - 0.7\text{m}^3/\text{s}$) and the loss of variability and flow under the present state an additional -15 is allowed.	Low
b. % similarity in mean annual frequency of floods	82	The major floods have not been affected significantly because both Clanwilliam and Bulshoek Dam have rather small storage capacities compared to the MAR. Also the floods from the Doring River are much the same as under Reference conditions. The major floods would have been reduced by about 18% from Reference Condition.	Medium
Hydrology Score	69		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	The mouth of the Olifants Estuary is permanently open under both the Reference Condition and Present State.	High
Hydrodynamic Score	100		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	50	Low flow periods ($<5\text{m}^3/\text{s}$) increased from 4 months (Dec - Mar) under the Reference Condition to 7 months (Nov - May) under the Present State. In addition, flows within the low flow period are reduced. Under the Reference Condition, State 2 ($2-5\text{m}^3/\text{s}$) was dominant limiting saline penetration to the middle reaches (about 15 km from the mouth). Under the Present State, State 1 ($<2\text{m}^3/\text{s}$) becomes dominant resulting in saline penetration to about 30 km upstream. Flows under the Present State are even below $1\text{m}^3/\text{s}$ - resulting in extensive saline penetration. The estuary remains freshwater dominated (State 4) for 4 months during the high flow period (Jun - Sep), thus no marked change is expected in terms of salinity distributions. The above translates into a largely modified salinity gradient.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2a. Nitrate (DIN)/phosphate (DRP) concentration in the estuary	50	During the high flow periods (Jun – Sep) the estuary remains freshwater dominated (State 4) under the Present State – as for the Reference Condition. However, the DIN concentrations introduced via river inflow are markedly higher as a result of agricultural activities in the catchment and along the banks of the upper estuary. To reflect modifications during this period assume a 20% change from the Reference Condition. The low flow period (<5 m³/s) increased from 4 months (Dec – Mar) under the Reference Condition to 7 months (Nov – May) under the Present State. In addition, flows within the low flow period are reduced. These significant reductions shifted the estuary from being mainly in State 2 under the Reference Condition to State 1 under the Present State, with the following results: In the upper reaches although DIN/DRP introduced through river inflow are less in terms of total load under the Present State (State 1), the actual concentration in river inflow are higher compared with the Reference Condition. In the middle reaches under the Present State, DIN concentrations will become near depleted, while DRP concentrations will tend to accumulate (State 1). Under the Reference Condition DIN and DRP concentrations followed a near linear gradient between the two endpoints (State 2). To reflect modifications during the low flow period assume an additional 30% change from the Reference Condition.	Medium
2b. Suspended solids (turbidity) in the estuary	80	Turbidity in the Olifants Estuary is mainly determined by river inflow (high flows) and wind turbulence (low flows). During the high flow period (Jun – Sep), the estuary remains freshwater dominated (State 4) under the Present State – as for the Reference Condition. It is therefore assumed that during this period changes in turbidity levels will be insignificant. The low flow period (<5 m³/s) increased from 4 months (Dec – Mar) under the Reference condition to 7 months (Nov – May) under the Present State. In addition, flows within the low flow period will be reduced. These significant reductions shifted the estuary from being mainly in State 2 under the Reference Condition to State 1 under the Present State. As a result it is expected that turbidity levels in the upper, but in particular the middle reaches of the estuary, will be reduced - not only as a result of less turbidity being introduced via river inflow, but also 'clear' seawater penetrating further upstream. To reflect modifications during the low flow period assume a 20% change from the Reference Condition.	Low
2c. Dissolved oxygen (DO) in the estuary	80	During high flow months (Jun – Sep), the estuary remains freshwater dominated (State 4) under the Present State – as under the Reference Condition - and remains well-oxygenated. The low flow period (<5 m³/s) increased from 4 months (Dec – Mar) under the Reference Condition to 7 months (Nov – May) under the Present State. In addition, flows within the low flow period are reduced. These significant reductions shifted the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 2. Although it is expected that DO concentrations in bottom waters (> 3 m) already become lower (~4 mg/ℓ) under State 2, this is aggravated by longer residence time under State 1 (< 3 mg/ℓ). Taking into account that the volume below 3m is quite small, assume a 20% change from the Reference Condition.	Medium
2d. Levels of toxins	80	As the estuary is not located in close proximity to major industrial areas, trace metals and petroleum hydrocarbons are not considered a major issue. However, the Olifants River catchment is extensively used for agriculture and toxic substances such as herbicides and pesticides may be of concern. Assume a 20% change from the Reference Condition.	Low
Water Quality Score	50		

Physical habitat alteration

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Resemblance of intertidal sediment structure and distribution to Reference Condition			
1a % similarity in intertidal area exposed	70	The estuary is about 10% narrower now than under Reference condition, but only over the upper 15 km (translates to about 5% in terms of scoring). The low water bridge at Lutzville is thought to reduce the tidal effect to a small degree, and as such reduces the intertidal area (5%). In the lower estuary, especially the blind arm of the river, the intertidal area has actually increased due to siltation in that area, by about 20%.	Medium
1b % similarity in sand fraction relative to total sand and mud	90	Some of the catchment sediment is trapped by the Clanwilliam and Bulshoek Dams. The floods reaching the estuary will therefore be able to scour more sediment and some of the fine materials from the upper reaches will be removed. The removal of fine material will however be limited.	Low
2. Resemblance of sub-tidal sediment structure and distribution to Reference Condition			
2 Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	75	The estuary is about 10% narrower now in the upper reaches than under Reference conditions. Also the river in the upper reaches will be about 0.5 m deeper at present. The bed material contains slightly more coarse material. The width and depth changes will alter the channel geometry, which would account for a change of about 15% in the subtidal area, while the change in bed material would account for a further 10%.	Medium
Physical Habitat Score	77.5		

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Phytoplankton			
1. Species richness	100	The increase in DIN & DRP would have resulted in a change of species dominance, especially. The full suite of species present are also likely to have been present under the reference condition	Medium
2a. Abundance	90	The increase in available DIN & DRP as a result of return flow would have resulted in an increase of chlorophyll-a.	High
2b. Community composition	70	The increase in salinity as a result of decreased flow and seawater penetration would have resulted in an increase in the time when the more saline species would have been dominant.	High
Benthic microalgae			
1. Species richness	100	Data have shown that the number of taxa present at any given site is very variable. The changes in flow and minerals are unlikely to have resulted in a higher or lower species richness.	High
2a. Abundance	80	The changes in DIN & DRP would have resulted in some increase in microphytobenthos biomass.	Medium
2b. Community composition	70	Although there are no data that specifically show a change in community composition with increased biomass, the fact that communities in freshwater do respond to nutrients by increased biomass suggests that there would have been some changes in the dominants and sub-dominants.	Medium
Microalgae Score	70		

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	80 (90%)	There has been an increase in colonization of the upper reaches of the estuary by macroalgae as a result of nutrient enrichment from agricultural activities and decreased flow due to water abstraction. Residence time in upper reaches has increased from 1-4 weeks (State 2) to greater than 4 weeks (State 1). Invasive plants have colonized the riparian zone in some disturbed areas and displaced the indigenous species. 90 % of the original species remain.	?
2a. Abundance	58	Nutrient enrichment and a reduction in flow and flushing of macrophytes have increased the biomass and aerial distribution of Potamogeton pectinatus and the macroalgae (-10). Under natural conditions the estuary was mostly in State 2 where salinity less than 20 ppt occurred from 6.5 km upstream. Now State 1 occurs for 6 months of the year and salinity can remain at 20 ppt for greater than 4 months at 12-14 km upstream. Salinity greater than 20 ppt will result in the die-back of reeds and sedges after 3 months. This represents a potential loss of 6.5 km of reeds and sedges (22%). Under natural conditions reeds would have	High

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
		occurred from 6.5 to 36 km, a distance of 29.5 km. The present patchy distribution of reeds and sedges in the middle reaches of the estuary can possibly be attributed to the increase in saline intrusion. (-7) An increase in salinity will decrease the distribution and growth of salt marsh plants. The supratidal and floodplain plants utilise the saline groundwater during the dry 8 months of the year. An increase in water column salinity has probably increased groundwater salinity leading to a loss of salt marsh cover. (-20) There has been a small (5%) loss in the area covered by macrophytes as a result of anthropogenic disturbances (e.g. grazing, agricultural activities, salt pan). (-5)	
2b. Community composition	75	Nuisance bloom forming macroalgal species have become more abundant. These could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches. Saline intrusion may have displaced the brackish marsh.	High
Macrophyte Score	58		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Zooplankton			
1. Species richness	100	Overall, species richness over the year is likely to have been the same compared to the Reference Condition.	Medium
2a. Abundance	70	Abundance levels, on average are likely to have increased on an annual basis. This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the present state).	Medium
2b. Community composition	70	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the present state).	Medium
Macroinvertebrates (hyperbenthos)			
1. Species richness	100	Overall, species richness over the year is likely to have been the same compared to the Reference Condition.	Medium
2a. Abundance	70	Abundance levels, on average are likely to have changed on an annual basis (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the present state).	Medium
2b. Community composition	70	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the present state).	Medium
Macrocrustaceans (benthos)			
1. Species richness	100	Overall, species richness over the year is likely to have been the same compared to the Reference Condition.	Medium
2a. Abundance	65	Abundance levels, on average are likely to have changed significantly on an annual basis (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the present state). Species such as Callinassa kraussi and Upogebia africana benefit because of the larger habitat made available through higher salinity values (breeding requirement).	Medium
2b. Community composition	70	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change along the gradient. This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the present state).	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Invertebrate Score	65		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	52 (74 %)	The loss of 4-5 indigenous freshwater species and their replacement by 4 introduced species represents a 26 % loss in species (absolute values). The species richness accorded to the marine, estuarine and estuarine dependent species is likely to have remained unchanged since reference conditions.	Medium
2a. Abundance	70	Overall 20 % increase in abundance from reference conditions largely due to the 90 % increase in category IIc species (<i>L.richardsonii</i>). Marine and partially estuarine dependent species have also increased 70-80 % but their contribution to overall abundance remains low. In turn, estuarine (<i>G.aestuaria</i>) and obligate estuarine dependent (<i>L.lithognathus</i>) species have undergone a 20 % and 50 % reduction in abundance respectively. The latter is cause for concern.	Medium
2b. Community composition	40	Indigenous freshwater species have been replaced by exotics. Category Ia (<i>G.aestuaria</i>) estuarine breeders now 41 % contribution to overall abundance as opposed to 62 % under reference conditions. Overall almost complete change from a year round dominant REI type community to a fish community with a preference for 10-30 ppt. In turn, the fish community is now dominated by a detritivore / benthic grazer (<i>L.richardsonii</i>) as opposed to a filter / selective feeder (<i>G.aestuaria</i>) under reference conditions. There has also been a decline in the proportion of piscivorous fish (<i>L.amia</i> & <i>P. saltatrix</i>) and large benthic feeders (<i>L. lithognathus</i> & <i>R. globiceps</i>) but this is likely to be mostly due to the gillnet fishery and the nationwide stock status of these species.	Medium
Fish Score	40		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	At least five species that occur at present would not have been present in the reference state. These species are species whose ranges have expanded and that would only have reached the estuary in the past 20 – 30 years. However the score only considers change in occurrence of original species. It is unlikely that there has been any losses of species.	Medium
2a. Abundance	98	Without considering exogenous factors such as changes in source populations of migratory species, waterbirds were probably not as abundant in the reference state as at present, although the difference is probably very slight. There would be slightly fewer invertebrate feeders (less food and habitat), slightly more piscivorous birds (more fish) and more waterfowl (more freshwater habitat) in the reference condition. However, there is also less productivity in the upper reaches. The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined in the accompanying report (refer to Appendix H).	Medium
2b. Community composition	95	Given the rather slight changes in different trophic groups outlined above, the community composition is not very different in the reference state from the present state. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.	Medium
Bird score	95		

The individual scores for each of the components (i.e. overall score listed) were incorporated into a Habitat health score and a Biological health score. This allowed for the determination of the Estuarine Health Index (EHI) Score as illustrated in Table 3.

TABLE 3: Estuarine Health Score results for the Present State of the Olifants Estuary

VARIABLE	WEIGHT	SCORE	WEIGHTED SCORE
Hydrology	25	69	17
Hydrodynamics and mouth condition	25	100	25
Water quality	25	50	13
Physical habitat alteration	25	78	19
Habitat health score			74
Microalgae	20	70	14
Macrophytes	20	58	12
Invertebrates	20	65	13
Fish	20	40	8
Birds	20	95	19
Biotic health score			66
ESTUARINE HEALTH SCORE			70

The EHI score for the Olifants Estuary, based on its Present State, was 70, translating into a Present Ecological Status of C as indicated in Table 4.

TABLE 4: Recommended guidelines for the classification of the Present Ecological Status (PES)

EHI SCORE	PRESENT ECOLOGICAL STATUS	GENERAL DESCRIPTION
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	C	Moderately modified
41 – 60	D	Largely modified
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

Although the Present State of the Olifants Estuary currently falls within an Ecological Category C, it is likely that the estuary is on a negative trajectory of change, because of the extremely low base flows under the Present State ($< 1 \text{ m}^3/\text{s}$) particularly during the summer months. Maintaining the *status quo* is therefore likely to result in continued modification of the Ecological Status of the estuary.

An estimation of the degree to which the Present State has been modified (compared with Reference Conditions) by non-flow related anthropogenic activities is listed in Table 5.

TABLE 5: Estimation of the degree to which Present State has been modified by non-flow related anthropogenic activities

COMPONENT	% CHANGE NON-FLOW RELATED	MOTIVATION	CONFIDENCE
Water Quality	50	Although modification in salinity, turbidity and dissolved oxygen are mainly flow related, modification related to nutrients and toxic substances are largely linked to agricultural activities in the catchment and along upper reaches of estuary	Medium
Physical habitat alteration: Intertidal and supratidal	2	Most of the changes can be attributed to the modifications in water inflow to the estuary. However, the low water bridge at Lutzville has some dampening effect on the tidal effect. The effect is thought to be very small.	High
Physical habitat alteration: Subtidal	2	Most of the changes can be attributed to the modifications in water inflow to the estuary. However, the low water bridge at Lutzville has some dampening effect on the tidal effect. The effect is thought to be very small.	High
Microalgae	80	Overall response would have been to nutrients only.	Medium
Macrophytes	5	Grazing occurs on the salt marsh in the middle and lower reaches. In the mouth area the salt pan has resulted in the removal of some vegetation. In the middle upper reaches a large area of supratidal and floodplain salt marsh was removed when a dam was constructed. The Ebenhaeser settlement has also resulted in the loss of some riparian vegetation most likely reeds and sedges. Alien invasive plants e.g. <i>Sesbania punicea</i> are common in the riparian zone indicating disturbance. Overgrazing in the Doring catchment has increased the sediment load to the estuary which may result in loss of submerged macrophytes during high flow turbid conditions.	High
Invertebrates	No change	-	Medium
Fish	30	Upstream distribution of REI species (<i>G.aestuaria</i> , <i>M. cephalus</i>) inhibited by the Lutzville Causeway and narrowing of the stream channel. These species would be able to use the freshwater reaches as an alternative habitat. The decline in piscivorous and larger bodied benthic feeders (e.g. <i>P.saltatrix</i> & <i>L.lithognathus</i>) is likely to be more due to gillnetting than to changes in flow. Much of the change in indigenous freshwater species can be attributed to the introduced species. Upstream distribution of the <i>Gobidae</i> and <i>Syngnathidae</i> may be partially inhibited by pesticides and bulldozing of the banks.	Medium
Birds	2	There is very little disturbance on bird life of the estuary. The numbers of Oystercatchers will have been higher in the Reference condition because their populations have been impacted generally.	Medium

3.5 Importance of the Olifants Estuary

Ecological importance is an expression of the value of a specific estuary to maintaining ecological diversity and functioning of estuarine systems on local and wider scales. The variables selected for the estuarine importance rating index were:

- Estuary size
- Zonal type rarity
- Habitat diversity
- Biodiversity importance
- Functional importance.

Each of the above can be categorised as measures of rarity, abundance or ecological function. The rationale for selecting these variables, as well as further details on the estuarine importance index are discussed in detail Appendix D of the *Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAf, 2004a).

For this study, the Ecological importance determination of the Olifants Estuary was obtained from the *Estuarine Prioritisation for RDM* project (Turpie *et al.*, 2004). The *Functional Importance* score, however, was derived at the Specialist Workshop held in Port Elizabeth on 25-28 July 2005.

The Estuarine Importance Index scores allocated to the Olifants Estuary, *based on its Present State*, were as follows:

Estuary Size

SCORE	MOTIVATION
100	Estuary size is defined as the total area (ha) within the geographical boundaries of the estuarine resource unit. Size is then converted to a measure of importance using scoring guidelines, which is based on 10% rank percentiles of estuaries of known size. With an area between 50.1–100 ha, the Olifants Estuary is assigned a score of 100.

Zonal Type Rarity

SCORE	MOTIVATION
90	The estuary is one of 2 permanently open estuaries within the cool temperate biogeographical zone. The Zonal Type Rarity index is thus $1/2 = 50$. The score assigned is thus 90.

Habitat Diversity

SCORE	MOTIVATION
100	This score is calculated on the basis of the amount of each habitat type present in the estuary in relation to the total area of this habitat in South African estuaries. The score ($x \text{ ha}/x \text{ ha}$) for each habitat is summed to obtain the rarity value. The value obtained falls within the top percentile for the scores generated, therefore a score of 100 is assigned.

Biodiversity Importance

SUB-COMPONENTS	SCORE	MOTIVATION
Plants	100	This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as $1/\text{number of estuaries in which the species occurs in South Africa (based on actual records of presence)}$. The summed value obtained falls within the top percentile for the scores generated from all South African estuaries, and is thus assigned a score of 100.
Invertebrates	90	This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as $1/\text{number of estuaries in which the species occurs in South Africa (based on interpolated presence records from species distributions)}$. The summed value obtained falls within the 2nd percentile for the scores generated from all South African estuaries, and is thus assigned a score of 90.
Fish	90	This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as $1/\text{number of estuaries in which the species occurs in South Africa (based on actual records of presence)}$. The summed value obtained falls within the 2 nd percentile for the scores generated from all South African estuaries, and is thus assigned a score of 90.
Bird	100	This score is calculated by adding rarity scores for each species present in the estuary, where

SUB-COMPONENTS	SCORE	MOTIVATION
		rarity scores for each species are calculated as 1/number of estuaries in which the species occurs in South Africa (based on actual records of presence). The summed value obtained falls within the top percentile for the scores generated from all South African estuaries, and is thus assigned a score of 100.
Biodiversity score	98	

Functional Importance

SUB-COMPONENTS	SCORE	SCORING GUIDELINES
a. Estuary: Input of detritus and nutrients generated in estuary	50	None = 0
b. Nursery function for marine-living fish and crustaceans	100	Little = 20
c. Movement corridor for river invertebrates and fish breeding in sea	20	Some = 40
d. Roosting area for marine or coastal birds	100	Important = 60
e. Catchment detritus, nutrients and sediments to sea	50	Very important = 80
Functional score	100*	Extremely important = 100

* Using the maximum score of the above

The individual scores obtained above were incorporated into the final Estuarine Importance Score as illustrated in Table 6.

TABLE 6: Estuarine Importance scores for the Olifants Estuary

CRITERION	SCORE	WEIGHT	WEIGHTED SCORE
Estuary Size	100	15	15
Zonal Rarity Type	90	10	9
Habitat Diversity	100	25	25
Biodiversity Importance	98	25	25
Functional Importance	100	25	25
ESTUARINE IMPORTANCE SCORE			99

The Estuarine Importance Score for the Olifants Estuary, based on its Present State, is 99, indicating that the estuary is highly important, as indicated in Table 7.

TABLE 7: Interpretation of Estuarine Importance scores for estuaries

IMPORTANCE SCORE	DESCRIPTION
81 – 100	Highly important
61 – 80	Important
0 – 60	Of low to average importance

3.6 Ecological Reserve Category for the Olifants Estuary

The recommended Ecological Reserve Category (ERC) represents the level of protection assigned to an estuary.

For estuaries the first step is to determine the 'minimum' ERC of an estuary, based on its Present Ecological Status (PES). The relationship between EHI Score, PES and ERC is set out in Table 8.

TABLE 8: Relationship between EHI, PES and minimum ERC

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

NOTE: Should the Present Ecological Status category of an estuary be either an E or F, recommendations must be made as to how the status can be elevated to at least achieve a Category D (as indicated above).

PES sets the minimum Ecological Reserve Category. The degree to which Ecological Category needs to be elevated higher than PES depends on level of the **importance** and level of **protection or desired** protection of a particular estuary (Table 9). Estuaries that currently have protection status and the current list of desired protected areas are given in Appendix C of the *Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAF, 2004a).

TABLE 9: Guidelines for assigning the recommended Ecological Category

CURRENT/DESIRED PROTECTION STATUS AND ESTUARY IMPORTANCE	RECOMMENDED ECOLOGICAL RESERVE CATEGORY	POLICY BASIS
Protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area (based on complementarity)		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category
Important	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D category

* BAS = Best Attainable State

In addition to being categorised as a 'Highly important estuary' (see above), the Olifants Estuary has also been targeted as a Desired Protected Area (DWAF, 2004). Therefore, according to the guidelines for assigning a recommended ERC (Table 9) the estuary needs to be in a Category A or the Best Attainable State (BAS).

At the specialist workshop (held on 25-27 July 2005 in Stellenbosch) it was, however, concluded that with large dam developments already existing in the catchment (e.g. Clanwilliam Dam) it will be difficult to improve the Olifants Estuary to a Category A. The workshop therefore decided to recommend that the Olifants Estuary be improved to the minimum ERC for a 'Highly Important estuary', namely a **Category B**. This also represents the PES + 1, i.e. the Olifants Estuary is currently a C plus 1 category up takes the estuary to a B category.

4. QUANTIFICATION OF ECOLOGICAL RESERVE SCENARIOS

4.1 Simulated Runoff Scenarios

Simulated monthly runoff was supplied by project hydrologist (Mr A Sparks Ninham Shand Consulting Engineers, Cape Town, pers. comm.). A summary of the suite of future runoff scenarios evaluated as part of this project are provided in Table 10.

TABLE 10: Summary of Simulated Scenarios evaluated as part of Olifants Estuary Ecological Reserve Determination

SCENARIO	DESCRIPTION	Mean annual runoff (MAR) (million m ³ /year)
Reference	Representative of flows before agricultural developments and impoundments in the catchment	1070.1
Present	Reflects the present agricultural developments and dam developments in the Olifants main stream (Clanwilliam and Bulshoek Dam) - simulated data reflect inflow without Bulshoek leakage	715.0
Scenario 2	Present inflow plus the Ecological Water Requirement releases of the River	800.3
Scenario 7	Raising Clanwilliam wall (15 m) plus the Ecological Water Requirement releases of the River	741.5
Scenario 5	Raising Clanwilliam wall (15 m) with no River EWR releases	605.7
Scenario 17	Brandewyn weir/dam development on the Brandewyn river (a tributary to the Doring River) with a capacity of 5 x 10 ⁶ m ³ , including an abstraction of 5 m ³ /s plus raising the Clanwilliam wall (15 m) with no River EWR releases	529.3
Scenario 10	Maximum development represents the Melkbosrug Dam in the Doring catchment. This development would regulate almost all of the inflows from the Doring River and maximise the yield from the Olifants / Doring River system. This scenario ignores the Ecological Water Requirement of the Doring river (includes 15 m raising of Clanwilliam wall) with no River EWR releases	423.5

***Note:** The overall confidence in the hydrology is very low as limited accurate baseflow data was available to base the hydrological assessment on.*

4.2 Assessment of Scenarios

4.2.1 Scenario 2: Present State plus EWR Releases

i. Seasonal variability in river inflow

Monthly simulated runoff data for the Scenario 2 is provided in Table 11. The mean annual runoff (MAR) is 800.3 Million m³ for this state. A summary of flow distribution (mean monthly flows in m³/s) for the Scenario 2, derived from the 70-year simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	48.13	32.08	21.50	37.21	24.46	7.77	96.73	194.20	550.92	472.06	230.02	153.70
90%ile	28.90	9.60	7.24	3.64	3.76	3.85	9.62	80.90	151.71	159.08	126.25	65.58
80%ile	16.05	4.30	2.06	1.75	1.68	2.21	4.85	22.01	93.83	104.19	79.44	48.08
70%ile	12.84	2.93	1.68	1.55	1.38	1.81	3.07	11.18	57.99	78.10	66.22	34.22
60%ile	11.49	2.93	1.51	1.51	1.37	1.46	2.88	8.24	42.45	58.26	50.45	25.66
50%ile	10.11	2.93	1.50	1.51	1.34	1.42	2.84	6.19	37.99	51.82	47.54	22.18
40%ile	9.01	2.49	1.50	1.51	1.34	1.42	2.49	3.57	36.22	39.92	44.77	16.34
30%ile	8.32	1.51	1.50	1.51	1.34	1.42	1.76	3.42	24.20	30.79	33.23	14.73
20%ile	6.36	1.43	1.18	1.51	0.91	1.11	1.41	2.05	15.78	21.17	28.07	11.21
10%ile	4.02	0.83	0.58	0.99	0.85	1.00	1.28	1.15	7.44	9.49	17.41	9.66
1%ile	1.01	0.15	0.00	0.99	0.34	0.00	0.04	0.29	0.82	2.07	5.35	4.04

ii. Predicted Flood regime under Scenario 2

This is very similar to Present State and has not changed much compared to the Reference Condition.

Confidence: Medium

iii. Predicted sediment processes under Scenario 2 compared with Reference Condition

This is very similar to Present State and has not changed much compared to the Reference Condition.

Confidence: Medium

TABLE 11: Monthly simulated runoff data in m³/s (70-year period) under Scenario 2

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	10.53	2.93	1.81	1.88	9.24	11.53	3.38	3.46	555.99	496.93	106.04	25.54
1921	9.01	2.93	9.34	4.76	1.35	1.42	2.84	3.46	39.04	51.82	74.12	62.48
1922	9.01	2.93	1.50	1.51	1.34	1.39	2.62	8.24	151.71	108.96	47.74	15.09
1923	9.01	2.93	1.50	1.51	1.36	1.00	1.87	3.08	37.74	30.79	47.40	16.09
1924	11.53	2.97	1.50	1.51	1.68	1.00	1.76	3.92	548.74	461.40	50.93	12.29
1925	12.84	3.39	1.50	1.51	1.34	1.42	2.86	9.57	37.99	35.45	33.23	10.30
1926	16.05	6.17	1.29	0.99	0.88	1.00	2.57	4.16	15.69	7.20	32.58	14.21
1927	8.65	2.73	1.00	0.99	0.91	1.00	1.68	1.15	40.39	39.92	23.90	10.33
1928	8.61	2.49	0.99	0.99	0.20	0.24	2.77	5.84	37.96	52.38	47.78	25.66
1929	11.19	0.46	0.49	1.51	5.13	2.16	0.00	0.61	2.18	3.60	9.76	38.18
1930	33.86	2.93	1.50	1.55	1.39	1.42	4.93	7.88	31.12	21.31	65.98	45.41
1931	12.97	2.93	1.50	1.51	6.04	4.34	2.88	6.27	50.60	51.82	47.33	14.73
1932	9.01	2.93	1.18	0.99	0.88	1.00	1.72	3.42	41.20	112.53	58.61	16.09
1933	1.71	0.76	0.58	1.51	0.85	3.85	2.70	0.71	3.21	6.02	6.01	11.09
1934	17.50	30.94	13.01	1.51	1.34	1.42	3.03	7.76	37.81	38.35	47.85	28.18
1935	12.18	2.93	1.50	1.51	1.38	1.46	2.38	3.57	12.78	21.17	46.01	33.63
1936	17.60	7.88	6.92	1.60	0.88	1.11	2.49	4.32	42.45	101.85	47.63	10.62
1937	9.01	2.93	7.42	12.20	1.34	1.42	2.66	9.27	30.22	19.76	28.07	15.92
1938	10.12	2.93	1.50	1.19	1.82	1.15	2.20	22.01	36.54	10.86	109.13	82.37
1939	1.51	0.03	0.00	0.99	4.47	1.81	1.51	1.50	7.44	8.61	6.41	5.71
1940	9.05	2.97	1.54	1.59	1.34	1.42	6.75	62.11	178.45	103.19	104.54	140.91
1941	30.14	2.93	1.50	1.51	1.34	1.42	3.32	5.39	193.82	113.25	47.33	11.86
1942	16.65	9.60	5.94	5.73	1.34	1.60	2.11	3.39	15.78	51.86	79.44	34.22
1943	11.49	10.19	7.24	1.51	1.38	2.32	2.88	12.52	59.13	82.18	66.22	39.70
1944	17.03	2.93	1.50	1.51	1.34	1.46	2.88	21.01	122.52	159.08	126.25	22.18
1945	11.04	2.93	1.50	1.51	1.34	1.42	3.03	3.53	17.08	14.59	23.00	52.54
1946	46.37	2.93	1.50	1.51	1.34	2.28	2.90	9.58	24.20	53.88	48.11	10.62
1947	9.01	2.93	1.50	1.51	1.46	6.17	8.51	8.18	31.38	51.90	36.17	17.76
1948	11.93	2.93	1.50	1.51	1.34	1.26	2.49	3.46	17.49	14.32	38.51	14.05
1949	10.11	18.31	6.84	1.51	1.34	1.31	10.11	9.09	13.44	64.74	54.36	24.29
1950	15.17	5.69	2.55	1.51	1.35	1.42	2.86	3.46	57.17	90.30	47.29	30.86
1951	11.18	6.48	1.50	1.51	2.23	1.72	2.88	11.18	36.22	58.78	110.29	61.10
1952	15.55	26.15	19.76	1.51	1.73	1.83	27.84	57.65	37.70	70.56	100.62	24.18
1953	9.01	2.93	2.31	2.07	1.34	2.21	3.40	95.32	93.83	193.40	144.89	55.95
1954	13.81	2.93	1.50	1.51	2.57	1.97	3.17	3.57	43.89	104.19	199.02	86.95
1955	28.90	9.69	2.06	1.55	1.38	1.81	2.95	3.55	39.93	66.39	70.58	23.73
1956	9.01	2.93	1.50	1.51	3.76	3.38	2.88	24.63	117.14	159.12	127.95	48.08
1957	38.27	3.99	1.92	1.92	1.34	1.42	2.88	19.21	39.07	30.91	24.74	10.62
1958	8.85	2.60	1.00	0.99	0.88	1.00	2.61	249.47	230.26	51.38	48.04	15.55
1959	4.16	0.83	0.49	1.43	0.41	0.00	0.24	1.88	11.48	10.98	5.98	4.34
1960	3.79	1.43	2.04	2.06	1.42	3.77	96.67	90.26	66.84	76.22	37.70	27.60
1961	11.70	1.43	1.50	1.51	1.34	1.42	1.41	2.28	303.62	261.53	157.26	75.19
1962	44.00	6.61	1.54	1.63	1.45	1.42	1.41	2.05	20.87	29.41	145.87	53.24
1963	7.51	1.50	1.51	1.51	1.38	1.42	1.37	2.13	67.58	76.01	34.38	17.02
1964	2.65	2.50	1.05	1.51	0.39	0.64	7.03	7.02	3.44	5.01	6.11	4.17
1965	4.02	1.44	1.51	1.51	1.34	1.42	1.37	1.98	18.67	31.30	30.21	9.66
1966	6.17	1.28	0.99	0.99	0.94	1.66	8.50	14.37	147.37	96.36	33.20	20.87
1967	7.65	1.49	1.51	1.51	1.38	1.42	1.37	31.79	38.60	38.05	47.54	16.34
1968	34.15	4.30	0.49	1.51	0.85	0.41	0.63	0.73	0.84	2.13	3.90	3.73
1969	6.66	1.98	1.50	1.51	1.34	1.42	1.28	6.19	34.53	48.84	50.45	18.81
1970	8.32	1.43	1.50	1.51	1.34	1.44	1.38	2.13	13.13	57.57	73.56	13.83
1971	0.79	0.20	0.00	1.59	0.60	0.14	0.27	1.10	5.93	9.49	7.82	5.49
1972	1.10	0.46	0.49	1.51	0.85	4.43	3.07	0.29	0.81	28.66	33.05	21.52
1973	8.41	1.43	1.68	1.69	2.50	2.79	1.50	6.25	57.99	58.26	302.36	183.52
1974	14.26	2.36	1.50	1.75	1.64	1.49	1.39	82.65	87.93	28.82	39.75	13.38
1975	10.24	1.84	2.47	6.72	7.48	2.13	7.33	8.96	121.84	152.73	44.84	16.94
1976	6.36	34.74	25.58	1.75	1.37	1.46	4.85	170.51	211.26	168.30	136.12	41.31
1977	13.04	0.46	2.03	3.64	0.85	0.41	0.37	0.29	0.82	1.93	17.41	23.90
1978	7.63	1.43	1.54	1.55	1.34	1.42	1.37	1.63	48.09	45.96	27.62	8.80
1979	3.14	0.46	0.49	1.51	0.82	0.00	0.06	1.69	15.52	13.42	22.55	15.59
1980	4.59	26.09	13.40	82.01	39.58	3.24	3.12	1.14	17.06	40.61	82.37	84.19
1981	12.37	1.51	1.51	1.52	1.34	1.42	9.62	11.32	21.65	28.42	27.82	4.44
1982	7.55	3.46	1.00	0.99	0.88	1.00	0.96	80.90	138.90	90.57	37.86	26.06
1983	12.02	1.43	1.50	1.51	1.38	4.40	2.92	85.15	69.05	39.96	28.37	65.58
1984	52.25	5.61	1.72	18.02	17.98	5.17	4.53	10.53	56.94	78.10	77.40	28.00
1985	7.00	1.63	17.52	11.28	1.34	1.42	1.44	1.38	117.28	124.25	72.21	40.99
1986	5.86	1.43	1.50	1.51	1.34	1.42	25.60	35.02	36.77	45.53	44.77	38.14
1987	16.34	1.43	1.50	1.51	1.38	4.27	18.07	14.06	26.15	28.13	33.07	23.67
1988	5.81	1.43	1.62	1.63	1.37	2.00	26.62	22.89	26.42	38.18	65.35	60.77
1989	18.94	2.12	1.50	1.51	1.48	1.56	96.88	110.53	48.43	152.03	60.89	11.21
1990	4.39	1.69	1.76	2.03	1.88	1.65	1.82	3.02	70.95	185.33	74.66	70.69
Median	10.11	2.93	1.50	1.51	1.34	1.42	2.84	6.19	37.99	51.82	47.54	22.18
Average	12.78	4.60	3.05	3.36	2.46	1.93	6.76	21.53	70.93	74.74	60.51	31.94

<2.0

02.0-5.0

5.0-20.0

>20.0

iv. Estimated occurrence and duration of different abiotic states under Scenario 2

The occurrence and duration of the different Abiotic States for Scenario 2 are illustrated in the simulated monthly river flow table (Table 11).

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under the Reference Condition, median (50%ile) monthly flows are displayed in Figure 6. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

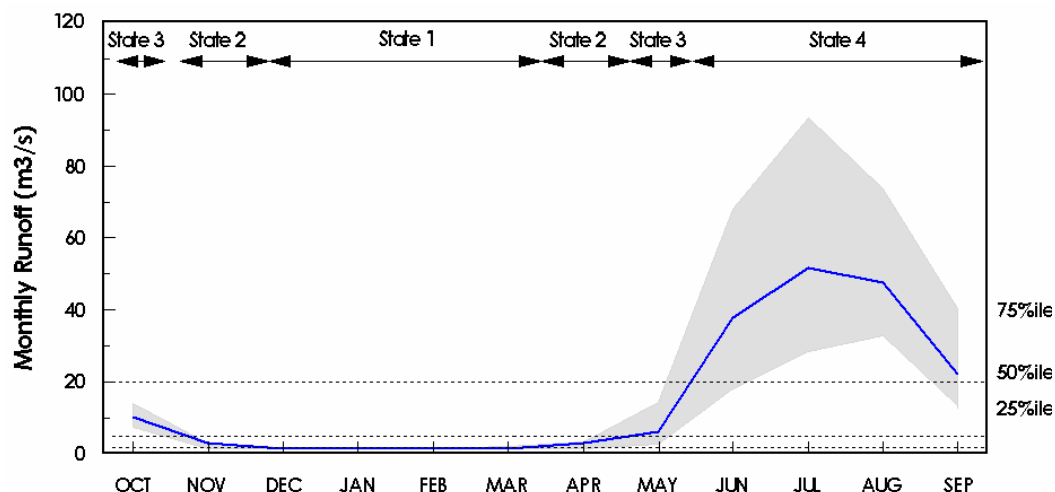


Figure 6: Predicted distribution of Abiotic States under Scenario 2 on for the Olifants Estuary, based on median monthly flows (blue line). The 75%ile and the 25%ile (shaded area) are used to illustrate variability in monthly flows

v. Predicted change in biotic characteristics under Scenario 2

MICROALGAE

There will be a change of species dominance and some change in species composition as a result of the higher mineral status of the water column. It is possible that there will be a 100% change in species composition to match the higher mineral status. The primary driver is flow rate and the consequent development of an REI. Biomass amplitude will also increase, especially in winter as a result of agricultural mineral inputs and the lower river flow. The microphytobenthos also likely change a little.

Confidence: Medium (based on our limited data set).

MACROPHYTES

Species diversity, richness and rarity: There has been an increase in colonization of the upper reaches of the estuary by macroalgae. These plants grow rapidly in response to increased nutrient inputs from agricultural activities which are still present for this scenario. Invasive plants would still occur in the riparian zone in disturbed areas. Aquatic waterweeds such as *Azolla filiculoids* will occur in the upper reaches but may not be as abundant as for present conditions because of the increase in flow and decrease in water residence time. State 1 with residence time of greater than 4 weeks occurs for 3 months of the year compared to 6 months for the Present State.

Biomass distribution: Nutrient enrichment will increase the biomass and aerial distribution of *Potamogeton pectinatus* and the macroalgae.

The environmental flow releases in the river will result in less saline intrusion. However State 1 will still occur for 3 months of the year and not 6 as is the current situation. There will be a reduction in the brackish reeds and sedges but the environmental releases could result in the reeds growing into the areas where they previously existed i.e. where salinity is less than 20 ppt for three months of the year. A more continuous fringe of reeds will form in the middle reaches. There has

MACROPHYTES

been an increase in salinity from the reference condition but it is an improvement from the present state. There will be a small decrease in the distribution and growth of salt marsh plants as a result of the increase in water column salinity that will influence groundwater salinity.

Seasonal variability and community composition: Because of the harsh environment a single salt marsh species *Sarcocornia pillansii* is dominant in the supratidal and floodplain areas. No change is expected in the composition of this community. Macroalgae were probably always present in the Olifants Estuary, however nuisance bloom forming species have become more abundant as a result of nutrient enrichment. These could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches. There was however no indication of this during the field survey.

Confidence: High

INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macro crustaceans)

Zooplankton

Biomass: Average annual biomass is likely to have been higher under Scenario 2 compared to the Reference Condition. This is because of high river dominance and very low salinity values over much of the estuary under the Reference Condition. Under Scenario 2, salinity only increased in the lower estuary during the dry season (5 – 6 months), and during this time zooplankton biomass would have increased, probably to relatively high levels.

Species richness: The number of species present in the estuary would have been similar compared to the Present State – some marine species may only have penetrated the estuary on a flood tide during the dry season. Marine associated species would have been absent for most of the year because of stronger river dominance. The estuarine copepod *Acartia longipatella* would also appear in very low numbers for brief periods when salinity values increased above about 20 ppt.

Seasonal variability: Biomass and species are likely to have changed significantly between seasons under the Reference Condition. This is in contrast to Scenario 2 where variations, although present, are less dramatic. In addition, large spatial shifts would have occurred between seasons because of changes in river low patterns.

Benthic invertebrates (Hyperbenthos)

As described for the zooplankton.

Macrocrustaceans (Benthos)

Biomass: Because of the presence of submerged macrophytes in the upper estuary under Scenario 2, the biomass of benthic organisms would have been higher (additional habitat developed) in these reaches compared to the Reference Condition. Only hardy species would have survived. Species such as *Callinasa kraussi* (sand dwelling in the lower reaches) and *Upogebia africana* (mud dwelling further upstream) would also benefit from higher salinity values that extended a little further upstream compared to Reference Conditions.

Species richness: The number of species present in the estuary would have been slightly higher compared to the Reference Condition. Marine associated species would also be absent for most of the year, although most probably penetrated the mouth area for brief periods during the dry season.

Seasonal variability: Biomass and species are likely to have changed between seasons to different degrees along the estuary because of changes in river dominance. In the lower estuary, changes were probably higher between seasons under Scenario 2 compared to the middle-upper estuary where salinity values remained low throughout the year. Similarly, the variation in salinity between high and low tide would also have influenced variability in the lower estuary.

Confidence: Medium

FISH

Biomass: Scenario 2 is similar to the Present State but includes the Ecological Flow Requirement releases of the River. As with the Present State, the system is progressing from a low diversity high biomass freshwater dominated system towards a high biomass medium diversity marine dominated system. Category Ia estuarine species (*G. aestuaria*) and IIc (*L. richardsonii*) species that occur in equal abundance in the marine & estuarine environments, contribute 47 % and 48 % to abundance respectively. This is slightly different from Present State where IIc species (*L. richardsonii*) dominate numerically. However, as with the Present State, *L. richardsonii* still contribute > 80% of the biomass. Similarly to the Present State, estuarine (*G. aestuaria*), facultative catadromous (*M. cephalus*) and freshwater species (*B. serra*) contribute much less (42%) to overall biomass than they did under reference conditions (65 %). Overall abundance (and biomass) under Scenario 2 is 115 % of that under reference conditions.

Species richness: With the exception of the indigenous freshwater species, species composition under Scenario 2 is likely to be similar to that under Reference Conditions and Present State. The endemic freshwater fish assemblage (e.g. *B. serra*) has mostly been replaced by introduced species such as bluegill (*L. macrochirus*) and smallmouth bass (*M. dolomieu*).

FISH

Consequently, the freshwater component has undergone a greater change than that purely influenced by a reduction in flow. Gillnet fishing effort is likely to remain the same under all the scenarios and will continue to have a major impact on the abundance and occurrence of large bodied estuarine dependent species such as white steenbras (*L. lithognathus*) and white stumpnose (*Rhabdosargus globiceps*). Overall, although species richness remains fairly stable under Scenario 2, the fish assemblage has, similar to the Present State, undergone a drastic change with an order of magnitude change in the frequency of occurrence of some species. Overall, in terms of % composition of the fish assemblage there is a 5 % difference between Scenario 2 and the Present State as opposed to a 20-30 % difference between the latter and reference conditions.

Seasonal variability: Under Scenario 2, the fish assemblage will remain strongly seasonal with the most species and highest catches in the gillnet fishery occurring during autumn and spring / early summer. Juvenile recruits will occur in both the summer and winter but with a peak in spring and early summer (September – December). There may be a slight increase in the “recruitment window” as flows, ultimately cues reaching the marine environment, remain incrementally higher during spring and early summer. Total catch and effort in the gillnet fishery is likely to be similar to the Present State but with a slight decrease in winter effort as slightly higher median flows make fishing a bit more difficult. Given that there is a strong negative correlation between effort and cpue and less fishers sharing the available fish during the winter months, the few fishers who do fish during these higher flow conditions, may actually experience an increase in cpue.

The upstream shift in distribution of estuarine, estuarine dependent and marine species during the low flow summer months may persist for a slightly shorter period than Present State. However, if low oxygen plugs of water in the middle reaches are a feature of the estuary, higher flows may delay their formation until late summer, thereby allowing more fish to find their way upstream than under Present State. However, as with the Present State, the bulk of the fish assemblage are likely to remain 4-12 km from the mouth throughout the year. Upwelling will remain the same and most fish will be confined above the intrusion of 5-10 °C cooler marine water.

Confidence: Low

BIRDS

Biomass: In Scenario 2, freshwater releases increase base flows, so restoring the flow patterns towards the reference state. However, nutrient inputs would not be diminished. Thus the estuary would more productive than in the reference state, but not as productive as at present, because of the shorter retention times. This has implications all the way up the food chain, with increased microphyte and invertebrate production, except that fish are still less abundant than in the reference state due to fishing pressure (about the same as in the present state). The intertidal area remains slightly smaller in the upper estuary (10% less than reference state) and is larger in the lower estuary (20% more than reference state, same as at present). However, there would be less freshwater habitat in the estuary than in the reference condition (but more than at present), due to lower base flows in summer than under Reference Conditions. Freshwater habitat would be more productive though.

Invertebrate feeders (such as the waders) are expected to be more abundant than in the reference condition due to more habitat and higher densities of invertebrates in the estuary. However, since the changes are smallest in the lower estuary, where most birds occur, it is unlikely that there has been a major change.

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) may decrease due to the reduction in availability of fish. Their composition would be different, since some species have only colonised the estuary relatively recently.

Waterfowl may be less abundant than in the reference state due to the smaller freshwater habitat and narrower intertidal in the mid to upper estuary, but would increase relative to the present state. However, the freshwater habitat would be somewhat more productive than the reference state, offsetting this effect to some degree.

Species richness: Apart from the recent colonisers, there is no reason to believe that any other species would be lost or gained.

Seasonal variability: There would not have been any significant changes in seasonal patterns of bird numbers.

Confidence: Medium

vi. EHI scoring for the Scenario 2

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	73	For the Olifants Estuary low flows are defined as flows associated with the State 1: Marine dominated and State 2: Saline penetration into middle reaches (i.e. flows $<5 \text{ m}^3/\text{s}$). Months with median low flows of $<5 \text{ m}^3/\text{s}$ increased from 4 months (Dec – Mar) under the Reference Condition to 6 months (Nov – Apr) under Scenario 2. This translates into a score of 83. Due to the introduction of State 1 (-5) and the loss of variability in flow (-5) under Scenario 2 an additional -10 is allowed.	Low
b. % similarity in mean annual frequency of floods	82	Similar to Present in terms of floods	Medium
Hydrology Score	77		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	The mouth of the Olifants Estuary is permanently open under both the Reference Condition and Present State	High
Hydrodynamics Score	100		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in longitudinal salinity gradient (%) and vertical salinity stratification	70	The low flow periods ($<5 \text{ m}^3/\text{s}$) increased from 4 months (Dec – Mar) under the Reference condition to 6 months (Nov – Apr) under Scenario 2. In addition, flows within the low flow period are reduced. Under the Reference Condition, State 2 ($2\text{--}5 \text{ m}^3/\text{s}$) was dominant limiting saline penetration to the middle reaches (about 15 km from the mouth). Under Scenario 2, State 1 ($<2 \text{ m}^3/\text{s}$) becomes dominant resulting in saline penetration to about 20 km upstream. Because the flows under Scenario 2 are slightly higher compared with the Present State, the saline penetration is somewhat less than under the Present State. The estuary remains freshwater dominated (State 4) for 4 months during the high flow period (Jun – Sep), thus no marked change is expected in terms of salinity distributions. The above translates into a moderately modified salinity gradient.	Medium
2a. Nitrate (DIN)/phosphate (DRP) concentration in the estuary	55	During the high flow period (Jun – Sep), the estuary will remain freshwater dominated (State 4) under Scenario 2 – as for the Reference Condition. However, the DIN concentrations introduced via river inflow are markedly higher as a result of agricultural activities in the catchment and along the banks of the upper estuary. To reflect modifications during this period assume a 20% change from the Reference Condition. The low flow period ($<5 \text{ m}^3/\text{s}$) will increase from 4 months (Dec – Mar) under the Reference condition to 6 months (Nov – Apr) under Scenario 2. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 2, with the following results: In the upper reaches although DIN/DRP introduced through river inflow are less in terms of total load under Scenario 2 (State 1), the actual concentration in river inflow are higher compared with the Reference Condition. In the middle reaches under Scenario 2 DIN concentrations will become near depleted, while DRP concentrations will tend to accumulate (State 1). Under the Reference Condition DIN and DRP concentrations followed a near linear gradient between the two endpoints (State 2). To reflect modifications during the low flow period assume an additional 25% change from the Reference Condition (slightly less than for the Present State - low flow conditions persist for a shorter period).	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2b. Suspended solids (turbidity) in the estuary	85	Turbidity in the Olifants Estuary is mainly determined by river inflow (high flows) and wind turbulence (low flow). During high flow period (Jun – Sep), the estuary will remain freshwater dominated (State 4) under Scenario 1 – as for the Reference Condition. It is therefore assumed that during this period changes in turbidity levels will be insignificant. The low flow period ($<5 \text{ m}^3/\text{s}$) will increase from 4 months (Dec – Mar) under the Reference Condition to 6 months (Nov – Apr) under Scenario 2. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 2. As a result it is expected that turbidity levels in the upper, but in particular the middle reaches of the estuary, will be reduced - not only as a result of less turbidity being introduced via river inflow, but also 'clear' seawater penetrating further upstream. To reflect modifications during the low flow period assume a 15% change from the Reference Condition (slightly less than for Present State - low flow conditions persist for shorter period).	Low
2c. Dissolved oxygen (DO) in the estuary	85	During high flow months (Jun – Sep), the estuary remains freshwater dominated (State 4) – as under the Reference Condition] and are well-oxygenated. Low flow periods ($<5 \text{ m}^3/\text{s}$) will increase from 4 months (Dec – Mar) under the Reference condition to 6 months (Nov – Apr) under Scenario 2. In addition, flows within the low flow period will be reduced. These significant reductions shifted the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 2. Although it is expected that DO concentrations in bottom waters ($> 3 \text{ m}$) already become lower ($\sim 4 \text{ mg}/\ell$) under State 2, this is aggravated by longer residence time under State 1 ($< 3 \text{ mg}/\ell$). Taking into account that the volume below 3m is quite small, assume a 15% change from the Reference Condition. (slightly less than for Present State - low flow conditions persist for shorter period).	Medium
2d. Levels of toxins	80	As the estuary is not located in close proximity to major industrial areas, trace metals and petroleum hydrocarbons are not considered a major issue. However, the Olifants River catchment is extensively used for agriculture and toxic substances such as herbicides and pesticides may be of concern. Assume a 20% change from the Reference Condition.	Low
Water Quality Score	61		

Physical habitat alteration

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Resemblance of <u>intertidal sediment</u> structure and distribution to Reference Condition			
1a % similarity in intertidal area exposed	70	Similar to Present State	Medium
1b % similarity in sand fraction relative to total sand and mud	90	Similar to Present State	Low
2. Resemblance of <u>sub-tidal sediment</u> structure and distribution to Reference Condition			
2 Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	75	Similar to Present State	Medium
Physical Habitat Score	77.5		

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Phytoplankton			
1. Species richness	100	There will be a change in species but it is unlikely that this change will be in the number of taxa. Species changes can be expected but these are natural. Evidence from data in estuaries around RSA show no special change in species richness between estuaries even though they have very different physico-chemical characteristics.	High
2a. Abundance	80	There will be an increase in biomass as a result of reduced flow towards the optimum for the REI in the Olifants Estuary ($1.87 \text{ m}^3/\text{s}$) and the increased DIN & DRP resulting from agricultural activities.	Medium
2b. Community composition	80	The dominant and sub-dominant diatom species will change, especially those in winter high flow conditions.	High

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
<i>Benthic microalgae</i>			
1. Species richness	100	There will be a change in species but it is unlikely that this change will be in the number of taxa. Evidence to data from estuaries around RSA shows no special change in species richness between estuaries even though they have very different physico-chemical characteristics.	High
2a. Abundance	80	There will be an increase in biomass as a result of the increased DIN & DRP resulting from agricultural activities. This change is unlikely to be as great as for phytoplankton.	High
2b. Community composition	80	The dominant and sub-dominant species will change, especially those in winter high flow conditions.	High
Microalgae Score	80		

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	80 (90 %)	There has been an increase in colonization of the upper reaches of the estuary by macroalgae as a result of nutrient enrichment from agricultural activities and decreased flow due to water abstraction. Residence time in upper reaches has increased from 1-4 weeks (State 2) to greater than 4 weeks (State 1). State 1 will persist for 3 months. Invasive plants have colonized the riparian zone in some disturbed areas and displaced the indigenous species. 90 % of the original species remain.	High
2a. Abundance	70	Nutrient enrichment and a reduction in flow and flushing of macrophytes have increased the biomass and aerial distribution of Potamogeton pectinatus and the macroalgae (-10). State 1 occurs for 3 months of the year and salinity greater than 20 ppt will occur at 10 km upstream but only for 1 month. This will have little effect on the reeds and the only loss will be that for reference conditions i.e. reeds from 6.5 km compared to present distribution from 8.5 km upstream of the mouth. This represents a 2 km loss (7%). The environmental flow release is beneficial for the reeds (-5.) An increase in salinity will decrease the distribution and growth of salt marsh plants. The supratidal and floodplain plants utilise the saline groundwater during the dry 8 months of the year. An increase in water column salinity has probably increased groundwater salinity leading to a loss of salt marsh cover. Because of the environmental flow releases the loss of salt marsh is lower than that for the Present State (-10) There has been a small (5%) loss in the area covered by macrophytes as a result of anthropogenic disturbances (e.g. grazing, agricultural activities, salt pan) (-5).	High
2b. Community composition	85	Nuisance bloom forming macroalgal species have become more abundant. These could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches. The situation is slightly better than the present state because of the environmental flow releases.	High
Macrophyte Score	70		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
<i>Zooplankton</i>			
1. Species richness	100	Overall, species richness over the year is likely to have been the same compared to the present.	Medium
2a. Abundance	80	Abundance levels, on average are likely to have increased on an annual basis (120% of Reference). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 2).	Medium
2b. Community composition	80	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 2).	Medium
<i>Macroinvertebrates - hyperbenthos</i>			
1. Species richness	100	Overall, species richness over the year is likely to have been the same compared to the present.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2a. Abundance	80	Abundance levels, on average are likely to have changed on an annual basis (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 2).	Medium
2b. Community composition	80	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference condition (low flow persists for longer and there is also an increase in the residence time under Scenario 2).	Medium
Macrocrustacea - benthos			
1. Species richness	100	Overall, species richness over the year is likely to have been the same compared to the present.	Medium
2a. Abundance	75	Abundance levels, on average are likely to have changed on an annual basis (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ per sec increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference condition (low flow persists for longer and there is also an increase in the residence time under the present state). Species such as Callinassa kraussi and Upogebia africana (mud dwelling further upstream) benefit because of the larger habitat made available through higher salinity values (breeding requirement).	Medium
2b. Community composition	80	Because of the change in salinity distribution over any year, community composition is also likely to have responded to the change along the gradient. This is because of the REI becoming more stable and median flows of <5 m ³ per sec increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the present state).	Medium
Invertebrates	75		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	52 (74 %)	Scenario 2 will be the same as the Present State. The loss of 4-5 indigenous freshwater species and their replacement by 4 introduced species represents a 26 % loss in species (absolute values). The species richness accorded to the marine, estuarine and estuarine dependent species is likely to have remained unchanged since reference conditions.	Medium
2a. Abundance	68 (21)	Overall 32 % decrease in abundance from reference conditions largely due to the 46 % decrease in category IIc species (L.richardsonii). Category III (marine) species have declined by 50 % whereas Ib (estuarine & marine breeding populations) have increased 50 % but their contribution to overall abundance remains low. In turn, estuarine (G.aestuaria) and obligate estuarine dependent (L.lithognathus) species have undergone a 14 % and 80 % reduction in abundance respectively. Note the score, 68 refers to a 32% decrease in overall abundance whereas 21 refers to a 79 % reduction in category IIa obligate estuarine dependent species. For abundance, the complete loss of endemic freshwater species has been ignored.	Medium
2b. Community composition	50	Similar to Present State, indigenous freshwater species have been replaced by exotics. Category Ia (G.aestuaria) estuarine breeders now 47 % and IIc species (L. richardsonii) now 48 % contribution to overall abundance as opposed to 62 % and 33 % under reference conditions respectively. Likely to be in-year switches between a REI type community to a fish community with a preference for 10-30 ppt. As with the Present State, there has also been a decline in the proportion of piscivorous fish (L.amia & P. saltatrix) and large benthic feeders (L. lithognathus & R. globiceps) but this is likely to be mostly due to the gillnet fishery and the nationwide stock status of these species. Score based on 50/50 dominance of Ia and IIc species as well as complete loss of endemic freshwater species.	Medium
Fish Score	50		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	It is unlikely that there would be a loss in average instantaneous species richness	Medium
2a. Abundance	94	Waterbirds are probably not as abundant in Scenario 2 as at present, although the difference is probably very slight. There would be slightly fewer invertebrate feeders (less food), slightly fewer piscivorous birds (fewer fish) and more waterfowl (more freshwater habitat and greater productivity). The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined in the accompanying report (Turpie 2005).	Medium
2b. Community composition	95	Given the rather slight changes in different trophic groups outlined above, the community composition is not very different in the reference state from the present state. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.	Medium
Bird score	94		

4.2.2 Scenario 7: Raising Clanwilliam Dam (15 m) with EWR Releases

i. Seasonal variability in river inflow

Monthly simulated runoff data for the Scenario 7 is provided in Table 12. The mean annual runoff (MAR) is 741.5 Million m³ for this state. A summary of flow distribution (mean monthly flows in m³/s) for the Scenario 7, derived from the 70-year simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	38.67	28.63	21.90	37.61	24.80	7.37	96.27	174.77	456.58	471.55	205.43	148.18
90%ile	16.94	8.24	7.64	4.04	4.13	4.07	9.92	69.28	127.88	158.65	111.97	51.47
80%ile	12.56	4.35	2.46	2.15	2.01	2.37	4.92	21.44	88.02	81.43	73.72	35.30
70%ile	10.61	3.29	2.08	1.91	1.77	1.96	3.25	10.60	57.48	67.52	57.21	26.31
60%ile	9.40	3.29	1.90	1.91	1.71	1.77	3.18	7.67	41.29	54.98	48.28	22.32
50%ile	9.33	3.29	1.90	1.91	1.71	1.77	2.86	5.48	38.23	51.94	47.57	16.21
40%ile	9.33	2.72	1.90	1.91	1.71	1.77	2.53	3.65	37.67	47.54	44.17	14.00
30%ile	7.22	1.87	1.90	1.88	1.30	1.26	1.76	3.41	26.23	29.53	34.55	12.50
20%ile	5.69	1.79	1.43	1.88	1.15	1.00	1.68	1.62	15.69	21.31	28.53	10.87
10%ile	4.34	1.13	0.98	0.99	0.88	1.00	1.00	1.21	6.44	7.88	15.28	8.11
1%ile	1.29	0.03	0.00	0.99	0.44	0.15	0.17	0.40	0.90	1.54	4.80	4.26

TABLE 12: Monthly simulated runoff data in m³/s (70-year period) under Scenario 7

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	9.33	3.29	2.21	2.25	9.53	11.66	3.00	3.32	455.47	496.51	105.14	23.80
1921	9.33	3.29	9.74	5.16	1.73	1.77	3.18	3.57	39.12	51.94	74.28	50.87
1922	9.33	3.29	1.90	1.91	1.71	1.77	3.18	7.67	98.28	108.28	47.90	13.54
1923	9.33	3.29	1.90	1.91	1.77	1.77	3.18	3.57	38.86	51.90	47.57	14.54
1924	9.71	3.33	1.90	1.88	2.09	1.15	1.97	3.92	459.17	460.86	51.09	10.91
1925	10.98	3.75	1.90	1.91	1.71	1.77	3.18	8.99	38.08	53.47	48.09	10.87
1926	14.82	6.53	1.88	1.67	0.88	1.00	2.57	4.13	15.69	7.20	32.58	12.66
1927	8.65	2.73	1.00	0.99	0.91	1.00	1.68	1.15	40.47	39.33	23.90	10.33
1928	8.61	2.49	0.99	0.99	0.20	0.24	2.77	5.26	38.04	52.50	47.94	24.11
1929	11.50	0.83	0.87	1.41	4.67	1.74	0.00	0.73	1.42	2.57	8.76	34.90
1930	27.94	3.29	1.90	1.95	1.68	1.59	4.92	7.31	21.38	21.31	66.15	35.30
1931	10.27	3.29	1.90	1.91	6.43	4.69	2.86	5.69	38.23	51.94	47.49	13.18
1932	9.33	2.83	1.18	0.99	0.88	1.00	1.72	3.34	41.29	68.36	54.57	12.69
1933	1.84	1.13	0.98	1.91	1.23	4.21	3.00	0.83	2.14	5.30	5.66	9.91
1934	14.81	22.18	13.41	1.91	1.71	1.77	3.33	7.18	37.89	47.54	48.01	26.16
1935	10.36	3.29	1.88	1.88	1.15	1.03	1.76	3.43	12.05	21.17	46.01	32.08
1936	15.65	8.24	7.30	1.11	0.88	1.11	2.33	3.74	42.53	67.52	47.79	10.87
1937	9.33	3.29	7.82	12.60	1.71	1.77	3.09	8.70	33.15	19.76	28.07	14.38
1938	9.36	3.29	1.43	0.99	1.39	1.15	2.04	21.44	36.54	10.71	109.13	80.82
1939	1.55	0.03	0.00	0.99	4.47	1.81	1.51	1.62	6.44	7.88	5.76	5.96
1940	9.36	3.33	1.91	1.81	0.88	1.00	6.81	60.53	127.88	79.44	86.30	139.37
1941	27.87	3.29	1.90	1.91	1.71	1.77	3.63	4.82	168.60	113.37	47.49	10.91
1942	14.67	9.96	6.34	6.13	1.71	1.96	3.18	3.65	38.19	51.98	60.13	30.09
1943	9.33	10.44	7.64	1.91	1.77	2.67	3.18	11.94	59.05	51.79	52.88	25.76
1944	10.02	3.29	1.90	1.91	1.71	1.81	3.18	20.43	93.20	158.65	125.35	20.33
1945	9.33	3.29	1.90	1.91	1.71	1.77	3.33	3.65	37.67	50.31	23.72	50.99
1946	44.55	3.29	1.90	1.88	1.62	1.96	2.53	8.87	22.73	54.00	48.28	10.87
1947	9.33	3.29	1.88	1.45	0.98	5.48	8.51	7.61	31.26	52.02	36.17	16.21
1948	10.11	3.29	1.88	1.88	0.88	1.00	2.49	3.49	16.30	14.18	38.51	12.50
1949	9.40	18.49	7.21	1.88	0.88	1.00	10.08	8.54	12.35	64.80	54.52	22.75
1950	13.34	6.05	2.92	1.88	1.32	1.00	2.35	3.41	57.25	68.21	47.45	13.65
1951	9.36	3.32	1.90	1.91	2.61	2.07	3.18	10.60	37.78	62.11	99.54	35.53
1952	9.33	26.51	20.15	1.91	2.10	2.18	25.99	46.43	37.78	56.91	57.27	22.32
1953	9.33	3.29	2.71	2.47	1.71	2.56	3.70	78.59	81.92	193.31	144.11	54.18
1954	11.46	3.29	1.90	1.91	2.94	2.32	3.48	3.69	43.98	77.41	198.54	85.21
1955	26.69	7.03	2.46	1.95	1.77	2.16	3.25	3.61	40.02	56.30	56.78	21.91
1956	9.33	3.29	1.90	1.91	4.13	3.73	3.18	24.05	88.83	158.65	127.07	46.31
1957	36.16	4.35	2.31	2.32	1.71	1.77	3.18	18.63	39.15	51.49	47.45	10.87
1958	9.33	3.29	1.15	0.99	0.88	1.00	2.61	239.26	210.35	51.49	48.20	14.00
1959	4.48	1.19	0.89	1.88	1.18	0.15	0.24	1.71	10.63	6.41	5.43	4.59
1960	4.11	1.79	2.41	2.43	1.37	3.34	96.50	89.56	66.33	76.34	37.86	19.90
1961	9.88	1.79	1.90	1.88	1.62	1.08	1.17	1.44	295.04	250.91	111.97	62.06
1962	22.28	6.55	1.94	2.03	1.82	1.77	1.71	1.48	20.95	29.53	118.42	51.47
1963	5.69	1.86	1.91	1.91	1.77	1.77	1.68	1.55	67.66	76.12	34.55	15.47
1964	2.96	2.86	1.45	1.91	1.23	1.26	7.34	7.13	2.30	4.27	5.11	4.42
1965	4.34	1.81	1.91	1.91	1.71	1.77	1.68	1.29	18.67	31.42	30.37	8.11
1966	4.80	0.99	0.99	0.99	0.94	1.66	8.50	13.66	124.65	96.43	31.52	10.34
1967	5.83	1.85	1.90	1.91	1.77	1.77	1.68	31.21	38.69	29.16	32.28	10.50
1968	16.94	4.66	0.89	1.91	1.23	0.77	0.93	0.84	0.92	1.54	4.06	3.98
1969	6.38	2.34	1.90	1.91	1.71	1.71	1.27	5.48	34.61	48.96	50.62	17.26
1970	6.74	1.79	1.88	1.88	1.30	1.02	1.00	1.26	11.71	57.69	73.72	11.55
1971	0.98	0.03	0.00	1.59	0.60	0.14	0.27	1.21	4.62	8.77	6.87	5.74
1972	1.42	0.83	0.87	1.88	0.54	4.07	2.69	0.40	0.89	27.06	32.05	12.87
1973	6.56	1.79	2.08	2.07	2.78	2.37	1.13	5.54	57.48	58.38	221.49	168.74
1974	12.44	2.72	1.90	2.15	2.01	1.84	1.69	79.16	88.02	28.94	39.91	11.84
1975	8.45	2.20	2.87	7.12	7.87	2.55	5.48	8.38	90.40	135.15	43.72	15.13
1976	4.90	33.59	25.98	2.15	1.75	1.81	5.15	147.14	211.24	167.93	135.43	39.54
1977	10.61	0.83	2.43	4.04	1.23	0.77	0.68	0.40	0.91	1.54	15.28	15.48
1978	5.26	1.79	1.94	1.95	1.71	1.77	1.68	1.75	46.89	46.08	27.96	9.05
1979	3.46	0.83	0.89	1.91	1.27	0.77	0.68	1.81	14.25	12.70	21.55	15.84
1980	4.90	26.45	13.80	82.41	39.86	3.53	2.75	1.14	9.73	40.73	70.09	67.36
1981	10.68	1.87	1.90	1.91	1.71	1.77	9.92	10.88	21.74	28.54	27.43	4.38
1982	7.87	3.22	1.00	0.99	0.88	1.00	0.96	80.33	138.39	81.43	38.02	18.09
1983	12.27	1.79	1.90	1.91	1.77	4.68	2.73	69.28	69.13	27.38	28.53	30.17
1984	27.85	5.98	2.12	18.42	18.35	5.53	4.83	8.21	46.43	54.98	72.81	26.31
1985	7.22	2.00	17.92	11.68	1.71	1.77	1.74	1.49	117.37	123.53	57.21	25.26
1986	6.10	1.79	1.90	1.91	1.71	1.77	25.90	34.44	36.85	45.65	44.17	27.38
1987	12.56	1.79	1.90	1.91	1.77	4.62	18.37	14.17	26.23	28.25	33.23	22.12
1988	6.13	1.79	2.02	2.03	1.75	2.35	26.92	23.00	26.50	38.30	64.35	46.07
1989	14.88	2.48	1.90	1.91	1.85	1.92	96.17	108.81	48.51	114.57	44.45	7.96
1990	4.71	2.05	2.16	2.42	2.25	2.00	2.43	3.13	75.66	184.61	74.82	30.92
Median	9.33	3.29	1.90	1.91	1.71	1.77	2.86	5.48	38.23	51.94	47.57	16.21
Average	10.76	4.67	3.40	3.68	2.69	2.09	6.83	20.07	64.28	71.49	56.07	26.92

<2.0
 02.0-5.0
 5.0-20.0
 >20.0

ii. Predicted Flood regime under Scenario 7

With the raising of Clanwilliam Dam by 15 m the major flood peaks will be reduced by about 25% from Reference. Some return period flood peaks are listed below.

Return Period (yrs)	Flood Peak (m ³ /s)
2	325
5	425
10	490

Confidence: Medium

iii. Predicted sediment processes under Scenario 7 compared with Reference Condition

The estuary will have more or less the same bed level as under Reference Conditions. It will however be about 15% narrower.

The sediment loads coming into the estuary will be lower, since the floods and the total effective catchment area are smaller now. However, the total annual catchment sediment yield (6 ton/km² per annum) would have been more or less the same. The sediment in the upper reaches will be slightly coarser than under Reference Condition.

iv. Estimated occurrence and duration of different abiotic states for Scenario 7

The occurrence and duration of the different Abiotic States under Scenario 7 are illustrated in the simulated monthly river flow table (Table 12).

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under the Reference Condition, median (50%ile) monthly flows are displayed in Figure 7. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

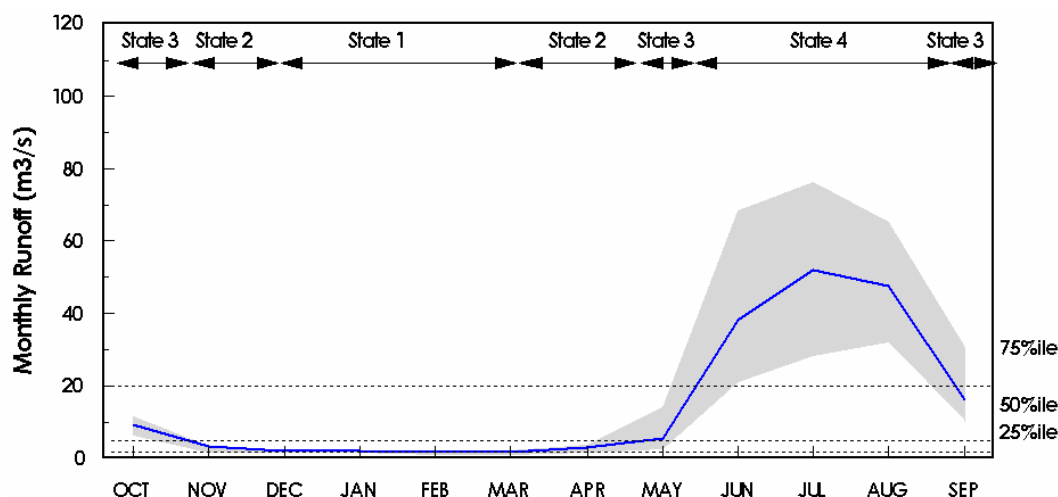


Figure 7: Predicted distribution of Abiotic States under Scenario 7 on for the Olifants Estuary, based on median monthly flows (blue line). The 75%ile and the 25%ile (shaded area) are used to illustrate variability in monthly flows

v. Predicted change in biotic characteristics under Scenario 7

MICROALGAE

Species richness is not expected to change in either the phytoplankton or the benthic microalgae. Abundance will change in the phytoplankton as a result of flow alteration (development of the REI). Abundance in the benthic microalgae will increase as a result of nutrient increases in the water column. This is a deviation from the Reference Condition.

Confidence: Medium

MACROPHYTES

Species diversity, richness and rarity: There has been an increase in colonization of the upper reaches of the estuary by macroalgae. Flood peaks will be reduced by 25% due to the raising of the Clanwilliam dam. These floods would have been important in flushing the macroalgae from the upper reaches of the estuary. They will now grow rapidly in response to reduced flows as well as increased nutrient inputs from agricultural activities which are still present for this scenario. Invasive plants would still occur in the riparian zone in disturbed areas. Aquatic waterweeds such as Azolla filiculoides will occur in the upper reaches.

Biomass distribution: Similar nutrient rich conditions occur compared to the present that will increase the biomass and aerial distribution of Potamogeton pectinatus and the macroalgae. The reduction in floods will also increase the growth and spread of these plants.

This scenario involves raising the Clanwilliam dam by 15 m but includes the environmental flow releases of the river therefore the period of low flow for this scenario is similar to Scenario 2. There is an improvement in the salinity conditions compared to the present state. There is slightly more saline intrusion compared to Scenario 2 (Score of 70 for salinity Scenario 2, Scenario 7 score is 65). The high flow season (State 4) is reduced from 4 months to 3 months. The higher water column salinity will result in less dilution of saline groundwater that will decrease the distribution and biomass of the supratidal and floodplain salt marsh plants.

The environmental flow releases in the river will result in less saline intrusion compared to the present state. However State 1 will still occur for 3 months of the year and not 6 as is the current situation. There will be a reduction in the brackish reeds and sedges but they will grow into the areas where salinity is less than 20 ppt for three months of the year. A more continuous fringe of reeds will form in the middle reaches of the estuary. There has been an increase in salinity from the Reference Condition but it is an improvement from the Present State.

Seasonal variability and community composition: Because of the harsh environment a single salt marsh species Sarcocornia pillansii is dominant in the supratidal and floodplain areas. No change is expected in the composition of this community. Macroalgae were probably always present in the Olifants Estuary, however nuisance bloom forming species have become more abundant as a result of nutrient enrichment and a reduction in flood peaks. These could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches. There was however no indication of this during the field survey.

Confidence: High

INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macro crustaceans)

This scenario from the perspective of the invertebrates is very similar to Scenario 2, with some small differences. On average, low flows at the 50%ile ($<5 \text{ m}^3/\text{s}$) are similar for the same category under Scenario 2. The low flow period ($<5 \text{ m}^3/\text{s}$) persists for about 6 months and is similar to Scenario 2. Higher flows at the same percentile do not follow a consistent pattern. However the variation up or down is of relatively short duration and unlikely to alter the overall pattern described for the invertebrates. Thus, the main change is likely to be small-scale shifts in spatial patterns with some populations (mainly the zooplankton) moving up or down-stream. Although small changes in salinity are likely to occur, the euryhaline nature of the fauna will accommodate these changes. A physical change to the cross section of the estuary will occur because of flood reduction – this is covered in the sections below.

Zooplankton

Biomass: Average annual biomass is likely to have been higher under Scenario 7 compared to the Reference Condition. This is because of high river dominance and very low salinity values over much of the estuary under the Reference Condition. Under Scenario 7, salinity only increased in the lower estuary during the dry season (4 months), and during this time zooplankton biomass would have increased, probably to relatively high levels. Because the estuary becomes slightly narrower (reduction in large floods that scour channels), overall biomass decreases by about 20%.

Species richness: The number of species present in the estuary would have been similar compared to the Present State – some marine species may only have penetrated the estuary on a flood tide during the dry season. Marine associated species would have been absent for most of the year because of stronger river dominance. The estuarine copepod *Acartia longipatella* would also appear in very low numbers for brief periods when salinity values increased above about 20ppt.

Seasonal variability: Biomass and species are likely to have changed significantly between seasons under the Reference Condition. This is in contrast to Scenario 7 where variations, although present, are less dramatic. In addition, large spatial shifts would have occurred between seasons.

Benthic invertebrates (Hyperbenthos)

As described for the zooplankton.

Macro crustaceans (Benthos)

Biomass: Because of the greater biomass of submerged macrophytes in the upper estuary under Scenario 7, the biomass of benthic organisms would have been higher (additional habitat developed) in these reaches compared to the Reference Condition. Only hardy species would have survived. Species such as *Callinasa kraussi* (sand dwelling in the lower reaches) and *Upogebia africana* (mud dwelling in the higher reaches) would also benefit from higher salinity values that extended a little further upstream compared to Reference Conditions. It is likely that intertidal banks will become more pronounced under Scenario 7, resulting in less subtidal habitat but more intertidal habitat by about 20% (see reference to sediments).

Species richness: The number of species present in the estuary would have been slightly higher compared to the Reference Condition. Marine associated species would also be absent for most of the year, although most probably penetrated the mouth area for brief periods during the dry season.

Seasonal variability: Under Scenario 7, seasonal variability would be less compared to the Reference Condition because of more persistent salinity values up the estuary. However variability will be also different along the length of the estuary. In the lower and middle reaches, changes will probably be less between seasons (more stable salinity values) compared to the upper estuary that has greater river dominance.

Confidence: Medium

FISH

Biomass distribution: Scenario 7 entails raising the Clanwilliam Dam by 15 m plus the Ecological Flow Requirement releases of the river. However, fish distribution and abundance is similar to the Present State and almost identical to Scenario 2. As with the Present State, the system is progressing from a low diversity high biomass freshwater dominated system towards a high biomass medium diversity marine dominated system. Category Ia estuarine species (*G. aestuaria*) and IIc (*L. richardsonii*) species that occur in equal abundance in the marine & estuarine environments, contribute 47 % and 48 % to abundance respectively. This is slightly different from Present State where IIc species (*L. richardsonii*) dominate numerically. However, as with the Present State, *L. richardsonii* still contribute > 80% of the biomass. Similarly to the Present State, estuarine (*G. aestuaria*), facultative catadromous (*M. cephalus*) and freshwater species (*B. serra*) contribute much less (48 %) to overall abundance than they did under Reference Conditions (65 %). Overall abundance (and biomass) under Scenario 2 is 116 % of that under Reference Conditions. Obligate estuarine dependent species (e.g. *L. lithognathus*) have improved from Present State and a 50 % decline from reference conditions to a 34 % decline under Scenario 7. This is likely due to an increase in area and persistence of their preferred estuarine 10-20 ppt salinity zone.

Species richness: With the exception of the indigenous freshwater species, species composition under Scenario 7 is likely to

FISH

be similar to that under Reference Conditions and Present State. The endemic freshwater fish assemblage (e.g. *Barbus serra*) has mostly been replaced by introduced species such as bluegill (*L. macrochirus*) and smallmouth bass (*M. dolomieu*). Consequently, the freshwater component has undergone a greater change than that purely influenced by a reduction in flow. In turn, the introduced species are likely to be far more tolerant of poor water quality conditions in the upper reaches of the estuary. Gillnet fishing effort is likely to remain the same under all the scenarios and will continue to have a major impact on the abundance and occurrence of large bodied estuarine dependent species such as white steenbras (*L. lithognathus*) and white stumpnose (*Rhabdosargus globiceps*). Overall, although species richness remains fairly stable under Scenario 7, the fish assemblage has, similar to the Present State, undergone a drastic change with an order of magnitude change in the frequency of occurrence of some species. Overall, in terms of % composition of the fish assemblage there is a 5 % difference between Scenario 7 and the Present State as opposed to a 20-30 % difference between the latter and Reference Conditions.

Seasonal variability: Under Scenario 7, the fish assemblage will remain strongly seasonal with the most species and highest catches in the gillnet fishery occurring during autumn and spring / early summer. Juvenile recruits will occur in both the summer and winter but with a peak in spring and early summer (September – December). Compared to Present State, there may be a slight increase in the “recruitment window” as flows, ultimately cues reaching the marine environment, remain incrementally higher during spring and early summer. Total catch and effort in the gillnet fishery is likely to be similar to the Present State but with a slight decrease in winter effort as slightly higher median flows make fishing a bit more difficult. Given that there is a strong negative correlation between effort and cpue and less fishers sharing the available fish during the winter months, the few fishers who do fish during these higher flow conditions, may actually experience an increase in cpue. In turn, the onset of lower flows earlier in spring (September) may see a slight increase in effort and overall catch at this time.

The upstream shift in distribution of estuarine, estuarine dependent and marine species during the low flow summer months may persist for a slightly shorter period than Present State. However, if low oxygen plugs of water in the middle reaches are a feature of the estuary, higher flows may delay their formation until late summer, thereby allowing more fish to find their way upstream than under Present State. However, as with the Present State, the bulk of the fish assemblage are likely to remain 4-12 km from the mouth throughout the year. Upwelling will remain the same and most fish will be confined above the intrusion of 5-10 °C cooler marine water.

Confidence: Low

BIRDS

Biomass: In Scenario 7, freshwater releases increase base flows towards reference condition as for the previous scenario, but the raising of the dam wall reduces floods, i.e. moving further away from reference condition than at present. The change in base flows has more of an impact than the change in flooding. Thus changes are similar to the previous scenario, but there are gains in intertidal area (due to lack of flushing) relative to present. Waterweed is similar to the present state, but saltmarsh area is greater than at present, but not as large as in the Reference Conditions. Nutrient inputs are still high, and dissolved nitrogen is higher than in the previous scenario. Thus the estuary would more productive than in the reference state and present state, and than in Scenario 2. This has implications all the way up the food chain, with increased invertebrate production, and fish are similar in abundance to the Present State and Scenario 2. The intertidal area remains slightly smaller in the upper estuary (10% less than reference state) and is larger in the lower estuary (25% more than reference state). There would be less freshwater habitat in the estuary than in the reference condition (but more than at present), due to lower base flows in summer than under Reference Conditions. Freshwater habitat would be more productive than in previous scenarios.

Invertebrate feeders (such as the waders) are expected to be more abundant than in the reference condition due to more habitat and higher densities of invertebrates in the estuary. However, since the changes in food are smallest in the lower estuary, where most birds occur, it is unlikely that there has been a major change.

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) may decrease due to the reduction in availability of fish. Their composition would be different, since some species have only colonised the estuary relatively recently.

Waterfowl may be less abundant than in the reference state due to the smaller freshwater habitat and smaller intertidal in the mid to upper estuary, but would increase relative to the present state. However, the freshwater habitat would be somewhat more productive than the Reference Condition, offsetting this effect to some degree.

Species richness: Apart from the recent colonisers, there is no reason to believe that any other species would be lost or gained.

Seasonal variability: There would not have been any significant changes in seasonal patterns of bird numbers.

Confidence: Medium

vi. EHI scoring for the Scenario 7

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	73	For the Olifants Estuary low flows are defined as flows associated with the State 1: Marine dominated and State 2: Saline penetration into middle reaches (i.e. flows $<5 \text{ m}^3/\text{s}$). Months with median low flows of $<5 \text{ m}^3/\text{s}$ increased from 4 months (Dec – Mar) under the Reference Condition to 6 months (Nov – Apr) under Scenario 7. This translates into a score of 83. Due to the introduction of State 1 (-5) and the loss of variability in flow (-5) under Scenario 7 an additional -10 is allowed.	Low
b. % similarity in mean annual frequency of floods	75	The raising of Clanwilliam Dam by 15 m will increase the effect that the dams on the Olifants River have on the major floods. Flood peaks will be about 25% lower than under Reference Condition.	Medium
Hydrology Score	74		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	The mouth of the Olifants Estuary is permanently open under both the Reference Condition and Present State	High
Hydrodynamics	100		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in longitudinal salinity gradient (%) and vertical salinity stratification	65	The lower flow period ($<5 \text{ m}^3/\text{s}$) will increase from 4 months (Dec – Mar) under the Reference Condition to 6 months (Nov – Apr) under Scenario 7. In addition, flows within the lower flow period will be reduced. Under the Reference Condition, State 2 ($2\text{-}5 \text{ m}^3/\text{s}$) was dominant limiting saline penetration to the middle reaches (about 15 km from the mouth). Under Scenario 2, State 1 ($<2 \text{ m}^3/\text{s}$) will become dominant resulting in saline penetration to about 20 km upstream. Because the flows under Scenario 7 will be slightly higher compared with the Present State, the saline penetration is somewhat less. During the high flow period the estuary will be freshwater dominated (State 4) for 3 months (Jun – Aug) under Scenario 7 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. This implies that the estuary becomes slightly more saline during this period. The above translates into a moderately modified salinity gradient.	Medium

2a. Nitrate (DIN)/phosphate (DRP) concentration in the estuary	50	During the high flow period the estuary will be freshwater dominated (State 4) for 3 months (Jun – Aug) under Scenario 7 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. State 3 will become the dominant state during this period. However, during both States 3 and 4 nutrient concentrations (in particular DIN) introduced via river inflow will remain markedly higher than for the Reference Condition as a result of agricultural activities in the catchment and along the banks of the upper estuary. To reflect modifications during this period assume a 20% change from the Reference Condition (similar to the Present State). The low flow period (<5 m³/s) will increase from 4 months (Dec – Mar) under the Reference Condition to 6 months (Nov – Apr) under Scenario 7. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 7, with the following results: In the upper reaches although DIN/DRP introduced through river inflow are less in terms of total load under Scenario 7 (State 1), the actual concentration in river inflow are higher compared with the Reference Condition. As return flows will probably make up a large proportion of the low flows under Scenario 7, the increase can be expected to be larger than under the Present State. In the middle reaches under Scenario 7 DIN concentrations will become near depleted, while DRP concentrations will tend to accumulate (State 1). Under the Reference Condition DIN and DRP concentrations followed a near linear gradient between the two endpoints (State 2). To reflect modifications during the low flow period assume an additional 30% change from the Reference Condition (similar to Scenario 2, but with higher concentrations in inflow).	Medium
2b. Suspended solids (turbidity) in the estuary	85	Turbidity in the Olifants Estuary is mainly determined by river inflow (high flows and wind turbulence (low flows). During the high flow period the estuary is freshwater dominated (State 4) for 3 months (Jun – Aug) under Scenario 7 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. However, flows in Sep are still relatively high (State 3), also characterised by high turbidity. It is therefore assumed that during this period changes in turbidity levels will be insignificant compared with the Reference Condition. The low flow periods (<5 m³/s) will increase from 4 months (Dec – Mar) under the Reference condition to 6 months (Nov – Apr) under Scenario 7. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 7. As a result it is expected that turbidity levels in the upper, but in particular the middle reaches of the estuary, will be reduced - not only as a result of less turbidity being introduced via river inflow, but also 'clear' seawater penetrating further upstream. To reflect modifications during the low flow period assume a 15% change from the Reference Condition (similar to Scenario 2).	Low
2c. Dissolved oxygen (DO) in the estuary	85	During the high flow period the estuary will be freshwater dominated (State 4) for 3 months (Jun – Aug) under Scenario 7 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. However, flows in Sep will still be relatively high (State 3), also characterised by well-oxygenated conditions. It is therefore assumed that changes in DO levels, compared to the Reference Condition, will be insignificant, i.e. remain well-oxygenated. The low flow period (<5 m³/s) will increase from 4 months (Dec – Mar) under the Reference condition to 6 months (Nov – Apr) under Scenario 7. In addition, flows within the low flow period will be reduced. These significant reductions shifted the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 7. Although it is expected that DO concentrations in bottom waters (> 3 m) already become lower (~4 mg/l) under State 2, this is aggravated by longer residence time under State 1 (< 3 mg/l). To reflect modifications during the low flow period assume a 15% change from the Reference Condition (similar to Scenario 2).	Medium

2d. Levels of toxins	70	As the estuary is not located in close proximity to major industrial areas, trace metals and petroleum hydrocarbons are not considered a major issue. However, the Olifants River catchment is extensively used for agriculture and toxic substances such as herbicides and pesticides may be of concern. With the expected increase in return flow under Scenario 5, inputs of toxic substances could also increase compared to the Present State. Assume a 30% change from the Reference Condition.	Low
Water Quality Score	56		

Physical habitat alteration

VARIABLE		SCORE	MOTIVATION	CONFIDENCE
1. Resemblance of intertidal sediment structure and distribution to Reference Condition				
1a	% similarity in intertidal area exposed	65	The estuary is about 15% narrower under Scenario 7 than under Reference conditions, but only over the upper 15 to 20 km (translates to about 5% in terms of scoring). The low water bridge at Lutzville is thought to reduce the tidal effect to a small degree, and as such reduces the intertidal area (5%). In the lower estuary, especially the blind arm of the river, the intertidal area will probably increase due to siltation in that area, by about 25%.	Medium
1b	% similarity in sand fraction relative to total sand and mud	85	Some of the catchment sediment is trapped by the Clanwilliam and Bulshoek Dams. The floods reaching the estuary will therefore be able to scour more sediment and some of the fine material from the upper reaches will be removed. The removal of fine material will however be limited.	Low
2. Resemblance of sub-tidal sediment structure and distribution to Reference Condition				
2	Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	75	The estuary will be about 15% narrower under Scenario 7 than under Reference Conditions, but only over the upper 15 to 20 km. The bed material contains slightly more coarse material. The depth will be more or less the same as under Reference Condition. The width changes will alter the channel geometry, which would account for a change of about 10% in the subtidal area, while the change in bed material would account for a further 15%.	Medium
Physical Habitat Score		75		

Microalgae

VARIABLE		SCORE	MOTIVATION	CONFIDENCE
Phytoplankton				
1. Species richness		100	This component will not alter significantly	Medium
2a. Abundance		75	Due to change in flow rate that increases biomass	Medium
2b. Community composition		75	Due to increase in inorganic nutrients biomass will increase	Medium
Benthic microalgae				
1. Species richness		100	This component will not alter significantly	Medium
2a. Abundance		75	Due to increase in inorganic nutrients	Medium
2b. Community composition		75	Due to increase in inorganic nutrients	Medium
Microalgae Score		75		

Macrophytes

VARIABLE		SCORE	MOTIVATION	CONFIDENCE
1. Species richness		80 (90%)	There has been an increase in colonization of the upper reaches of the estuary by macroalgae as a result of nutrient enrichment from agricultural activities and decreased flow due to water abstraction and a 25% reduction in flood peaks. Residence time in upper reaches has increased from 1-4 weeks (State 2) to greater than 4 weeks (State 1). The estuary can remain in State 1 for 3 months. Invasive plants have colonized the riparian zone in some disturbed areas and displaced the indigenous species. 90 % of the original species remain.	High
2a. Abundance		55	Nutrient enrichment and a reduction in flow and flushing of macrophytes have increased the biomass and aerial distribution of Potamogeton pectinatus and the macroalgae in the upper reaches. This will occur to a greater extent compared to Scenario 1 and the present state due to the 25% reduction in flood peaks as a result of the Clanwilliam dam (-15). There is an improvement in the salinity conditions compared to the Present State. There is slightly more saline intrusion compared to	High

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
		Scenario 2 (Score of 70 for salinity Scenario 2, Scenario 7 salinity score is 65). However the high flow season (State 4) is reduced from 4 months to 3 months and there has been a 25% reduction in flood peaks. The higher water column salinity will result in less dilution of saline groundwater which will decrease the distribution and biomass of the supratidal and floodplain salt marsh plants (-15). The environmental flow releases in the river will result in less saline intrusion compared to the present state. However State 1 will still occur for 3 months of the year and not 6 as is the current situation. There will be a reduction in the brackish reeds and sedges but they will grow into the areas where salinity is less than 20 ppt for three months of the year. A more continuous fringe of reeds will form in the middle reaches. There has been an increase in salinity from the reference condition but it is an improvement from the Present State (-10). There has been a small (5%) loss in the area covered by macrophytes as a result of anthropogenic disturbances (e.g. grazing, agricultural activities, salt pan) (-5).	
2b. Community composition	75	Nuisance bloom forming macroalgal species have become more abundant due to the 25 % reduction in flood peaks. These macroalgae could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches.	High
Macrophytes	55		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Zooplankton			
1. Species richness	100	Overall, species richness over the year is likely to have been the same compared to the present.	Medium
2a. Abundance	75	Abundance levels, on average are likely to have increased on an annual basis (120% of Reference, but estuary becomes narrower compared to Scenario 2). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 7).	Medium
2b. Community composition	75	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 7).	Medium
Macroinvertebrates- hyperbenthos			
1. Species richness	100	Overall, species richness over the year is likely to have been the same compared to the present.	Medium
2a. Abundance	75	Abundance levels, on average are likely to have changed on an annual basis (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 7). By contrast, the available habitat (volume) will decrease because of less erosion by floods.	Medium
2b. Community composition	75	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 7).	Medium
Macrocrustacea- benthos			
1. Species richness	100	Overall, species richness over the year is likely to have been the same compared to the present.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2a. Abundance	70	Abundance levels, on average are likely to have changed on an annual basis (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the present state). Species such as <i>Callinassa kraussi</i> and <i>Upogebia africana</i> (mud dwelling in the higher reaches) benefit because of the larger habitat made available through higher salinity values (breeding requirement). Intertidal organisms will also increase under Scenario 7 because of a reduction in the width of the channel.	Medium
2b. Community composition	75	Because of the change in salinity distribution over any year, community composition is also likely to have responded to the change along the gradient. This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 6 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the present state).	Medium
Invertebrate Score	70		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	52 (74 %)	Scenario 7 will be the same as the Present State. The loss of 4-5 indigenous freshwater species and their replacement by 4 introduced species represents a 26 % loss in species (absolute values). The species richness accorded to the marine, estuarine and estuarine dependent species is likely to have remained unchanged since Reference Conditions.	Medium
2a. Abundance	68 (21)	Overall 32% decrease in abundance from Reference Conditions largely due to the 46 % decrease in category IIc species (<i>L.richardsonii</i>). Category III marine species have also decreased by 50 % but their contribution to overall abundance remains low. Category Ib (estuarine & marine breeding populations) have increased by 51 %. In turn, estuarine (<i>G.aestuaria</i>) and obligate estuarine dependent (<i>L.lithognathus</i>) species have undergone a 13 % and 79 % reduction in abundance respectively. Abundance of partially estuarine dependent IIb species identical to Present State, a slight improvement on Scenario 2. Note score, 68 refers to a 32 % decrease in overall abundance whereas 21 refers to a 79 % reduction in category IIa obligate estuarine dependent species. For abundance, the complete loss of endemic freshwater species has been ignored. Also, < 1 % difference between Scenarios 1 & 2.	Medium
2b. Community composition	84	Similar to Scenario 2 & Present State indigenous freshwater species replaced by exotics. Category Ia (<i>G.aestuaria</i>) estuarine breeders now 47 % and IIc species (<i>L. richardsonii</i>) now 48 % contribution to overall abundance as opposed to 37 % and 60 % under Reference Conditions respectively. Likely to be in-year switches between a REI type community to a fish community with a preference for 10-30 ppt. As with the Present State, there has also been a decline in the proportion of piscivorous fish (<i>L.amia</i> & <i>P. saltatrix</i>) and large benthic feeders (<i>L. lithognathus</i> & <i>R. globiceps</i>) but this is likely to be mostly due to the gillnet fishery and the nationwide stock status of these species. Score based on 50/50 dominance of Ia and IIc species as well as complete loss of endemic freshwater species.	Medium
Fish Score	52		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	It is unlikely that there would be a loss in average instantaneous species richness	Medium
2a. Abundance	96	Waterbirds are probably not as abundant in Scenario 7 as at present, although the difference is probably very slight. There would be slightly fewer invertebrate feeders (less food), slightly fewer piscivorous birds (fewer fish) and more waterfowl (more freshwater habitat and greater productivity). The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined in the accompanying report (refer to Appendix H).	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2b. Community composition	95	Given the rather slight changes in different trophic groups outlined above, the community composition is not very different in the Reference Condition from the Present State. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.	Medium
Bird score	95		

4.2.3 Scenario 5: Raising Clanwilliam dam wall (15 m)

i. Seasonal variability in river inflow

Monthly simulated runoff data for the Scenario 5 is provided in Table 13. The mean annual runoff (MAR) is 605.7 Million m³ for this state. A summary of flow distribution (mean monthly flows in m³/s) for the Scenario 5, derived from the 70-year simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	42.17	28.76	21.52	37.04	24.33	7.43	95.80	153.56	471.91	470.40	210.01	149.81
90%ile	23.61	7.85	7.27	3.66	3.84	4.07	9.43	66.69	112.14	150.96	116.78	65.34
80%ile	11.33	3.96	2.33	1.62	1.80	2.11	4.34	17.92	72.07	78.37	81.56	40.07
70%ile	7.85	2.16	1.64	1.53	1.46	1.73	2.24	8.84	44.03	53.49	52.19	30.07
60%ile	5.44	1.67	1.52	1.53	1.45	1.39	1.79	4.84	21.61	38.99	33.68	20.61
50%ile	4.36	1.42	1.52	1.53	1.41	1.32	1.23	2.33	14.39	22.60	27.35	13.96
40%ile	3.17	1.36	1.52	1.53	1.41	1.32	1.15	1.65	9.02	12.62	17.14	12.10
30%ile	2.00	1.36	1.52	1.53	1.41	1.32	1.15	0.90	5.01	8.22	11.91	8.78
20%ile	1.70	1.36	1.52	1.53	1.41	1.32	1.15	0.52	2.19	5.28	8.21	5.68
10%ile	1.43	1.36	1.52	1.24	0.95	0.70	0.80	0.43	0.84	2.91	3.92	3.28
1%ile	1.20	1.19	0.89	0.88	0.40	0.22	0.00	0.04	0.32	0.49	0.84	1.59

ii. Predicted Flood regime under Scenario 5

This is very similar to Scenario 7 conditions in terms of floods.

Confidence: Medium

iii. Predicted sediment processes under Scenario 5 compared with Reference Condition

This is very similar to Scenario 5 conditions.

Confidence: Medium

TABLE 13: Monthly simulated runoff data in m³/s (70-year period) under Scenario 5

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	2.72	1.36	1.54	1.24	8.64	10.56	2.04	0.06	457.33	495.35	103.55	21.06
1921	3.13	1.36	9.36	4.78	1.43	1.32	1.15	0.52	14.39	11.84	81.56	59.55
1922	1.43	1.36	1.52	1.53	1.41	1.32	2.16	2.72	100.36	108.39	30.15	12.80
1923	2.00	1.38	1.52	1.53	1.46	1.32	1.15	0.43	7.49	7.36	10.51	15.85
1924	5.44	1.73	1.52	1.53	1.88	1.32	1.15	1.24	505.91	459.70	44.76	5.12
1925	10.19	3.35	1.52	1.53	1.41	1.32	1.15	5.07	4.43	12.62	10.29	2.36
1926	13.83	6.14	1.52	1.53	1.41	1.32	2.48	2.20	0.76	0.72	8.53	7.71
1927	1.20	1.46	1.52	1.53	0.85	1.11	0.22	0.00	13.31	10.95	3.38	4.33
1928	1.70	1.36	1.52	0.88	0.73	0.48	0.80	0.98	5.99	28.29	20.17	18.07
1929	11.63	1.36	1.52	1.53	5.68	3.08	1.15	0.76	0.84	0.51	4.77	30.15
1930	23.89	1.36	1.52	1.57	0.99	0.70	4.01	4.13	2.36	6.36	39.86	31.65
1931	4.50	1.36	1.52	1.53	6.12	4.24	1.15	3.00	9.90	15.91	9.24	12.10
1932	3.27	1.62	1.71	1.53	1.41	1.32	1.15	2.00	23.96	76.57	55.77	9.00
1933	1.97	1.66	1.61	1.53	1.41	4.76	3.48	0.86	1.35	2.91	2.71	7.21
1934	12.59	21.79	13.03	1.53	1.41	1.32	2.24	4.41	8.25	7.17	28.28	20.61
1935	5.25	1.36	1.52	1.53	1.46	1.36	1.15	1.62	1.09	5.24	12.27	28.53
1936	12.96	7.85	6.94	1.62	1.41	1.51	0.86	1.10	29.26	53.49	17.14	4.62
1937	1.58	1.36	7.44	12.22	1.41	1.32	1.99	5.97	5.76	3.57	6.98	8.78
1938	3.66	1.36	1.52	1.53	2.55	2.08	1.15	17.92	19.39	2.91	88.14	75.99
1939	1.95	1.36	1.52	0.88	5.18	1.93	1.51	1.65	4.07	5.09	2.81	3.26
1940	1.53	1.33	0.91	0.95	0.41	0.00	5.78	54.77	117.29	78.54	101.77	137.16
1941	24.78	2.66	1.52	1.53	1.41	1.32	1.60	2.33	143.49	108.51	32.94	11.87
1942	12.50	9.57	5.96	5.75	1.41	1.51	1.15	0.51	4.64	19.64	66.94	30.07
1943	5.12	10.04	7.26	1.53	1.46	2.22	1.94	8.84	46.10	43.98	63.78	35.81
1944	10.83	2.16	1.52	1.53	1.41	1.36	1.15	14.79	77.47	157.50	123.77	17.38
1945	4.69	1.68	1.52	1.53	1.41	1.32	1.35	0.77	0.32	0.52	0.74	41.82
1946	40.08	1.36	1.52	1.53	1.41	2.18	1.36	7.02	7.72	27.98	20.83	3.59
1947	1.79	1.36	1.52	1.53	1.54	6.09	8.56	4.84	5.01	16.02	13.03	25.39
1948	11.33	1.42	1.52	1.53	1.41	1.32	1.15	0.51	0.61	1.18	5.19	5.37
1949	2.80	19.56	7.27	1.53	1.41	1.32	9.93	9.34	2.19	51.62	31.14	18.16
1950	9.96	5.66	2.57	1.53	1.43	1.32	1.15	0.57	44.03	50.52	42.07	28.53
1951	4.93	2.92	1.52	1.53	2.31	1.62	1.15	7.87	9.02	46.29	100.55	56.93
1952	8.92	26.57	19.78	1.53	1.80	1.73	24.88	39.50	9.42	65.70	97.97	19.42
1953	1.28	2.06	2.33	2.09	1.41	2.11	2.35	74.15	63.21	192.16	142.52	51.73
1954	7.50	1.36	1.52	1.53	2.65	1.87	1.79	1.11	29.28	68.13	196.96	82.76
1955	23.61	5.73	2.08	1.57	1.46	1.71	1.23	0.90	21.49	41.40	65.18	18.98
1956	1.72	1.36	1.52	1.53	3.84	3.28	1.15	19.46	72.13	156.22	125.49	43.86
1957	33.07	3.96	1.94	1.94	1.41	1.32	1.15	14.48	19.87	5.28	8.21	5.22
1958	1.52	1.36	1.52	1.53	1.41	1.32	1.82	233.60	196.28	2.94	16.12	13.96
1959	5.45	1.76	1.52	1.53	1.46	1.32	1.15	1.74	6.43	4.17	2.47	1.89
1960	1.20	1.36	1.95	2.04	1.45	3.67	96.07	86.39	53.85	58.03	16.28	11.72
1961	5.98	1.36	1.52	1.53	1.41	1.32	1.15	0.43	284.39	234.72	116.78	71.04
1962	38.82	6.16	1.56	1.53	1.43	1.32	1.19	0.43	4.13	10.36	124.96	49.02
1963	1.74	1.44	1.52	1.53	1.46	1.32	1.15	0.43	53.37	55.74	11.91	11.11
1964	3.09	3.44	2.08	1.53	1.41	1.82	7.82	7.17	1.73	1.86	2.11	1.72
1965	1.20	1.36	1.52	0.88	0.73	0.44	0.25	0.24	2.07	11.91	7.26	3.28
1966	1.35	1.36	1.49	0.88	0.73	0.69	7.56	12.51	112.14	78.37	8.52	5.68
1967	2.47	1.40	1.52	1.53	1.46	1.32	1.15	25.45	24.14	11.40	26.21	12.38
1968	28.92	5.24	1.52	1.53	1.41	1.32	1.41	0.87	0.34	0.51	0.88	1.28
1969	3.39	1.92	1.52	1.53	0.73	0.57	0.00	2.91	17.83	30.92	27.84	12.94
1970	3.63	1.36	1.52	1.53	1.41	1.32	0.99	0.43	1.76	36.97	51.49	8.34
1971	1.20	1.36	1.02	1.47	0.95	0.31	0.27	1.24	2.14	5.29	3.92	3.04
1972	1.55	0.87	0.87	0.88	0.38	4.07	2.69	0.26	0.31	22.60	27.35	10.17
1973	3.70	1.36	1.50	1.03	1.89	1.42	0.00	1.96	45.00	38.99	240.48	179.34
1974	7.85	2.19	1.52	1.71	1.72	1.32	1.15	73.39	72.07	8.22	16.80	8.49
1975	5.59	1.67	2.49	6.74	7.56	2.10	4.89	3.95	80.33	150.96	42.14	12.47
1976	1.50	33.87	25.60	1.66	1.41	1.32	4.66	119.26	210.43	166.78	133.85	37.09
1977	7.53	1.36	3.06	3.66	1.41	1.32	1.15	0.43	0.33	0.46	12.32	12.78
1978	1.87	1.36	1.52	1.53	1.41	1.32	0.44	0.78	21.61	25.36	4.84	6.47
1979	3.58	1.36	1.52	1.53	1.46	0.70	0.36	1.84	11.32	10.09	17.64	13.14
1980	1.51	26.52	13.42	81.37	38.97	2.25	1.48	0.26	0.32	20.09	52.19	40.07
1981	7.82	1.39	1.52	1.53	1.41	1.32	9.43	10.06	4.77	7.82	4.87	1.80
1982	5.01	3.60	1.52	1.53	1.41	1.32	1.02	76.49	99.91	42.54	30.06	26.96
1983	9.41	1.36	1.52	1.53	1.46	4.24	2.38	66.69	52.31	16.62	22.04	65.34
1984	47.07	5.58	1.64	18.04	18.06	5.08	4.34	5.82	16.77	68.38	74.92	23.86
1985	4.36	1.60	17.54	11.30	1.41	1.32	1.15	0.46	102.71	103.40	47.30	36.78
1986	2.79	1.36	1.52	1.53	1.41	1.32	25.41	31.93	20.43	27.33	23.08	32.24
1987	10.78	1.36	1.52	1.53	1.46	4.17	17.88	13.35	9.41	7.77	10.11	11.06
1988	3.17	1.36	1.53	1.53	1.45	1.83	26.43	22.18	9.69	17.64	33.68	77.01
1989	13.52	1.96	1.52	1.53	1.47	1.39	95.68	103.47	36.33	118.70	58.18	6.75
1990	1.28	1.62	1.78	1.94	1.88	1.47	1.86	2.14	36.34	133.73	98.91	66.94
Median	4.36	1.42	1.52	1.53	1.41	1.32	1.23	2.33	14.39	22.60	27.35	13.96
Average	8.04	4.02	3.24	3.35	2.58	1.90	5.99	17.28	49.02	56.01	44.89	26.61

<2.0

02.0-5.0

5.0-20.0

>20.0

iv. Estimated occurrence and duration of different abiotic states during Scenario 5

The occurrence and duration of the different Abiotic States under Scenario 5 are illustrated in the simulated monthly river flow table (Table 13).

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under the Reference Condition, median (50%ile) monthly flows are displayed in Figure 8. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

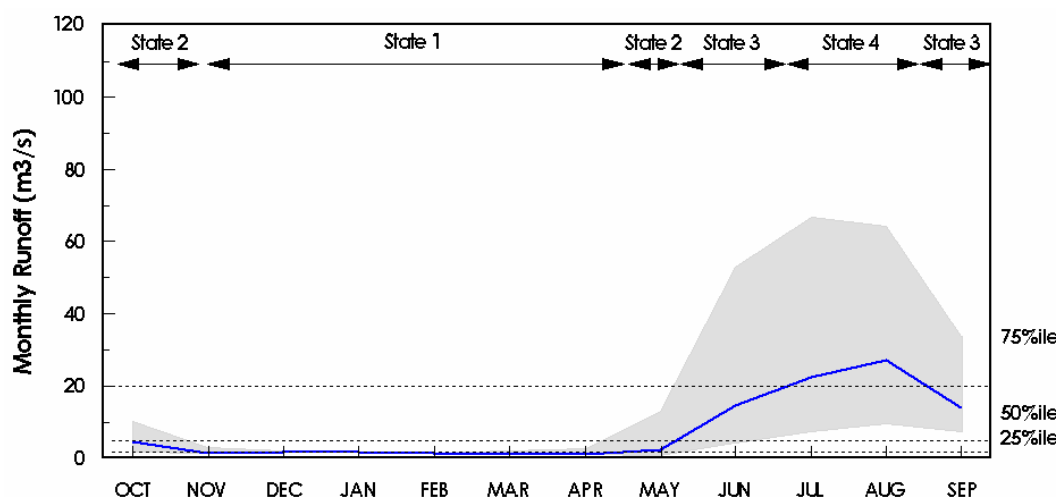


Figure 8: Predicted distribution of Abiotic States under Scenario 5 on for the Olifants Estuary, based on median monthly flows (blue line). The 75%ile and the 25%ile (shaded area) are used to illustrate variability in monthly flows

v. Predicted change in biotic characteristics under Scenario 5

MICROALGAE

Because flow will be reduced below that of the Present State, there will be a greater number of flow velocities below 2.0 m³/s. This will result in a well developed REI zone that is different to the Reference Condition and Present State. The higher mineral nutrient content associated with agricultural activities will increase the biomass of both phytoplankton and benthic microalgae. Because the benthic microalgae have a supply of nutrients from the interstitial pores of the sediment, the effect is less for them (25% more rather than 30%)

Confidence: Medium

MACROPHYTES

Species diversity, richness and rarity: Return flow will make up a large proportion of the lower flows under Scenario 5. Nutrients will be potentially higher than they are for the present state. There is a decrease in the high flow period (State 4) from 4 months (Reference) to 2 months and a 25% decrease in flood peaks. An increase in colonization of the upper reaches of the estuary by macroalgae will occur. These plants grow rapidly in response to increased nutrient inputs. Invasive plants have colonized the riparian zone in some disturbed areas. Aquatic waterweeds such as *Azolla filiculoides* will grow in the upper reaches.

Biomass distribution: The reduction in freshwater inflow has resulted in stagnant waters in the upper reaches of the estuary. Agricultural activities have resulted in nutrient enrichment. This together with a reduction in flood peaks has increased the biomass and aerial distribution of *Potamogeton pectinatus* and the macroalgae. During summer in 2004 pondweed filled the water column. This increase in organic load has the potential to cause anoxic conditions during decomposition.

There has been an increase in salinity from the Reference Condition that may have decreased the distribution of brackish

reeds and sedges. This change over time is difficult to determine from aerial photographs as distribution is very patchy in the middle reaches of the estuary. This patchy distribution may be as a result of high salinity. In the upper reaches where salinity is lower then a continuous reed fringe is found. An increase in salinity will decrease the distribution and growth of salt marsh plants. The supratidal and floodplain plants utilise the saline groundwater during the dry 8 months of the year. Any change in water column salinity will influence the salinity of the groundwater.

Seasonal variability and community composition: Because of the harsh environment a single salt marsh species *Sarcocornia pillansii* is dominant in the supratidal and floodplain areas. No change is expected in the composition of this community. Macroalgae were probably always present in the Olifants Estuary, however nuisance bloom forming species have become more abundant. These could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches. There was however no indication of this during the field survey.

Confidence: High

INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macro crustaceans)

This scenario from the perspective of the invertebrates generally represents an upstream shift in the invertebrate community because of the change in salinity upstream (penetrates up to about 20 km compared to 15 km in Scenario 7). The low flow period ($<5 \text{ m}^3/\text{s}$) persists for about 7 months – 50%ile. However, compared to the Present State, low flows during the dry season (Nov – Apr) are higher, but high flows during the winter are much lower. The net result is probably less variability in invertebrate communities. Thus, the main change is likely to be medium-scale shifts in spatial patterns with some populations (mainly the zooplankton) moving up or down-stream, but to a lesser extent compared to Scenario 7. A physical change to the cross section of the estuary will occur because of flood reduction – this is covered in the sections below.

Zooplankton

Biomass: Average annual biomass is likely to have been higher under Scenario 5 compared to the Reference Condition. This is because of high river dominance and very low salinity values over much of the estuary under the Reference condition. Phytoplankton concentrations are also potentially higher under Scenario 5. Under Scenario 5, salinity penetrates 20 km upstream during the dry season (6 months). Because the estuary becomes slightly narrower (reduction in large floods that scour channels), overall biomass decreases by about 15%.

Species richness: The number of species present in the estuary would probably increase slightly compared to the Reference Condition – this is because saline water penetrates further upstream and persists for longer during the year. Under the Reference Condition, some marine species may only have penetrated the estuary on a flood tide during the dry season. Marine associated species would have been absent for most of the year because of stronger river dominance. The estuarine copepod *Acartia longipatella* is likely to establish itself for most of the year (9 – 10 months) because of the more persistent salinity values.

Seasonal variability: Biomass and species are likely to have changed significantly between seasons under the Reference Condition. This is in contrast to Scenario 5 where variations are less. These variations will probably also be less compared to Scenario 7. In addition, large spatial shifts would have occurred between seasons under the Reference Condition, but spatial shifts will be less under Scenario 5.

Benthic Invertebrates (Hyperbenthos)

As described for the zooplankton.

Macro Crustaceans (Benthos)

Biomass: Because of the presence of submerged macrophytes in the upper estuary under Scenario 5, the biomass of benthic organisms would have been higher (additional habitat developed) in these reaches compared to the Reference Condition. Only hardy species would have survived. Species such as *Callinasa kraussi* (sand dwelling in the lower reaches) and *Upogebia africana* (Mud dwelling in the higher reaches) would also benefit from higher salinity values that extended a little further upstream compared to Reference Conditions. It is likely that intertidal banks will become more pronounced under Scenario 5, reducing subtidal habitat but increasing intertidal habitat by about 15% (see reference to sediments).

Species richness: The number of species present in the estuary would have been slightly higher compared to the Reference Condition. Marine associated species would also be absent for most of the year, although most probably penetrated the mouth area for brief periods during the dry season.

Seasonal variability: Under Scenario 5, seasonal variability would be less compared to the Reference Condition because of more persistent salinity values up the estuary. However variability will also be different along the length of the estuary. In the lower and middle reaches, changes will probably be less between seasons (more stable salinity values) compared to the upper estuary that has greater river dominance.

Confidence: Medium

FISH

Biomass distribution: Scenario 5 entails raising the Clanwilliam Dam by 15 m without the Ecological Flow Requirement releases of the river. However, fish distribution and abundance is almost identical to Present State. As with the Present State, the system is progressing from a low diversity high biomass freshwater dominated system towards a high biomass medium diversity marine dominated system. Category IIc species that occur in equal abundance in the marine and estuarine environments, (mostly *L. richardsonii*), dominate numerically (52 %) and contribute > 80 % of the biomass. Similarly to the Present State, estuarine (*G.aestuaria*), facultative catadromous (*M. cephalus*) and freshwater species (*B. serra*) contribute much less (43 %) to overall abundance than they did under Reference Conditions (65 %). Overall abundance (and biomass) under Scenario 5 is 118 % of that under Reference Conditions. Obligate estuarine dependent species (e.g. *L. lithognathus*) have improved from Present State and a 50 % decline from Reference Conditions to a 42 % decline under Scenario 5. This is likely due to an increase in area and persistence of their preferred estuarine 10-20 ppt salinity zone.

Species richness: With the exception of the indigenous freshwater species, species composition under Scenario 5 is likely to be similar to that under Reference Conditions and Present State. The endemic freshwater fish assemblage (e.g. *Barbus serra*) has mostly been replaced by introduced species such as bluegill (*L. macrochirus*) and smallmouth bass (*M. dolomieu*). Consequently, the freshwater component has undergone a greater change than that purely influenced by a reduction in flow. In turn, the introduced species are likely to be far more tolerant of poor water quality conditions in the upper reaches of the estuary. Gillnet fishing effort is likely to remain the same under all the scenarios and will continue to have a major impact on the abundance and occurrence of large bodied estuarine dependent species such as white steenbras (*L. lithognathus*) and white stumpnose (*Rhabdosargus globiceps*). Overall, although species richness remains fairly stable under Scenario 5, the fish assemblage has, similar to the Present State, undergone a drastic change with an order of magnitude change in the frequency of occurrence of some species. Overall, in terms of % composition of the fish assemblage there is a 1-4 % difference between Scenario 5 and the Present State as opposed to a 20-30 % difference between the latter and reference conditions.

Seasonal variability: Under Scenario 5, the fish assemblage will remain strongly seasonal with the most species and highest catches in the gillnet fishery occurring during autumn and spring / early summer. Juvenile recruits will occur in both the summer and winter but with a peak in spring and early summer (September – December). Compared to Present State, there may be a slight decrease in the “recruitment window” as flows, ultimately cues reaching the marine environment, become incrementally lower during spring and early summer. Total catch and effort in the gillnet fishery is likely to be similar to the Present State but with a slight increase in winter effort as the low flow season occurs earlier.

The upstream shift in distribution of estuarine, estuarine dependent and marine species during the low flow summer months may persist for a slightly longer period than Present State. However, if low oxygen plugs of water in the middle reaches are a feature of the estuary, lower flows during the spring months may accelerate their formation thereby reducing the “recruitment window” and inhibiting the upstream movement of fish above the 16 km mark. In the absence of any barrier, most estuarine, estuarine dependent and marine species will be able to extend their range upstream, some (*L. richardsonii*, *P. saltatrix* & *M. cephalus*), 20-36 km to the Lutzville Causeway. However, as with the Present State, the bulk of the fish assemblage are likely to remain 4-12 km from the mouth throughout the year. Upwelling will remain the same and most fish will be confined above the intrusion of 5-10 °C cooler marine water.

Confidence: Low

BIRDS

Biomass: In Scenario 5, base flows are reduced as at present, and freshwater flows are further reduced in terms of reduction in floods, i.e. flow patterns in general moving further away from Reference Condition than at present. The change in flooding exacerbates the problems already caused by reduced base flows. Nutrient inputs are still high, but dissolved nitrogen is not as high as in the previous scenario. The estuary is more productive than in previous scenarios. This has implications all the way up the food chain, with increased invertebrate production, and fish are similar in abundance to the Present State and Scenarios 1 and 2. Waterweed is more abundant than in any previous scenarios, but other plant habitats remain similar to the present state. The intertidal area remains slightly smaller in the upper estuary (10% less than reference state) and is larger in the lower estuary (25% more than Reference Condition). There would be less freshwater habitat in the estuary than in the Reference Condition, and very slightly more than in the present state. Freshwater habitat would be more productive than in previous scenarios.

Invertebrate feeders (such as the waders) are expected to be more abundant than in the Reference Condition due to more habitat and higher densities of invertebrates in the estuary. However, since the changes in food are smallest in the lower estuary, where most birds occur, it is unlikely that there has been a major change.

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) would be similar in abundance to previous scenarios. Their composition would be slightly different from Reference Condition, since some species have only colonised the estuary relatively recently.

Waterfowl may be less abundant than in the Reference Condition due to the smaller freshwater habitat and smaller intertidal in the mid to upper estuary, but would be similar or slightly higher than in the Present State – freshwater habitat is slightly more, and its productivity is much greater.

Species richness: Apart from the recent colonisers, there is no reason to believe that any other species would be lost or gained.

Seasonal variability: There would not have been any significant changes in seasonal patterns of bird numbers.

Confidence: Medium

vi. EHI for the Future Scenario 5

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	57	For the Olifants Estuary low flows are defined as flows associated with the State 1: Marine dominated and State 2: Saline penetration into middle reaches (i.e. flows <5 m ³ /s). Months with median low flows of <5 m ³ /s increased from 4 months (Dec – Mar) under the Reference Condition to 8 months (Oct – May) under Scenario 5. This translate into a score of 67. Due to the introduction of State 1 (-5) and the loss of variability in flow (-5) under Scenario 5 an additional -10 is allowed.	Low
b. % similarity in mean annual frequency of floods	75	The raising of Clanwilliam Dam by 15 m will increase the effect that the dams on the Olifants River have on the major floods. Flood peaks will be about 25% lower than under Reference Condition (similar to Scenario 7).	Medium
Hydrology Score	64		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of closure	100	The mouth of the Olifants Estuary is permanently open under both the Reference Condition and Present State	High
Hydrodynamic Score	100		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in longitudinal salinity gradient (%) and vertical salinity stratification	55	The low flow period ($<5 \text{ m}^3/\text{s}$) will increase from 4 months (Dec – Mar) under the Reference Condition to 8 months (Oct – May) under Scenario 5. In addition, flows within the low flow period will be reduced. Under the Reference Condition, State 2 ($2\text{-}5 \text{ m}^3/\text{s}$) was dominant limiting saline penetration to the middle reaches (about 15 km from the mouth). Under Scenario 5, State 1 ($<2 \text{ m}^3/\text{s}$) will become dominant resulting in saline penetration to about 20 km upstream. Because the flows under Scenario 5 are slightly higher compared with the Present State, the saline penetration will be somewhat less. During the high flow period the estuary is freshwater dominated (State 4) for 2 months (Jul – Aug) under Scenario 5 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. This implies that the estuary will become more saline during this period. The above translates into a largely modified salinity gradient.	Medium
2a. Nitrate (DIN)/phosphate (DRP) concentration in the estuary	40	During the high flow period the estuary is freshwater dominated (State 4) for 2 months (Jul – Aug) compared to 4 months (Jun – Sep) under the Reference Condition and Present State. State 3 will become the dominant state during this period. However, during both States 3 and 4 nutrient concentrations (in particular DIN) introduced via river inflow will remain markedly higher than for the Reference Condition as a result of agricultural activities in the catchment and along the banks of the upper estuary. To reflect modifications during this period assume a 20% change from the Reference Condition (similar to the Present State). The low flow period ($<5 \text{ m}^3/\text{s}$) will increase from 4 months (Dec – Mar) under the Reference Condition to 8 months (Oct – May) under Scenario 5. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 5, with the following results: In the upper reaches although DIN/DRP introduced through river inflow are less in terms of total load under Scenario 5 (State 1), the actual concentration in river inflow are higher compared with the Reference Condition. As return flows will probably make up a large proportion of the lower flows under Scenario 5, the increase can be expected to be larger than under the Present State. In the middle reaches under Scenario 5 DIN concentrations will become near depleted, while DRP concentrations will tend to accumulate (State 1). Under the Reference Condition DIN and DRP concentrations followed a near linear gradient between the two endpoints (State 2). To reflect modifications during the low flow period assume an additional 40% change from the Reference Condition more than for the Present State - low flow conditions persist for a longer period and nutrient concentrations expected to be higher in inflows)	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2b. Suspended solids (turbidity) in the estuary	75	Turbidity in the Olifants Estuary is mainly determined by river inflow (high flows) and wind turbulence (low flows). During the winter/spring period the estuary is freshwater dominated (State 4) for 2 months (Jul – Aug) under Scenario 5 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. However, flows in Jun & Sep are still relatively high (State 3), also characterised by high turbidity. It is therefore assumed that changes in turbidity levels, compared to the Reference Condition, will be insignificant during this period. The low flow period (<5 m³/s) will increase from 4 months (Dec – Mar) under the Reference Condition to 8 months (Oct – May) under Scenario 5. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 5. As a result it is expected that turbidity levels in the upper, but in particular the middle reaches of the estuary, will be reduced under Scenario 5. This is not only as a result of less turbidity being introduced via river inflow, but also that 'clear' seawater now penetrates further upstream. To reflect modifications during the low flow period assume a 25% change from the Reference Condition (slightly more than for the Present State - low flow conditions persist for a longer period).	Low
2c. Dissolved oxygen (DO) in the estuary	75	During the high flow period the estuary is freshwater dominated (State 4) for 2 months (Jul – Aug) under Scenario 5 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. However, flows in Jun & Sep are still relatively high (State 3), also characterised by well-oxygenated conditions. It is therefore assumed that changes in DO levels, compared to the Reference Condition, are not significant under Scenario 5 during this period, i.e. well oxygenated. The low flow period (<5 m³/s) will increase from 4 months (Dec – Mar) under the Reference Condition to 8 months (Oct – May) under Scenario 5. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 5. As a result residence times of water in the estuary have increased. Although it could be expected that DO concentrations in bottom waters (> 3 mg/l) could already decrease (~4 mg/l) under State 2, it is likely to be aggravated by longer residence time under State 1 (< 3 mg/l). To reflect modifications during the lower flow period assume a 25% change from the Reference Condition (slightly more than for the Present State - low flow conditions persist for a longer period).	Medium
2d. Levels of toxins	70	As the estuary is not located in close proximity to major industrial areas, trace metals and petroleum hydrocarbons are not considered a major issue. However, the Olifants River catchment is extensively used for agriculture and toxic substances such as herbicides and pesticides may be of concern. With the expected increase in return flow under Scenario 5, inputs of toxic substances could also increase compared to the Present State. Assume a 30% change from the Reference Condition.	Low
Water Quality Score	46		

Physical habitat alteration

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Resemblance of <u>intertidal sediment</u> structure and distribution to Reference Condition			
1a % similarity in intertidal area exposed	65	Similar to Scenario 7	Medium
1b % similarity in sand fraction relative to total sand and mud	85	Similar to Scenario 7	Low
2. Resemblance of <u>sub-tidal sediment</u> structure and distribution to Reference Condition			
2 Resemblance of subtidal estuary to Reference Condition: depth, bed or channel morphology	75	Similar to Scenario 7	Medium
Physical Habitat Score	75		

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
<i>Phytoplankton</i>			
1. Species richness	100	Species richness is unlikely to alter significantly under this flow scenario.	Low
2a. Abundance	70	Greater development of the REI and higher concentrations of DIN & DRP.	Low
2b. Community composition	70	The greater degree of salinity will result in a change of species composition. This may be reflected both in the microalgal groups and within the diatoms.	Low
<i>Benthic microalgae</i>			
1. Species richness	100	Species richness is unlikely to alter significantly under this flow scenario.	Low
2a. Abundance	75	The higher concentrations of DIN & DRP are likely to raise the biomass.	Low
2b. Community composition	70	At the lower flow rates, there will be a greater penetration of the saline wedge into the estuary. The result of this will be a change in the species tolerant to higher salinity.	Low
Microalgae Score	70		

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	73 (85%)	There has been an increase in colonization of the upper reaches of the estuary by macroalgae as a result of nutrient enrichment from agricultural activities and a 25% reduction in flood peaks. Nutrients are higher than the other scenarios because of an increase in agricultural return flows. Residence time in upper reaches has increased from 1-4 weeks (State 2) to greater than 4 weeks (State 1). The high flow months (State 4) that are important in flushing out macroalgae have been reduced from 4 months to 2 months. Invasive plants have colonized the riparian zone in some disturbed areas and displaced the indigenous species. 85 % of the original species remain.	High
2a. Abundance	49	Nutrient enrichment and a reduction in flow and flushing of macrophytes have increased the biomass and aerial distribution of Potamogeton pectinatus and the macroalgae in the upper reaches. Flood peaks have been reduced by 25% because of the Clanwilliam dam. Clear seawater will penetrate further upstream. The decrease in suspended solids and increase in light penetration will result in an increase in submerged macrophyte and macroalgal growth (-20). An increase in salinity will decrease the distribution and growth of salt marsh plants. The supratidal and floodplain plants utilise the saline groundwater during the dry 8 months of the year. An increase in water column salinity has probably increased groundwater salinity leading to a loss of salt marsh cover. Freshwater state (State 4) has been reduced from 4 to only 2 months (-20). Saline intrusion will result in salinity of 20 ppt at 12 km upstream for 3 months. There will be 5.5 km loss of reeds and sedges (12 – 6.5 km, 17%) as they die-back after 3 months exposure to 20 ppt. (-6) There has been a small (5%) loss in the area covered by macrophytes as a result of anthropogenic disturbances (e.g. grazing, agricultural activities, salt pan) (-5).	High
2b. Community composition	65	Nuisance bloom forming macroalgal species have become more abundant due to the 25 % reduction in flood peaks and increase in nutrients in return flows. These macroalgae could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches.	High
Macrophyte Score	49		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
<i>Zooplankton</i>			
1. Species richness	80 (90%)	Overall, species richness over the year is likely to increase slightly compared to the present.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2a. Abundance	60	Abundance levels, on average are likely to have increased on an annual basis (140% of Reference Condition, but estuary becomes narrower). This is because of the REI becoming more stable and median flows of <5 m ³ per sec increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 5).	Medium
2b. Community composition	75	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference condition (low flow persists for longer and there is also an increase in the residence time under Scenario 5).	Medium
Macroinvertebrates (hyperbenthos)			
1. Species richness	80 (90%)	Overall, species richness over the year is likely to have increased compared to the present.	Medium
2a. Abundance	60	Abundance levels, on average are likely to have changed on an annual basis (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 5). By contrast, the available habitat (volume) will decrease because of less erosion by floods.	Medium
2b. Community composition	75	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 5).	Medium
Macrocrustacea - benthos			
1. Species richness	80	Overall, species richness over the year is likely to increase compared to the present.	Medium
2a. Abundance	55	Abundance levels, on average are likely to have changed on an annual basis (small increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the Present State). Species such as <i>Callinassa kraussi</i> and <i>Upogebia africana</i> (mud dwelling in the higher reaches) benefit because of the larger habitat made available through higher salinity values (breeding requirement). Intertidal organisms will also increase under Scenario 5 because of a reduction in the width of the channel.	Medium
2b. Community composition	60	Because of the change in salinity distribution over any year, community composition is also likely to have responded to the change along the gradient. This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 7 months. The REI also penetrates further upstream compared to the Reference condition (low flow persists for longer and there is also an increase in the residence time under the present state).	Medium
Invertebrate Score	55		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	52 (74 %)	Scenario 5 will be the same as the Present State. The loss of 4-5 indigenous freshwater species and their replacement by 4 introduced species represents a 26 % loss in species (absolute values). The species richness accorded to the marine, estuarine and estuarine dependent species is likely to have remained unchanged since Reference Conditions.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2a. Abundance	69 (19)	Overall 31 % decrease in abundance from Reference Conditions largely due to the 41 % decrease in category IIc species (<i>L.richardsonii</i>). Category III marine species have also decreased 46 % but their contribution to overall abundance remains low. Category Ib (estuarine & marine breeding populations) have increased 66 %. In turn, estuarine (<i>G.aestuaria</i>) and obligate estuarine dependent (<i>L.lithognathus</i>) species have undergone a 19 % and 81 % reduction in abundance respectively. Abundance of partially estuarine dependent IIb species 70 % less than reference. Note score, 69 refers to a 31 % decrease in overall abundance whereas 19 refers to an 81 % reduction in category IIa obligate estuarine dependent species. For abundance, the complete loss of endemic freshwater species has been ignored.	Medium
2b. Community composition	40	Similar to Present State, indigenous freshwater species replaced by exotics. Category Ia (<i>G.aestuaria</i>) estuarine breeders now 43 % and IIc species (<i>L. richardsonii</i>) now 52 % contribution to overall abundance as opposed to 62 % and 33 % under Reference Conditions respectively. For a limited period during the high flow season, there may be a switch to a REI type community from a fish community with a preference for 10-30 ppt. However, the latter will dominate for at least 10 months of the year. Consequently, the community will have changed from a year round dominant REI type community to a fish community with a preference for 10-30 ppt. In turn, the fish community will now be dominated by a detritivore / benthic grazer (<i>L. richardsonii</i>) as opposed to a filter / selective feeder (<i>G.aestuaria</i>) under Reference Conditions. As with the Present State, there will also have been a decline in the proportion of piscivorous fish (<i>L.amia</i> & <i>P. saltatrix</i>) and large benthic feeders (<i>L. lithognathus</i> & <i>R. globiceps</i>) but this is likely to be mostly due to the gillnet fishery and the nationwide stock status of these species. Score based on change in dominance of Ia to IIc species, decline in piscivorous and large bodied benthic feeders and almost complete loss of endemic freshwater species.	Medium
Fish Score	40		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	It is unlikely that there would be a loss in average instantaneous species richness	Medium
2a. Abundance	98	Waterbirds numbers are probably similar to present. The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined in the accompanying report (Turpie 2005).	Medium
2b. Community composition	95	Given the rather slight changes in different trophic groups outlined above, the community composition is not very different in the Reference Condition from the Present State. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.	Medium
Bird score	95		

4.2.4 Scenario 17: Brandewyn

i. Seasonal variability in river inflow

Monthly simulated runoff data for the Scenario 17 is provided in Table 14. The mean annual runoff (MAR) is 529.3 Million m³ for this scenario. A summary of flow distribution (mean monthly flows in m³/s) for the Scenario 17, derived from the 70-year simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	36.85	26.10	21.25	36.41	23.93	6.63	86.04	137.02	446.75	459.95	199.56	140.54
90%ile	17.01	7.10	6.79	3.50	2.31	3.38	4.85	56.18	101.70	142.02	117.27	60.52
80%ile	7.08	3.83	2.08	1.57	1.53	1.84	1.89	9.24	62.60	65.22	69.92	34.26
70%ile	5.06	2.80	1.64	1.53	1.46	1.47	1.31	3.18	34.62	44.46	43.60	23.69
60%ile	2.95	2.09	1.52	1.53	1.44	1.32	1.19	1.51	19.07	32.72	30.17	15.48
50%ile	1.75	1.87	1.52	1.53	1.41	1.32	1.15	0.78	12.54	20.11	21.10	10.19
40%ile	1.24	1.68	1.52	1.53	1.41	1.32	1.15	0.56	5.51	10.57	14.26	7.92
30%ile	1.20	1.48	1.52	1.53	1.41	1.32	1.15	0.47	1.35	5.32	7.84	5.85
20%ile	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.43	0.38	2.23	4.51	2.96
10%ile	1.20	1.36	1.52	1.27	1.11	0.70	0.36	0.43	0.31	0.50	0.71	1.00
1%ile	1.20	1.22	0.89	0.88	0.46	0.22	0.05	0.07	0.31	0.46	0.63	0.97

ii. Predicted Flood regime under Scenario 17

Similar to Scenario 5 in terms of floods. The weir is not expected to influence the larger floods on the Doring River.

Confidence: Medium

iii. Predicted sediment processes under Scenario 17 compared with Reference Condition

Similar to Scenario 5, except that the Brandewyn weir will probably trap some of the sediment from the Doring River, especially since the weir is located quite low in the catchment on the Doring River itself.

Confidence: Medium

TABLE 14: Monthly simulated runoff data in m³/s (70-year period) under Scenario 17

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	1.20	1.83	1.49	0.88	7.49	10.47	0.07	0.10	432.87	494.75	102.22	18.92
1921	2.95	1.72	7.50	4.63	1.41	1.32	1.15	0.43	12.54	8.56	67.76	50.75
1922	1.20	1.57	1.52	1.53	1.41	1.32	1.15	0.93	89.54	95.75	27.30	9.36
1923	1.20	1.91	1.52	1.53	1.46	1.32	1.15	0.43	5.29	5.34	7.84	14.69
1924	1.78	2.45	1.52	1.53	1.41	1.32	1.15	1.05	479.12	445.03	43.60	5.60
1925	7.98	2.80	1.52	1.53	1.41	1.32	1.15	1.72	0.90	9.84	7.23	0.97
1926	6.75	4.35	1.52	1.53	1.41	1.32	1.30	0.60	0.31	0.46	4.51	4.44
1927	1.20	2.09	1.52	1.53	1.31	0.70	0.22	0.00	11.84	8.95	0.67	1.00
1928	1.20	1.68	1.52	1.01	0.73	0.58	0.80	0.52	1.80	26.18	17.14	10.19
1929	5.78	1.36	1.52	1.53	5.14	2.97	1.15	0.52	0.38	0.46	2.71	21.03
1930	17.01	2.80	1.52	1.53	1.11	0.70	2.56	1.19	0.31	2.23	35.58	21.85
1931	2.60	1.87	1.52	1.53	4.20	4.13	1.15	0.43	7.20	11.26	4.68	9.10
1932	1.20	2.09	1.52	1.53	1.41	1.32	1.15	0.43	23.60	62.69	49.84	6.94
1933	1.20	1.66	1.60	1.53	1.41	3.38	1.89	0.43	0.35	0.64	0.67	1.16
1934	6.41	19.62	12.35	1.53	1.41	1.32	1.30	1.09	5.52	4.85	22.94	10.11
1935	3.12	1.76	1.52	1.53	1.46	1.36	1.15	0.54	0.35	1.77	11.21	15.48
1936	7.08	7.10	6.79	1.53	1.41	1.44	1.15	0.43	25.91	41.25	14.26	2.96
1937	1.20	1.64	5.58	12.06	1.41	1.32	1.15	2.99	2.81	0.46	3.70	4.68
1938	1.24	1.80	1.52	1.53	1.93	1.47	1.15	9.24	15.24	0.74	75.75	65.90
1939	1.20	1.36	1.52	1.01	4.13	1.72	0.73	0.60	0.53	0.59	0.63	1.00
1940	1.24	1.99	0.90	0.95	0.49	0.00	1.31	44.57	105.80	69.52	97.81	129.67
1941	20.10	2.80	1.52	1.53	1.41	1.32	1.60	0.66	130.93	95.95	30.17	7.92
1942	7.16	7.70	5.82	5.59	1.41	1.32	1.15	0.51	1.02	20.11	54.67	24.41
1943	3.27	8.17	7.11	1.53	1.46	1.84	1.15	4.48	36.40	41.36	58.73	28.72
1944	8.75	2.55	1.52	1.53	1.41	1.32	1.15	7.44	71.54	150.12	117.27	14.14
1945	2.56	2.21	1.52	1.53	1.41	1.32	1.30	0.52	0.31	0.46	0.63	31.83
1946	32.03	2.80	1.52	1.53	1.41	1.55	1.19	1.80	2.58	26.38	18.09	4.58
1947	1.20	1.68	1.52	1.53	1.54	4.30	3.80	2.55	1.47	14.96	8.25	23.69
1948	7.47	1.98	1.52	1.53	1.41	1.32	1.15	0.43	0.31	0.50	1.90	2.56
1949	1.28	16.23	6.70	1.53	1.41	1.32	4.85	3.13	0.31	41.88	26.04	11.25
1950	6.85	3.87	2.42	1.53	1.41	1.32	1.15	0.45	34.62	47.61	39.24	24.46
1951	1.20	2.84	1.52	1.53	2.31	1.62	1.15	3.18	7.45	33.50	93.36	50.79
1952	7.27	24.25	19.62	1.53	1.53	1.62	18.80	32.49	6.41	61.19	90.70	16.29
1953	1.20	2.60	1.93	1.64	1.41	2.11	1.71	64.39	59.29	184.66	134.10	46.14
1954	5.64	1.91	1.52	1.53	1.60	1.40	1.45	0.56	24.58	56.52	188.04	74.64
1955	18.88	5.62	1.92	1.57	1.46	1.47	1.23	0.47	21.06	35.35	60.62	14.97
1956	1.20	1.57	1.52	1.53	1.99	3.17	1.15	11.81	65.65	148.85	117.41	38.34
1957	28.39	3.83	1.79	1.78	1.41	1.32	1.15	6.54	19.07	2.80	3.69	1.23
1958	1.20	1.65	1.52	1.53	1.41	1.32	1.19	211.24	176.08	3.90	20.75	12.25
1959	1.20	1.36	1.52	1.53	1.46	1.32	1.15	0.52	0.38	0.52	0.63	0.97
1960	1.20	1.36	1.95	2.01	1.45	3.47	86.07	73.82	46.64	45.89	13.96	9.39
1961	4.34	1.36	1.52	1.53	1.41	1.32	1.15	0.43	261.64	226.96	118.67	68.69
1962	35.83	6.03	1.56	1.54	1.44	1.32	1.19	0.43	1.35	5.89	121.92	36.36
1963	1.20	1.44	1.52	1.53	1.46	1.32	1.15	0.43	45.50	44.46	10.18	6.84
1964	1.35	3.12	2.08	1.53	1.41	1.62	2.95	1.16	0.31	0.46	0.67	0.97
1965	1.20	1.36	1.52	1.27	0.73	0.63	0.27	0.26	0.38	10.57	4.85	1.00
1966	1.20	1.36	1.52	0.88	0.73	0.85	3.65	6.63	101.70	65.22	5.73	1.57
1967	1.20	1.40	1.52	1.53	1.46	1.32	1.15	19.35	18.73	8.94	27.88	8.38
1968	17.90	4.79	1.52	1.53	1.41	1.32	1.38	0.56	0.31	0.46	0.63	0.97
1969	1.20	1.88	1.52	1.53	0.73	0.70	0.13	1.42	12.95	25.08	20.47	9.33
1970	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.43	0.31	32.72	39.84	5.85
1971	1.20	1.36	1.33	1.47	0.95	0.31	0.27	0.47	0.57	0.67	0.71	0.97
1972	1.20	0.87	0.87	0.88	0.38	2.70	0.96	0.26	0.31	14.53	21.10	5.44
1973	1.79	1.36	1.67	1.02	1.18	1.06	0.00	0.66	36.66	28.77	226.45	165.92
1974	5.00	2.23	1.52	1.70	1.65	1.32	1.15	61.92	62.60	5.32	11.54	4.59
1975	1.88	1.71	2.30	5.04	7.44	1.99	1.93	0.78	74.67	142.02	36.73	10.23
1976	1.20	30.42	25.05	1.65	1.41	1.32	1.67	105.22	197.27	162.67	132.56	34.78
1977	4.63	1.36	2.61	3.50	1.41	1.32	1.15	0.43	0.31	0.46	4.83	7.45
1978	1.20	1.36	1.52	1.53	1.41	1.32	0.45	0.47	17.97	20.29	1.76	2.74
1979	1.20	1.36	1.52	1.53	1.46	0.70	0.36	0.56	3.79	4.48	11.62	7.45
1980	1.20	22.99	13.26	81.22	38.84	2.24	0.15	0.26	0.31	14.99	42.61	34.26
1981	5.06	1.38	1.52	1.53	1.41	1.32	5.01	5.15	1.09	4.02	0.88	0.97
1982	1.75	3.51	1.52	1.53	1.41	1.32	1.04	63.05	87.62	36.52	26.91	20.92
1983	4.98	1.36	1.52	1.53	1.46	4.22	1.19	56.18	44.79	13.87	17.42	60.52
1984	39.23	5.52	1.64	17.21	17.54	4.98	2.95	1.51	12.54	58.21	69.92	19.77
1985	1.59	1.48	16.02	10.90	1.41	1.32	1.15	0.43	89.72	87.56	39.96	31.48
1986	2.31	1.36	1.52	1.53	1.41	1.32	20.12	24.40	14.50	21.39	17.30	28.59
1987	6.56	1.36	1.52	1.53	1.46	3.55	14.59	5.49	5.51	5.15	6.37	6.73
1988	1.24	1.36	1.53	1.54	1.45	1.82	19.87	17.14	7.20	12.07	24.60	72.19
1989	8.86	2.00	1.52	1.53	1.46	1.39	86.02	93.46	30.32	113.31	56.59	6.69
1990	1.28	1.62	1.78	1.93	1.87	1.47	1.86	2.02	33.60	116.29	90.96	61.49
Median	1.75	1.87	1.52	1.53	1.41	1.32	1.15	0.78	12.54	20.11	21.10	10.19
Average	5.53	3.84	3.11	3.29	2.44	1.77	4.70	13.61	43.56	50.52	40.39	22.08

<2.0

02.0-5.0

5.0-20.0

>20.0

iv. Estimated occurrence and duration of different abiotic states under Scenario 17

The occurrence and duration of the different Abiotic States under Scenario 17 are illustrated in the simulated monthly river flow table (Table 14).

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under the Reference Condition, median (50%ile) monthly flows are displayed in Figure 9. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

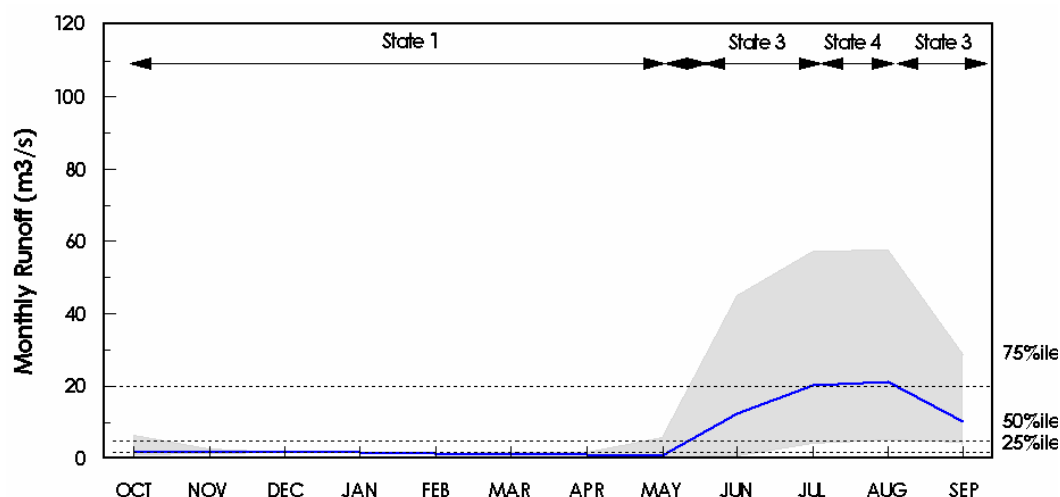


Figure 9: Predicted distribution of Abiotic States under Scenario 17 on for the Olifants Estuary, based on median monthly flows (blue line). The 75%ile and the 25%ile (shaded area) are used to illustrate variability in monthly flows

v. Predicted change in biotic characteristics under Scenario 17

MICROALGAE

The further reduction of reference flow will result in an even higher proportion of low flow periods and a further reduction in floods. These conditions will further alter the state of the REI and the phytoplankton biomass. The further increase in nutrients will amplify the biomass increase.

Confidence: Medium

MACROPHYTES

Species diversity, richness and rarity: There has been an increase in colonization of the upper reaches of the estuary by macroalgae. These plants grow rapidly in response to increased nutrient inputs. Agricultural activities in the catchment and along the banks of the estuary have resulted in nutrient enrichment. Invasive plants have colonized the riparian zone in some disturbed areas. Aquatic waterweeds such as *Azolla filiculoides* occur in the upper reaches.

Biomass distribution: The reduction in freshwater inflow has resulted in stagnant waters in the upper reaches of the estuary. Agricultural activities have resulted in nutrient enrichment. This has increased the biomass and aerial distribution of *Potamogeton pectinatus* and the macroalgae. During summer in 2004 pondweed filled the water column. This increase in organic load has the potential to cause anoxic conditions during decomposition.

There has been an increase in salinity from the Reference Condition that may have decreased the distribution of brackish reeds and sedges. This change over time is difficult to determine from aerial photographs as distribution is very patchy in the middle reaches of the estuary. This patchy distribution may be as a result of high salinity during summer but low salinity during winter. In the upper reaches where salinity is lower (<15 ppt) then a continuous reed fringe is found. An increase in salinity during drought years will result in a significant dieback of reeds. An increase in salinity will decrease the distribution and growth of salt marsh plants. The supratidal and floodplain plants utilise the saline groundwater during

MACROPHYTES

the dry 8 months of the year. Any change in water column salinity will influence the salinity of the groundwater.

Seasonal variability and community composition: Because of the harsh environment a single salt marsh species *Sarcocornia pillansii* is dominant in the supratidal and floodplain areas. No change is expected in the composition of this community. Macroalgae were probably always present in the Olifants Estuary, however nuisance bloom forming species have become more abundant. These could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches. There was however no indication of this during the field survey. The increase in saline intrusion upstream may have decreased the size and extent of brackish salt marsh dominated by *Cotula coronopifolia* and *Juncus kraussii*.

Confidence: High

INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macro crustaceans)

This scenario from the perspective of the invertebrates generally represents an upstream shift in the invertebrate community because of the change in salinity upstream (penetrates up to about 20- 25 km compared to 20 km in Scenario 5). The low flow period ($<5 \text{ m}^3/\text{s}$) persists for about 8 months – 50%ile. However, compared to the Present State, low flows during the dry season (Nov – Apr) are higher, but high flows during the winter are much lower. The nett result is probably less variability in invertebrate communities. Thus, the main change is likely to be fairly large scale shifts in spatial patterns with some populations (mainly the zooplankton) moving up or down-stream, but to a lesser extent compared to Scenario 5.

Zooplankton

Biomass: Average annual biomass is likely to have been higher under Scenario 17 compared to the Reference Condition. This is because of high river dominance and very low salinity values over much of the estuary under the Reference Condition. Phytoplankton concentrations are also potentially higher under Scenario 5. Under Scenario 5, salinity penetrates 20 – 25 km upstream during the dry season (8 months).

Species richness: The number of species present in the estuary would increase compared to the Reference Condition – this is because saline water penetrates further upstream and persists for longer during the year. Under the Reference Condition, some marine species may only have penetrated the estuary on a flood tide during the dry season. Marine associated species would have been absent for most of the year because of stronger river dominance. The estuarine copepod *Acartia longipatella* is likely to establish itself for most of the year (9 – 10 months) because of the more persistent salinity values.

Seasonal variability: Biomass and species are likely to have changed significantly between seasons under the Reference Condition. This is in contrast to Scenario 17 where variations are less. These variations will probably also be less compared to Scenario 17. In addition, large spatial shifts would have occurred between seasons under the Reference Condition, but spatial shifts will be less under Scenario 17.

Benthic Invertebrates (Hyperbenthos)

As described for the zooplankton.

Macro Crustaceans (Benthos)

Biomass: Because of the presence of submerged macrophytes in the upper estuary under Scenario 17 for longer periods during the year, the biomass of benthic organisms would have been higher (additional habitat developed) in these reaches compared to the Reference Condition. Only hardy species would have survived. Species such as *Callinassa kraussi* (sand dwelling in the lower reaches) and *Upogebia africana* (mud dwelling in the higher reaches) would also benefit from higher salinity values that extended a little further upstream compared to Reference Conditions.

Species richness: The number of species present in the estuary is likely to be much higher compared to the Reference Condition. Marine associated species would also be absent for most of the year (Reference Condition), although most probably penetrated the mouth area for brief periods during the dry season.

Seasonal variability: Under Scenario 17, seasonal variability would be less compared to the Reference Condition because of more persistent salinity values up the estuary. However variability will also be different along the length of the estuary. In the lower and middle reaches, changes will probably be less between seasons (more stable salinity values) compared to the upper estuary that has greater river dominance.

Confidence: Medium

FISH

Biomass distribution: Scenario 17 entails the construction of dam on the Brandewyn, a tributary of the Doring with a capacity of $5 \times 10^6 \text{ m}^3$. Fish distribution and abundance undergoes a drastic change compared to Reference Conditions and the Present State. The system will have changed from a low diversity high biomass freshwater dominated system to a high biomass medium diversity marine dominated system. However, the overall increase in abundance seen from Reference Conditions to Present State will be lost. Overall abundance (and biomass) under Scenario 17 is 93 % of that under reference conditions and 77 % of that of the Present State. This is largely due to the almost complete loss of the REI zone and a 25 % decrease in available estuarine habitat. Category IIc species that occur in equal abundance in the marine and estuarine environments, (mostly *L. richardsonii*), dominate numerically (55 %) and contribute > 80 % of the biomass. Similarly to the Present State, estuarine (*G.aestuaria*), facultative catadromous (*M. cephalus*) and freshwater species (*B. serra*) contribute much less (40 %) to overall abundance than they did under Reference Conditions (65 %). Obligate estuarine dependent species (e.g. *L. lithognathus*) have undergone a 70 % decline from Reference Conditions and a 40 % decline from Present State.

Species richness: With the exception of the indigenous freshwater species, species composition under Scenario 17 is likely to be similar to that under Reference Conditions and Present State. Depending on the persistence of marine dominated conditions, there may be a low risk of the complete loss of category Ia species (*G. aestuaria*) from the system. Similar to the Present State, the endemic freshwater fish assemblage (e.g. *Barbus serra*) has mostly been replaced by introduced species such as bluegill (*L. macrochirus*) and smallmouth bass (*M. dolomieu*). Consequently, the freshwater component has undergone a greater change than that purely influenced by a reduction in flow. However, the salinity tolerant Mozambique tilapia (*Oreochromis mossambicus*) may out-compete the less salinity tolerant introduced species such as *M. dolomieu* and *L. macrochirus*. If conditions deteriorate, *O. mossambicus* may also out-compete some of the estuarine and estuarine dependent species. Gillnet fishing effort is likely to remain the same under all the scenarios and will continue to have a major impact on the abundance and occurrence of large bodied estuarine dependent species such as white steenbras (*L. lithognathus*) and white stumpnose (*Rhabdosargus globiceps*). Overall, although species richness remains fairly stable under Scenario 17, the fish assemblage has undergone a drastic change with an order of magnitude change in the frequency of occurrence of some species. Overall, in terms of % composition of the fish assemblage there is a 10 - 20 % difference between Scenario 17 and the Present State as opposed to a 20-30 % difference between the latter and Reference Conditions.

Seasonal variability: Under Scenario 17, the fish assemblage will remain strongly seasonal with the most species and highest catches in the gillnet fishery occurring during autumn and spring / early summer. Juvenile recruits will occur in both the summer and winter but with a peak in spring and early summer (September – December). Compared to Present State, there may be a significant decrease in the “recruitment window” as flows, ultimately cues reaching the marine environment, become lower during spring and early summer. Seasonal changes in fish abundance are likely to be driven more by seasonal changes in the marine environment than by seasonal changes in flow. Total catch and effort in the gillnet fishery is likely to be similar to the Present State but with an increase in winter effort as the low flow season occurs earlier and persists longer.

The upstream shift in distribution of estuarine, estuarine dependent and marine species during the low flow summer months may persist for a slightly longer period than Present State and sometimes throughout the year. However, if low oxygen plugs of water in the middle reaches are a feature of the estuary, lower flows during the spring months may accelerate their formation thereby reducing the “recruitment window” and inhibiting the upstream movement of fish above the 16 km mark. In the absence of any such barrier, most estuarine, estuarine dependent and marine species will be able to extend their range upstream, some (*L. richardsonii*, *P. saltatrix* & *M. cephalus*), 20-36 km to the Lutzville Causeway. However, as with the Present State, the bulk of the fish assemblage are likely to remain 4-12 km from the mouth throughout the year. Upwelling will remain the same and most fish will be confined above the intrusion of 5-10 °C cooler marine water.

Confidence: Low

BIRDS

Biomass: In Scenario 17, base flows are reduced further than at present, but there is no significant reduction in floods. This degrades the system further than in previous scenarios. Nutrient inputs are still high, dissolved nitrogen is higher than in previous scenarios and salinity distribution is as far from Reference Condition as the Present State. The estuary is more productive than in all previous scenarios. This has implications all the way up the food chain, with increased invertebrate production, except that fish less abundant than in previous scenarios. There is less waterweed than in the previous two scenarios, and reedmarsh area has also decreased. The intertidal area remains slightly smaller in the upper estuary (10% less than reference state) and is larger in the lower estuary (25% more than reference state). There would be less freshwater habitat in the estuary than in the Reference Condition, similar to the Present State. Freshwater habitat would be more productive than in previous scenarios.

Invertebrate feeders (such as the waders) are expected to be more abundant than in the Reference Condition due to more habitat and higher densities of invertebrates in the estuary. However, since the changes in food are smallest in the lower estuary, where most birds occur, it is unlikely that there has been a major change.

BIRDS

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) would be less abundant than in previous scenarios. Their composition would be slightly different from Reference Condition, since some species have only colonised the estuary relatively recently.

Waterfowl would be less abundant than in the Reference Condition due to the smaller freshwater habitat and smaller intertidal in the mid to upper estuary, and may be fewer than in the Present State – freshwater is similar, but upper intertidal and reedmarsh is reduced, although productivity in the upper estuary is much greater.

Species richness: It could be expected that average species richness might decline in the upper estuary due to reduction in availability of freshwater habitat.

Seasonal variability: There would not have been any significant changes in seasonal patterns of bird numbers.

Confidence: Medium

vi. EHI scoring for the Scenario 17

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	52	For the Olifants Estuary low flows are defined as flows associated with the State 1: Marine dominated and State 2: Saline penetration into middle reaches (i.e. flows $<5 \text{ m}^3/\text{s}$). Months with median low flows of $<5 \text{ m}^3/\text{s}$ increased from 4 months (Dec – Mar) under the Reference Condition to 8 months (Oct – May) under Scenario 17. This translates into a score of 67. Due to the introduction of State 1 (-5) and the loss of variability (-10) in flow under Scenario 17 an additional -15 is allowed.	Low
b. % similarity in mean annual frequency of floods	75	Similar to Scenario 5 in terms of floods	Medium
Hydrology Score	61		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	The mouth of the Olifants Estuary is permanently open under both the Reference Condition and Present State	High
Hydrodynamics Score	100		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in longitudinal salinity gradient (%) and vertical salinity stratification	50	The low flow period ($<5 \text{ m}^3/\text{s}$) will increase from 4 months (Dec – Mar) under the Reference Condition to 8 months (Oct – May) under Scenario 17. In addition, flows within the low flow period will be reduced. Under the Reference Condition, State 2 ($2\text{--}5 \text{ m}^3/\text{s}$) was dominant limiting saline penetration to the middle reaches (about 15 km from the mouth). Under Scenario 17, State 1 ($<2 \text{ m}^3/\text{s}$) becomes dominant resulting in saline penetration to about 20–25 km upstream. Because the flows under Scenario 17 are slightly lower compared with Scenario 5, the saline penetration is somewhat more than under Scenario 5. During the high flow period the estuary will be freshwater dominated (State 4) for 2 months (Jul – Aug) under Scenario 17 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. This implies that the estuary becomes more saline during this period. The above translates into a largely modified salinity gradient.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2a. Nitrate (DIN)/phosphate (DRP) concentration in the estuary	35	During the high flow period the estuary is freshwater dominated (State 4) for 2 months (Jul – Aug) under Scenario 17 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. State 3 will become more dominant state during this period. However, during both States 3 and 4 nutrient concentrations (in particular DIN) introduced via river inflow will remain markedly higher than for the Reference Condition as a result of agricultural activities in the catchment and along the banks of the upper estuary. To reflect modifications during this period assume a 25% change from the Reference Condition (similar to the Present State). The low flow period ($<5 \text{ m}^3/\text{s}$) will increase from 4 months (Dec – Mar) under the Reference Condition to 8 months (Oct – May) under Scenario 17. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 17, with the following results: In the upper reaches although DIN/DRP introduced through river inflow are less in terms of total load under Scenario 17 (State 1), the actual concentration in river inflow are higher compared with the Reference Condition. In the middle reaches under Scenario 17 DIN concentrations will become near depleted, while DRP concentrations will tend to accumulate (State 1). Under the Reference Condition DIN and DRP concentrations followed a near linear gradient between the two endpoints (State 2). To reflect modifications during the low flow period assume an additional 35% change from the Reference Condition +5% return flows (more than for the Present State - low flow conditions persist for a longer period)	Medium
2b. Suspended solids (turbidity) in the estuary	65	Turbidity in the Olifants Estuary is mainly determined by river inflow (high flows) and wind turbulence (low flows). During the winter/spring period the estuary is freshwater dominated (State 4) for 2 months (Jul – Aug) under Scenario 17 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. Flows in Jun & Sep will now be representative of State 3 ($5 - 20 \text{ m}^3/\text{s}$). Because Scenario 17 involves damming (weir) on the Doring River, it can be expected that the turbidity inputs to the estuary during those months will be less. To reflect modifications during the high flow period assume a 10% change from the Reference Condition (more than Scenario 5 – reduction in turbidity load from Doring River). The low flow period ($<5 \text{ m}^3/\text{s}$) will increase from 4 months (Dec – Mar) under the Reference Condition to 8 months (Oct – May) under Scenario 17. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 5. As a result it is expected that turbidity levels in the upper, but in particular the middle reaches of the estuary, will be reduced under Scenario 17. This is not only as a result of less turbidity being introduced via river inflow, but also that 'clear' seawater now penetrates further upstream. To reflect modifications during the low flow period assume an additional 25% change from the Reference Condition (similar to Scenario 5).	Low

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2c. Dissolved oxygen (DO) in the estuary	75	During the high flow period the estuary is freshwater dominated (State 4) for 2 months (Jul – Aug) under Scenario 17 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. However, flows in Jun & Sep are still relatively high (State 3), also characterised by well-oxygenated conditions. It is therefore assumed that changes in DO levels, compared to the Reference Condition, are not significant under Scenario 5 during this period, i.e. well oxygenated. The low flow period (<5 m³/s) will increase from 4 months (Dec – Mar) under the Reference condition to 8 months (Oct – May) under Scenario 17. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 17. As a result residence times of water in the estuary have increased. Although it could be expected that DO concentrations in bottom waters (> 3 mg/l) could already decrease (~4 mg/l) under State 2, it is likely to be aggravated by longer residence time under State 1 (< 3 mg/l). To reflect modifications during the lower flow period assume a 25% change from the Reference Condition (similar to Scenario 5).	Medium
2d. Levels of toxins	70	As the estuary is not located in close proximity to major industrial areas, trace metals and petroleum hydrocarbons are not considered a major issue. However, the Olifants River catchment is extensively used for agriculture and toxic substances such as herbicides and pesticides may be of concern. Assume a 30% (return flows) change from the Reference Condition (similar to the Present State).	Low
Water Quality Score	41		

Physical habitat alteration

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Resemblance of intertidal sediment structure and distribution to Reference Condition			
1a % similarity in intertidal area exposed	65	Similar to Scenario 5	Medium
1b % similarity in sand fraction relative to total sand and mud	70	Some of the catchment sediment is trapped by the Clanwilliam and Bulshoek Dams as well as the Brandewyn weir, which is situated in the lower Doring catchment. Also most of the finer catchment sediment comes from the Doring, which means that the fine sediment component will be affected by the weir. The floods reaching the estuary will therefore be able to scour more sediment and some of the fine materials from the upper reaches will be removed.	Low
2. Resemblance of sub-tidal sediment structure and distribution to Reference Condition			
2 Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	70	The estuary will be about 15% narrower under Scenario 17 than under Reference conditions. The bed material contains more coarse material, because less fine sediment comes into the estuary as a result of the dams on the Olifants and the weir on the Doring and some of the fine sediment in the bed will also be flushed out. The depth will be more or less the same as under Reference. The width changes will alter the channel geometry, which would account for a change of about 10% in the subtidal area, while the change in bed material would account for a further 20%.	Medium
Physical Habitat Score	70		

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Phytoplankton			
1. Species richness	90 (95%)	Under these flow conditions there may be a decrease in species abundance because of the lower, more stable, flow conditions. Because there will be a lower inflow from the river, there will be a greater number of marine or high brak species and a reduction in the number of freshwater species.	Low
2a. Abundance	65	The lower flow rates will result in higher (biomass) abundance than under the high Reference flow conditions.	Low
2b. Community composition	50	The community composition will change to reflect the greater number of salinity tolerant and marine species.	Low
Benthic microalgae			

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90 (95%)	Under these flow conditions there is likely to be a decrease in species abundance because of the lower, more stable, flow conditions. Because there will be a lower inflow from the river, there will be a greater number of marine or high brak species and a reduction in the number of freshwater species.	Low
2a. Abundance	75	The lower flow rates will result in higher (biomass) abundance than under the high Reference flow conditions.	Low
2b. Community composition	50	There will be a larger high brak and marine subtidal area. The species will change accordingly.	Low
Microalgae Score	50		

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	73 (85%)	There has been an increase in colonization of the upper reaches of the estuary by macroalgae as a result of nutrient enrichment from agricultural return flows and a 25% reduction in flood peaks. Residence time in upper reaches has increased from 1-4 weeks (State 2) to greater than 4 weeks (State 1). The high flow months (State 4) that are important in flushing out macroalgae have been reduced from 4 months to 1 month. Invasive plants have colonized the riparian zone in some disturbed areas and displaced the indigenous species. 85 % of the original species remain.	High
2a. Abundance	47	Nutrient enrichment and a reduction in flow and flushing of macrophytes have increased the biomass and aerial distribution of Potamogeton pectinatus and macroalgae. Flood peaks have been reduced by 25% because of the Clanwilliam dam. Clear seawater will penetrate further upstream. The decrease in suspended solids and increase in light penetration will result in an increase in submerged macrophyte and macroalgal growth and distribution (-20). An increase in salinity will decrease the distribution and growth of salt marsh plants. The supratidal and floodplain plants utilise the saline groundwater during the dry 8 months of the year. An increase in water column salinity has probably increased groundwater salinity leading to a loss of salt marsh cover. Freshwater state (State 4) has been reduced from 4 to only 1 month (-20). Saline intrusion will result in salinity of 20 ppt at 12-16 km upstream for 3 months. There will be 7.5 km loss of reeds and sedges (14 – 6.5 km, 25%) as they die-back after 3 months exposure to 20 ppt (-8). There has been a small (5%) loss in the area covered by macrophytes as a result of anthropogenic disturbances (e.g. grazing, agricultural activities, salt pan) (-5).	High
2b. Community composition	60	Nuisance bloom forming macroalgal species have become more abundant due to the 25% reduction in flood peaks and increase in nutrients in return flows. These macroalgae could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches. The increase in saline intrusion upstream may have decreased the size and extent of brackish salt marsh dominated by Cotula coronopifolia and Juncus kraussii.	High
Macrophyte Score	47		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Zooplankton			
1. Species richness	65	Overall, species richness over the year is likely to increase compared to the present because of higher and more stable salinity values.	Medium
2a. Abundance	50	Abundance levels, on average are likely to have increased on an annual basis (150% of Reference), but estuary becomes narrower. This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 8 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 17). However, during droughts, abundance levels will decrease sharply.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2b. Community composition	50	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (increase). Particularly in the lower estuary. Further upstream, the REI will become more stable and median flows of <5 m ³ /s increasing from 4 to 8 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 17). During droughts (1 in 10 yrs), composition will also change significantly because of relatively high salinity values.	Medium
<i>Macroinvertebrates (hyperbenthos)</i>			
1. Species richness	65	Overall, species richness over the year is likely to increase compared to the present because of higher and more stable salinity values.	Medium
2a. Abundance	50	Abundance levels, on average are likely to have increased on an annual basis (150% of Reference, but estuary becomes narrower). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 8 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 17). However, during droughts, abundance levels will decrease sharply.	Medium
2b. Community composition	50	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (increase), particularly in the lower estuary. Further upstream, the REI will become more stable and median flows of <5 m ³ /s increasing from 4 to 8 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 17). During droughts (1 in 10 yrs), composition will also change significantly.	Medium
<i>Macrocrustaceans (benthos)</i>			
1. Species richness	65	Overall, species richness over the year is likely to increase compared to the present because of higher and more stable salinity values.	Medium
2a. Abundance	45	Abundance levels, on average are likely to have changed on an annual basis (increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 8 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the Present State). Species such as <i>Callinassa kraussi</i> and <i>Upogebia africana</i> benefit because of the larger habitat made available through higher salinity values (breeding requirement).	Medium
2b. Community composition	50	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (increase), particularly in the lower estuary. Further upstream, the REI will become more stable and median flows of <5 m ³ /s increasing from 4 to 8 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 17). During droughts (1 in 10 yrs), composition will also change significantly because of higher salinity values.	Medium
Invertebrate Score	45		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	50 (70 %)	Scenario 17 will be the same as the Present State. The loss of 4-5 indigenous freshwater species and their replacement by 4 introduced species represents a 26 % loss in species (absolute values). The species richness accorded to the marine, estuarine and estuarine dependent species is likely to have remained unchanged since Reference Conditions. There may be a low risk of losing category Ia species (G.aestuaria) from the system.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2a. Abundance	54 (10)	Overall 46 % decrease in abundance from Reference Conditions. Category III marine species have decreased 53 % but their contribution to overall abundance remains low. Category Ib (estuarine & marine breeding populations) has increased 50 % from reference but are a lot less abundant than Present State. In turn, estuarine (G.aestuaria) and obligate estuarine dependent (L.lithognathus) species have undergone a 42 % and 90 % reduction in abundance respectively. Abundance of partially estuarine dependent IIb species 74 % less than reference conditions. Note score, 54 refers to a 46 % decrease in overall abundance whereas 10 refers to a 90 % reduction in category IIa obligate estuarine dependent species. For abundance, the complete loss of endemic freshwater species has been ignored.	Medium
2b. Community composition	30	Similar to Present State, indigenous freshwater species replaced by exotics. Category Ia (G.aestuaria) estuarine breeders now 39 % and IIc species (L. richardsonii) now 55 % contribution to overall abundance as opposed to 62 % and 33 % under reference conditions respectively. For a limited period during the high flow season, there may be an infrequent switch to a REI type community from a fish community with a preference for 10-30 ppt. However, the latter will dominate for at least 10 months of the year. Consequently, the community will have changed from a year round dominant REI type community to a fish community with a preference for 10-30 ppt. In turn, the fish community will now be dominated by a detritivore / benthic grazer (L. richardsonii) as opposed to a filter / selective feeder (G.aestuaria) under Reference Conditions. As with the Present State, there will also have been a decline in the proportion of piscivorous fish (L.amia & P. saltatrix) and large benthic feeders (L. lithognathus & R. globiceps) but this is likely to be mostly due to the gillnet fishery and the nationwide stock status of these species. Annual recruitment window may be severely reduced for some species. Score based on change in dominance of Ia to IIc species, decline in piscivorous and large bodied benthic feeders, reduced recruitment and almost complete loss of endemic freshwater species.	Medium
Fish Score	30		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90 (95%)	It is possible that there would be a loss in average instantaneous species richness due to loss of freshwater habitat.	Medium
2a. Abundance	94	Waterbirds numbers are probably slightly more abundant than at present and higher than in the Reference Condition. Invertebrate feeders are more abundant, piscivores are fewer, and herbivores slightly less abundant than the Present State. The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined in the accompanying report (Turpie 2005).	Medium
2b. Community composition	92	Given the rather slight changes in different trophic groups outlined above, the community composition is not very different in the Reference Condition from the Present State. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.	Medium
Bird score	90		

4.2.5 Scenario 10: Maximum development

i. Seasonal variability in river inflow

Monthly simulated runoff data for the Scenario 10 is provided in Table 15. The mean annual runoff (MAR) is 423.5 Million m³ for this scenario. A summary of flow distribution (mean monthly flows in m³/s) for the Scenario 10, derived from the 70-year simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	35.07	15.97	13.61	9.22	13.15	2.96	33.40	121.63	322.41	468.45	189.47	144.94
90%ile	7.03	1.77	1.93	1.61	1.60	1.55	2.56	22.28	70.34	148.86	100.53	60.62
80%ile	3.99	1.47	1.56	1.53	1.46	1.44	1.71	2.33	47.25	66.16	62.08	32.18
70%ile	1.77	1.40	1.52	1.53	1.45	1.32	1.30	1.42	14.01	38.42	41.71	19.06
60%ile	1.33	1.36	1.52	1.53	1.41	1.32	1.19	1.05	6.42	10.74	26.17	8.62
50%ile	1.24	1.36	1.52	1.53	1.41	1.32	1.15	0.67	2.20	4.53	13.11	6.36
40%ile	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.56	1.31	2.25	3.12	2.58
30%ile	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.47	0.64	1.15	1.55	1.38
20%ile	1.20	1.36	1.52	1.53	1.41	1.32	1.02	0.43	0.38	0.64	0.84	1.00
10%ile	1.20	1.36	1.52	1.02	0.85	0.70	0.36	0.43	0.31	0.46	0.67	0.97
1%ile	1.20	1.09	0.89	0.88	0.40	0.09	0.00	0.04	0.31	0.46	0.63	0.97

ii. Predicted Flood regime under Scenario 10

The proposed dam on the Doring River will have a major impact on all floods. The major flood peaks will be reduced by about 50% from Reference Conditions. Some return period flood peaks are listed below.

Return Period (yrs)	Flood Peak (m ³ /s)
2	190
5	270
10	325

Confidence: Medium

iii. Predicted sediment processes under Scenario 10 compared with Reference Condition

The estuary bed level will be between 1 to 2 m deeper in the upper reaches than under reference conditions. It will however be about 25% narrower.

The sediment loads coming into the estuary will be significantly lower. The sediment in the upper reaches could become much coarser than under Reference Conditions, as much of the fine sediment is flushed out.

Confidence: Medium

TABLE 15: Monthly simulated runoff data in m³/s (70-year period) under Scenario 10

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	1.20	1.36	1.23	0.88	1.39	0.80	0.00	0.06	280.29	493.51	100.53	16.03
1921	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.43	4.07	1.15	54.22	54.52
1922	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.93	47.25	106.08	27.07	7.80
1923	1.20	1.36	1.52	1.53	1.46	1.32	1.15	0.43	1.54	0.89	0.80	8.45
1924	1.20	1.40	1.52	1.53	1.41	1.32	1.15	1.05	420.70	457.71	41.71	1.74
1925	3.37	1.36	1.52	1.53	1.41	1.32	1.15	1.72	0.90	2.65	1.51	0.97
1926	1.49	1.53	1.52	1.53	1.41	1.32	1.30	0.60	0.31	0.46	1.67	1.38
1927	1.20	1.36	1.52	1.53	0.85	0.70	0.22	0.00	3.30	1.60	0.67	1.00
1928	1.20	1.36	1.52	0.88	0.73	0.48	0.80	0.52	1.80	6.51	3.12	2.14
1929	1.77	1.36	1.52	1.53	1.41	1.32	1.15	0.52	0.38	0.46	2.71	5.31
1930	2.93	1.36	1.52	1.53	0.93	0.70	2.56	1.19	0.31	0.75	9.03	3.55
1931	1.28	1.36	1.52	1.53	1.65	1.40	1.15	0.43	2.20	2.99	0.76	4.28
1932	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.43	7.58	26.07	26.17	2.67
1933	1.20	1.66	1.60	1.53	1.41	3.38	1.89	0.43	0.35	0.64	0.67	1.00
1934	1.20	7.86	3.99	1.53	1.41	1.32	1.30	1.09	0.64	0.56	7.33	1.90
1935	1.40	1.36	1.52	1.53	1.46	1.36	1.15	0.54	0.35	0.82	0.95	2.58
1936	1.81	4.72	2.72	1.53	1.41	1.44	0.85	0.43	5.38	9.02	1.30	0.97
1937	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.67	0.45	0.46	0.63	1.08
1938	1.24	1.36	1.52	1.53	1.93	1.47	1.15	1.91	1.31	0.74	17.55	63.34
1939	1.20	1.36	1.52	0.88	4.13	1.19	0.73	0.60	0.53	0.52	0.63	1.00
1940	1.24	1.19	0.90	0.95	0.41	0.00	1.16	10.58	64.06	76.43	98.81	132.33
1941	18.42	1.36	1.52	1.53	1.41	1.32	1.60	0.66	96.54	106.13	29.81	7.64
1942	5.61	1.77	1.56	1.53	1.41	1.32	1.15	0.51	1.02	1.23	50.20	25.14
1943	1.32	3.07	2.12	1.53	1.46	1.32	1.15	2.17	14.02	41.68	60.75	30.95
1944	6.60	1.36	1.52	1.53	1.41	1.32	1.15	2.06	39.17	155.49	120.72	12.36
1945	2.56	1.36	1.52	1.53	1.41	1.32	1.30	0.52	0.31	0.46	0.63	7.18
1946	5.10	1.36	1.52	1.53	1.41	1.55	1.19	1.42	0.79	7.03	2.41	0.97
1947	1.20	1.36	1.52	1.53	1.54	1.33	1.30	1.31	0.64	1.16	0.91	12.29
1948	5.16	1.36	1.52	1.53	1.41	1.32	1.15	0.43	0.31	0.50	0.92	1.08
1949	1.28	1.44	1.52	1.53	1.41	1.32	2.20	0.82	0.31	10.74	2.37	6.36
1950	3.56	1.40	1.52	1.53	1.41	1.32	1.15	0.45	9.57	38.42	38.96	23.59
1951	1.20	1.36	1.52	1.53	2.31	1.62	1.15	0.86	0.49	8.77	97.66	52.09
1952	7.03	14.53	10.98	1.53	1.41	1.32	4.11	28.98	7.65	63.66	94.95	14.40
1953	1.20	1.36	1.93	1.64	1.41	2.11	1.71	22.43	61.51	190.23	139.59	46.76
1954	3.99	1.36	1.52	1.53	1.60	1.40	1.45	0.56	5.46	39.86	194.19	77.76
1955	17.37	1.96	1.71	1.57	1.46	1.47	1.23	0.47	3.14	12.58	62.08	13.98
1956	1.20	1.36	1.52	1.53	1.56	1.36	1.15	2.84	37.63	154.27	122.55	38.94
1957	26.81	1.36	1.52	1.53	1.41	1.32	1.15	3.89	1.80	0.46	0.67	0.97
1958	1.20	1.36	1.52	1.53	1.41	1.32	1.19	169.22	194.51	0.60	13.11	9.01
1959	1.20	1.36	1.52	1.53	1.46	1.32	1.15	0.52	0.38	0.46	0.63	0.97
1960	1.20	1.36	1.78	1.76	1.45	2.78	26.03	57.44	52.58	55.96	13.14	6.95
1961	1.33	1.36	1.52	1.53	1.41	1.32	1.15	0.43	232.83	232.64	113.98	66.09
1962	32.57	1.51	1.56	1.53	1.41	1.32	1.19	0.43	1.35	4.05	83.55	44.06
1963	1.20	1.44	1.52	1.53	1.46	1.32	1.15	0.43	10.13	40.96	8.80	6.22
1964	1.35	3.12	2.08	1.53	1.41	1.62	2.95	1.16	0.31	0.46	0.67	0.97
1965	1.20	1.36	1.52	0.88	0.73	0.44	0.25	0.24	0.38	2.14	0.84	1.00
1966	1.20	1.36	1.49	0.88	0.73	0.68	3.59	3.55	45.33	14.51	3.86	0.97
1967	1.20	1.40	1.52	1.53	1.46	1.32	1.15	11.50	6.91	3.71	18.08	7.49
1968	13.39	1.47	1.52	1.53	1.41	1.32	1.38	0.56	0.31	0.46	0.63	0.97
1969	1.20	1.36	1.52	1.53	0.73	0.57	0.00	1.42	1.67	4.53	1.55	0.97
1970	1.20	1.36	1.52	1.53	1.41	1.32	0.99	0.43	0.31	2.92	2.52	1.19
1971	1.20	1.36	1.02	1.47	0.95	0.31	0.27	0.47	0.57	0.59	0.63	0.97
1972	1.20	0.87	0.87	0.88	0.38	2.70	0.96	0.26	0.31	2.25	2.22	1.08
1973	1.20	1.36	1.48	1.02	0.83	0.13	0.00	0.66	14.01	4.55	187.44	174.38
1974	1.55	1.36	1.52	1.53	1.41	1.32	1.15	26.84	70.34	5.93	13.66	3.50
1975	1.24	1.36	1.52	1.83	2.08	1.51	1.86	0.78	47.51	148.86	38.94	8.62
1976	1.20	19.32	16.96	1.61	1.41	1.32	1.30	90.95	208.94	164.72	130.88	32.18
1977	4.63	1.36	1.52	1.53	1.41	1.32	1.15	0.43	0.31	0.46	3.68	2.16
1978	1.20	1.36	1.52	1.53	1.41	1.32	0.44	0.47	1.90	1.15	0.65	0.97
1979	1.20	1.36	1.52	1.53	1.46	0.70	0.36	0.56	3.26	1.60	4.47	2.50
1980	1.20	1.47	1.56	18.65	30.90	0.81	0.14	0.26	0.31	3.31	49.26	35.26
1981	1.52	1.36	1.52	1.53	1.41	1.32	2.16	0.89	0.68	1.01	0.84	0.97
1982	1.75	1.57	1.52	1.53	1.41	1.32	1.02	12.97	86.01	40.37	26.84	22.30
1983	2.97	1.36	1.52	1.53	1.46	1.51	1.19	22.28	50.49	14.36	18.83	60.62
1984	40.92	1.53	1.63	1.91	5.54	1.55	1.27	1.31	10.69	66.16	71.79	19.06
1985	1.20	1.40	12.17	5.19	1.41	1.32	1.15	0.43	61.62	101.24	44.34	31.85
1986	1.20	1.36	1.52	1.53	1.41	1.32	1.72	2.33	18.85	25.26	20.01	27.54
1987	4.32	1.36	1.52	1.53	1.46	1.58	5.71	2.20	0.94	0.94	0.77	1.34
1988	1.24	1.36	1.52	1.53	1.45	1.36	2.69	0.93	0.95	15.38	30.66	72.16
1989	7.14	1.36	1.52	1.53	1.41	1.32	50.61	101.23	34.80	116.62	54.91	2.52
1990	1.28	1.62	1.78	1.61	1.52	1.47	1.86	2.02	6.42	105.91	95.68	62.26
Median	1.24	1.36	1.52	1.53	1.41	1.32	1.15	0.67	2.20	4.53	13.11	6.36
Average	3.94	2.02	2.08	1.77	1.88	1.30	2.37	8.60	32.25	45.17	34.86	19.66

<2.0
 02.0-5.0
 5.0-20.0
 >20.0

iv. Estimated occurrence and duration of different abiotic states under Scenario 10

The occurrence and duration of the different Abiotic States during the Scenario 10 are illustrated in the simulated monthly river flow table (Table 15).

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under the Reference Condition, median (50%ile) monthly flows are displayed in Figure 10. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

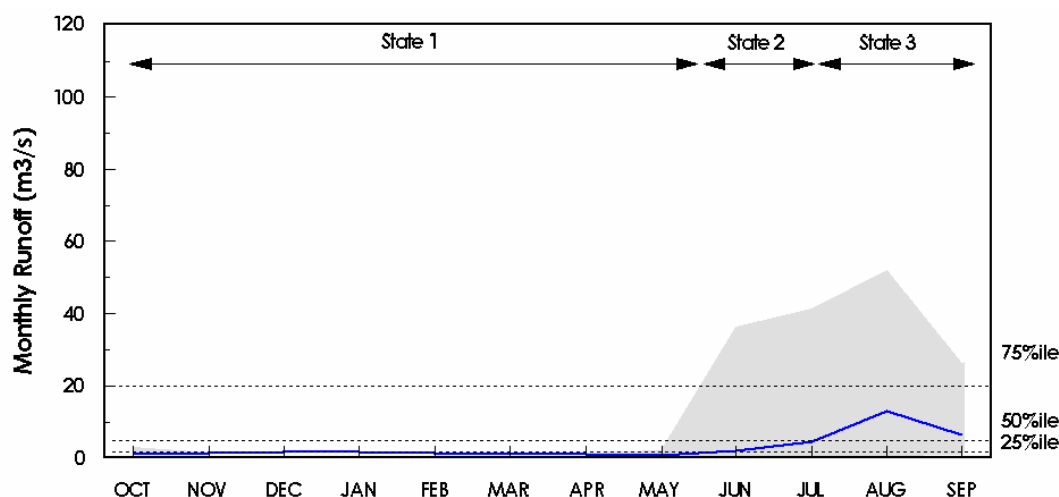


Figure 10: Predicted distribution of Abiotic States under Scenario 10 on for the Olifants Estuary, based on median monthly flows (blue line). The 75%ile and the 25%ile (shaded area) are used to illustrate variability in monthly flows

v. Predicted change in biotic characteristics under Scenario 10

MICROALGAE

Because the salinity gradients will be markedly altered, this will affect the position of the REI. Under drought conditions, there may be no REI zone at an increased frequency. The upper estuary areas will likely develop stagnant weed macrophyte beds that will remove much of the nutrient and will alter the balance of macrophytes and microphytes.

Confidence: Low

MACROPHYTES

Species diversity, richness and rarity: Nutrient input will be potentially higher than they are for the present state. The high flow period (State 4) no longer occurs, the estuary is characterized by low flow for 10 months of the year and flood peaks are reduced by 50 %. An increase in colonization of the upper and middle reaches of the estuary by macroalgae will occur. These plants grow rapidly in response to increased nutrient inputs. Invasive plants have colonized the riparian zone in some disturbed areas. Aquatic waterweeds such as *Azolla filiculoides* will grow in the upper reaches.

Biomass distribution: The reduction in freshwater inflow has resulted in stagnant waters in the upper reaches of the estuary. Agricultural activities have resulted in nutrient enrichment. This together with a 50 % reduction in flood peaks has increased the biomass and aerial distribution of *Potamogeton pectinatus* and the macroalgae. During summer in 2004 pondweed filled the water column. This increase in organic load has the potential to cause anoxic conditions during decomposition.

The estuary is characterized by low flows for most of the year. The increase in saline intrusion will decrease the distribution of brackish reeds and sedges particularly during drought years. An increase in salinity will decrease the distribution and growth of salt marsh plants. The supratidal and floodplain plants utilise the saline groundwater during the dry 8 months of the year. Any change in water column salinity will influence the salinity of the groundwater.

MACROPHYTES

Seasonal variability and community composition: Because of the harsh environment a single salt marsh species *Sarcocornia pillansii* is dominant in the supratidal and floodplain areas. An increase in salinity will result in die-back and an increase in bareground. Macroalgae were probably always present in the Olifants Estuary, however nuisance bloom forming species have become more abundant. These could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches. There was however no indication of this during the field survey. The increase in saline intrusion upstream may have decreased the size and extent of brackish salt marsh dominated by *Cotula coronopifolia* and *Juncus kraussii*.

Confidence: High

INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macro crustaceans)

This scenario from the perspective of the invertebrates generally represents a significant upstream shift in the invertebrate community because of the change in salinity upstream (penetrates up to about 20 - 30 km compared to 20- 25 km in Scenario 17). The low flow period ($<5 \text{ m}^3/\text{s}$) persists for about 10 months – 50%ile. However, compared to the Present State, low flows during the dry season (Nov – Apr) are higher, but high flow during the winter is much lower and no river dominance occurs. The net result is probably less variability in invertebrate communities. Thus, the main change is likely to be fairly large scale shifts in spatial patterns with some populations (mainly the zooplankton) moving up-stream.

Zooplankton

Biomass: Average annual biomass is likely to have been higher under Scenario 10 compared to the Reference Condition. This is because of high river dominance and very low salinity values over much of the estuary under the Reference Condition. Under Scenario 10, salinity penetrates 20 – 30 km upstream during the dry season (10 months).

Species richness: The number of species present in the estuary would increase compared to the Reference Condition – this is because saline water penetrates further upstream and persists for longer during the year. Under the Reference Condition, some marine species may only have penetrated the estuary on a flood tide during the dry season. Marine associated species would have been absent for most of the year because of stronger river dominance. The estuarine copepod *Acartia longipatella* is likely to establish itself throughout the year because of the persistent high salinity values under Scenario 10.

Seasonal variability: Biomass and species are likely to have changed significantly between seasons under the Reference Condition. This is in contrast to Scenario 10 where variations will be considerably less (less variation in salinity values). In addition, large spatial shifts would have occurred between seasons under the Reference Condition, but spatial shifts will be considerably less under Scenario 10.

Benthic Invertebrates (Hyperbenthos)

As described for the zooplankton.

Macrocrustaceans (Benthos)

Biomass: Because of higher biomass of submerged macrophytes in the upper estuary under Scenario 10 for long periods during the year, the biomass of benthic organisms would have been higher (additional habitat available) in these reaches compared to the Reference Condition. Whereas biomass increases in the macrophytes, biomass in the sediments would decrease because of much coarser sediments. Species such as *Callinasa kraussi* (sand dwelling in the lower reaches) and *Upogebia africana* (mud dwelling in the higher reaches) would also benefit from higher salinity values that extended much further upstream compared to Reference Conditions.

Species richness: The number of species present in the estuary is likely to be much higher compared to the Reference Condition. Marine associated species would also be absent for most of the year (Reference Conditions), although most probably penetrated the mouth area for brief periods during the dry season. Under Scenario 10, species richness would increase mostly in the lower estuary.

Seasonal variability: Under Scenario 10, seasonal variability would be less compared to the Reference Condition because of more persistent salinity values up the estuary. However variability will also be different along the length of the estuary. In the lower and middle estuary, changes will probably be less between seasons (more stable salinity values) compared to the upper estuary that has greater river dominance.

Confidence: Medium

FISH

Biomass distribution: Scenario 10 entails the construction of the Melkbosrug Dam on the Doring River just upstream of its confluence with the Olifants River. In all, it's a more extreme version of Scenario 17. Fish distribution and abundance undergoes a drastic change compared to reference conditions and the Present State. The system will have changed from a low diversity high biomass freshwater dominated system to a high biomass medium diversity marine dominated system. However, the overall increase in abundance seen from Reference Condition to Present State will be lost. Overall abundance (and biomass) under Scenario 10 is 93 % of that under Reference Conditions and 77 % of that of the Present State. This is largely due to the almost complete loss of the REI zone and a 25 % decrease in available estuarine habitat. Category IIc species that occur in equal abundance in the marine and estuarine environments, (mostly *L. richardsonii*), dominate numerically (57 %) and contribute > 80 % of the biomass. Similarly to the Present State, estuarine (*G. aestuaria*), facultative catadromous (*M. cephalus*) and freshwater species (*B. serra*) contribute much less (37 %) to overall abundance than they did under Reference Conditions (65 %). Obligate estuarine dependent species (e.g. *L. lithognathus*) have undergone a 74 % decline from reference conditions and a 50 % decline from Present State.

Species richness: With the exception of the indigenous freshwater species, species composition under Scenario 10 is likely to be similar to that under Reference Conditions and Present State. Depending on the persistence of marine dominated conditions, there may be a slightly higher risk than Scenario 17 of the complete loss of category Ia species (*G. aestuaria*) from the system. Similar to the Present State, the endemic freshwater fish assemblage (e.g. *Barbus serra*) has mostly been replaced by introduced species such as bluegill (*L. macrochirus*) and smallmouth bass (*M. dolomieu*). Consequently, the freshwater component has undergone a greater change than that purely influenced by a reduction in flow. However, the salinity tolerant Mozambique tilapia (*Oreochromis mossambicus*) may out-compete the less salinity tolerant introduced species such as *M. dolomieu* and *L. macrochirus*. If conditions deteriorate, *O. mossambicus* may also out-compete some of the estuarine and estuarine dependent species. Gillnet fishing effort is likely to remain the same under all the scenarios and will continue to have a major impact on the abundance and occurrence of large bodied estuarine dependent species such as white steenbras (*L. lithognathus*) and white stumpnose (*Rhabdosargus globiceps*). Overall, although species richness remains fairly stable under Scenario 10, the fish assemblage has undergone a drastic change with an order of magnitude change in the frequency of occurrence of some species. Overall, in terms of % composition of the fish assemblage there is a 10 - 25 % difference between Scenario 10 and the Present State as opposed to a 20-30 % difference between the latter and Reference Conditions.

Seasonal variability: Under Scenario 10, the fish assemblage will remain strongly seasonal with the most species and highest catches in the gillnet fishery occurring during autumn and spring / early summer. Juvenile recruits will occur in both the summer and winter but with a peak in spring and early summer (September – December). Compared to Present State, there may be a dramatic decrease in the “recruitment window” as the system becomes marine dominated and flows, ultimately cues reaching the marine environment, become lower during spring and early summer. Seasonal changes in fish abundance are likely to be driven more by seasonal changes in the marine environment than by seasonal changes in flow. Total catch and effort in the gillnet fishery is likely to be similar to the Present State but with an increase in winter effort as the low flow season occurs earlier, persists longer and there are no high flow periods to curtail fishing.

The upstream shift in distribution of estuarine, estuarine dependent and marine species during the low flow summer months may persist longer period than the Present State and frequently throughout the year. However, if low oxygen plugs of water in the middle reaches are a feature of the estuary, lower flows during the spring months may accelerate their formation thereby reducing the “recruitment window” to a month or less and inhibiting the upstream movement of fish above the 16 km mark. In the absence of any such barrier, most estuarine, estuarine dependent and marine species will be able to extend their range upstream, some (*L. richardsonii*, *P. saltatrix* & *M. cephalus*), 20-36 km to the Lutzville Causeway. However, as with the Present State, the bulk of the fish assemblage are likely to remain 4-12 km from the mouth throughout the year. Upwelling will remain the same and most fish will be confined above the intrusion of 5-10 °C cooler marine water.

Confidence: Low

BIRDS

Biomass: In Scenario 10, base flows are reduced further than at present, and there is significant reduction in floods. This degrades the system even further than in previous scenarios. Nutrient inputs are still high, dissolved nitrogen is higher than in previous scenarios and salinity distribution further from Reference Condition than the Present State. The estuary is more productive than in all previous scenarios. This has implications all the way up the food chain, with increased invertebrate production, except that fish less abundant than in previous scenarios. Abundance of waterweed is similar to Scenario 5, and reedmarsh area has decreased further. The intertidal area remains slightly smaller in the upper estuary (10% less than Reference Condition) and has increased in the lower estuary relative to previous scenarios (30% more than reference state). There would be less freshwater habitat in the estuary than in the Reference Condition and less than in the Present State. Freshwater habitat would be more productive than in previous scenarios.

Invertebrate feeders (such as the waders) are expected to be more abundant than in the Reference Condition due to more habitat and higher densities of invertebrates in the estuary. However, since the changes in food are smallest in the lower estuary, where most birds occur, it is unlikely that there has been a major change.

BIRDS

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) would be less abundant than in previous scenarios. Their composition would be slightly different from Reference Condition, since some species have only colonised the estuary relatively recently.

Waterfowl would be less abundant than in previous scenarios due to the smaller freshwater habitat and smaller intertidal in the mid to upper estuary, even though productivity in the upper estuary is much greater.

Species richness: It could be expected that average species richness might decline in the upper estuary due to reduction in availability of freshwater habitat.

Seasonal variability: There would not have been any significant changes in seasonal patterns of bird numbers.

Confidence: Medium

vi. EHI scoring for the Scenario 10

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. % similarity in period of low flows OR Present MAR as a % of MAR in the Reference Condition	30	For the Olifants Estuary low flows are defined as flows associated with the State 1: Marine dominated and State 2: Saline penetration into middle reaches (i.e. flows $<5 \text{ m}^3/\text{s}$). Months with median low flows of $<5 \text{ m}^3/\text{s}$ increased from 4 months (Dec – Mar) under the Reference Condition to 10 months (Oct – Jul) under Scenario 10. This translates into a score of 50. Due to the introduction of State 1 (-5) and the loss of variability in flow (-15) under Scenario 10 an additional -20 is allowed.	Low
b. % similarity in mean annual frequency of floods	50	A dam on the Doring River with a large storage capacity will trap most of the smaller floods and significantly attenuate even the larger floods. Flood peaks will reduce by about 50%.	Medium
Hydrology Score	38		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of closure, e.g. over a 5 or 10 year period	100	The mouth of the Olifants Estuary is permanently open under both the Reference Condition and Present State	High
Hydrodynamics Score	100		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in longitudinal salinity gradient (%) and vertical salinity stratification	40	The low flow period ($<5 \text{ m}^3/\text{s}$) increased from 4 months (Dec – Mar) under the Reference Condition to 10 months (Oct – Jul) under Scenario 10. In addition, flows within the low flow period were reduced. Under the Reference Condition, State 2 ($2-5 \text{ m}^3/\text{s}$) was dominant limiting saline penetration to the middle reaches (about 15 km from the mouth). Under Scenario 10, State 1 ($<2 \text{ m}^3/\text{s}$) becomes dominant resulting in saline penetration to about 20-30 km upstream. During the high flow period the estuary will no longer go into a freshwater dominated state (State 4) under Scenario 10 compared to 4 months (Jun – Sep) under the Reference Condition and Present State. This implies that the estuary will become markedly more saline during this period under Scenario 10. The above translates into a largely modified salinity gradient.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2a. Nitrate (DIN)/phosphate (DRP) concentration in the estuary	30	Under Scenario 10, during the high flow period median flows in the will no longer reflect a freshwater dominated state (State 4) compared to 4 months (Jun – Sep) under the Reference Condition and Present State. State 3 will become the dominant state during this period. However, during both States 3 and 4 nutrient concentrations (in particular DIN) introduced via river inflow will remain markedly higher than for the Reference Condition as a result of agricultural activities in the catchment and along the banks of the upper estuary. To reflect modifications during this period assume a 25% change from the Reference Condition (similar to the Present State). The low flow period (<5 m³/s) will increase from 4 months (Dec – Mar) under the Reference Condition to 10 months (Oct – Jul) under Scenario 10. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 10, with the following results: In the upper reaches although DIN/DRP introduced through river inflow are less in terms of total load under Scenario 10 (State 1), the actual concentration in river inflow are higher compared with the Reference Condition. In the middle reaches under Scenario 10 DIN concentrations will become near depleted, while DRP concentrations will tend to accumulate (State 1). Under the Reference Condition DIN and DRP concentrations followed a near linear gradient between the two endpoints (State 2). To reflect modifications during the low flow period assume an additional 40% (+5% return-flow) change from the Reference Condition (more than Scenario 17 - low flow conditions persist for a longer period)	Medium
2b. Suspended solids (turbidity) in the estuary	50	Turbidity in the Olifants Estuary is mainly determined by river inflow, and wind turbulence. Under Scenario 10, during the high flow period, median flows in the estuary will no longer reflect a freshwater dominated state (State 4) compared to 4 months (Jun – Sep) under the Reference Condition and Present State. State 3 (5 – 20 m³/s) will become more dominant during this period. Because Scenario 10 involves damming (weir) on the Doring River, it can be expected that the turbidity inputs to the estuary during those months will be less compared to the Reference Condition. To reflect modifications during the high flow period assume a 20% change from the Reference Condition (more than for Scenario 17). The low flow period (<5 m³/s) will increase from 4 months (Dec – Mar) under the Reference Condition to 10 months (Oct – Jul) under Scenario 10. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 10. As a result it is expected that turbidity levels in the upper, but in particular the middle reaches of the estuary, will be reduced under Scenario 10. This is not only as a result of less turbidity being introduced via river inflow, but also that 'clear' seawater now penetrates further upstream. To reflect modifications during the low flow period assume an additional 30% change from the Reference Condition (more than for Scenario 17 – low flow conditions persist for longer period).	Low

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2c. Dissolved oxygen (DO) in the estuary	70	Under Scenario 10, during the high flow period, median flows in the estuary will no longer reflect a freshwater dominated state (State 4) compared to 4 months (Jun – Sep) under the Reference Condition and Present State. State 3 (5 – 20 m³/s) will become more dominant during this period. However, flows under State 3 are still relatively high, also indicative of well-oxygenated conditions. It is therefore assumed that changes in DO levels, compared to the Reference Condition, are not significant under Scenario 10 during this period, i.e. well oxygenated. The low flow period (<5 m³/s) will increase from 4 months (Dec – Mar) under the Reference Condition to 10 months (Oct – May) under Scenario 10. In addition, flows within the low flow period will be reduced. These significant reductions will shift the estuary from being mainly in State 2 under the Reference Condition to State 1 under Scenario 10. As a result residence times of water in the estuary have increased. Although it could be expected that DO concentrations in bottom waters (> 3 mg/l) could already decrease (~4 mg/l) under State 2, it is likely to be aggravated by longer residence time under State 1 (< 3 mg/l). To reflect modifications during the lower flow period assume a 30% change (small volume below 3 m) from the Reference Condition (more than Scenario 17 – low flow conditions persist for longer period).	Medium
2d. Levels of toxins	70	As the estuary is not located in close proximity to major industrial areas, trace metals and petroleum hydrocarbons are not considered a major issue. However, the Olifants River catchment is extensively used for agriculture and toxic substances such as herbicides and pesticides may be of concern (i.e. return flows). Assume a 20% change from the Reference Condition.	Low
Water Quality Score	34		

Physical habitat alteration

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Resemblance of intertidal sediment structure and distribution to Reference Condition			
1a % similarity in intertidal area exposed	50	The estuary is about 25% narrower under Scenario 10 than under Reference Condition, but only over the upper 15 to 20 km (translates to about 10% in terms of scoring). The low water bridge at Lutzville is thought to reduce the tidal effect to a small degree, and as such affects the intertidal area (5%). In the lower estuary, especially the blind arm of the river, the intertidal area will probably increase due to siltation in that area, by about 35%.	Medium
1b % similarity in sand fraction relative to total sand and mud	50	A significant quantity of catchment sediment is trapped by the existing as well as proposed dams. The floods reaching the estuary will therefore be able to scour more sediment and most of the fine materials from the upper reaches will be removed.	Low
2. Resemblance of sub-tidal sediment structure and distribution to Reference Condition			
2 Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	50	The estuary is about 25% narrower under Scenario 10 than under Reference Conditions. Also the river in the upper reaches will be between 1 to 2 m deeper. The bed material consists of much coarser material. The width and depth changes will alter the channel geometry, which would account for a change of about 25% in the subtidal area, while the change in bed material would account for a further 25%.	Medium
Physical Habitat Score	50		

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Phytoplankton			
1. Species richness	80 (90%)	Despite the low flow conditions, species richness will not be greatly reduced.	Medium
2a. Abundance	60	Competition from macrophytes and the removal of minerals by them, will likely cause the biomass to be reduced but not with the same frequency or periodicity as under the Present State. There is a possibility that if macrophyte growth does not become excessive, there may be blooms of microalgae.	Medium
2b. Community composition	40	Although there will still be a fairly good species richness under Scenario 10 conditions, the species composition is likely to be considerably altered from that expected under Present State.	Low
Benthic microalgae			
1. Species richness	80 (90%)	The greater proportion of high brackish/marine subtidal conditions will result in a reduction in species.	Low

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2a. Abundance	50	Depending on the extent of macroalgal growth (competition), the benthic microalgae maybe reduced.	Low
2b. Community composition	40	The community will be dominated by increasing numbers of high brak and marine species.	Medium
Microalgae Score	40		

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	50 (70 %)	There has been an increase in colonization of the upper reaches of the estuary by macroalgae as a result of nutrient enrichment from agricultural activities and a 50% reduction in flood peaks. Nutrients are high because of an increase in agricultural return flows. Residence time in upper reaches has increased. The high flow months (State 4) that are important in flushing out macroalgae no longer occur. The increase in salinity may result in the loss of the brackish salt marsh species. Invasive plants have colonized the riparian zone in some disturbed areas and displaced the indigenous species. 70% of the original species remain.	60%
2a. Abundance	40	Nutrient enrichment and a reduction in flow and flushing of macrophytes have increased the biomass and aerial distribution of Potamogeton pectinatus and the macroalgae in the upper reaches. Flood peaks have been reduced by 50%. Clear seawater will penetrate further upstream. The decrease in suspended solids and increase in light penetration will result in an increase in submerged macrophyte and macroalgal growth (-20). An increase in salinity will decrease the distribution and growth of salt marsh plants. The supratidal and floodplain plants utilise the saline groundwater during the dry 8 months of the year. An increase in water column salinity will increase groundwater salinity and result in a die-back of salt marsh and increase in bare area. Freshwater state (State 4) no longer occurs (-25). Saline intrusion will result in salinity of 20 ppt at 20 km upstream at times. On average this will result in a 25% loss in reeds, approximately 7.5 km. Reeds will die-back after 3 months exposure to 20 ppt (-10). There has been a small (5%) loss in the area covered by macrophytes as a result of anthropogenic disturbances (e.g. grazing, agricultural activities, salt pan) (-5).	80%
2b. Community composition	50	Nuisance bloom forming macroalgal species have become more abundant due to the 50 % reduction in flood peaks and increase in nutrients in return flows. These macroalgae could potentially shade out the submerged macrophytes i.e. pondweed in the upper reaches. The increase in saline intrusion upstream may have decreased the size and extent of brackish salt marsh dominated by Cotula coronopifolia and Juncus kraussii.	80%
Macrophyte Score	40		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Zooplankton			
1. Species richness	50	Overall, species richness over the year is likely to increase compared to the Reference Condition because of higher and more stable salinity values.	Medium
2a. Abundance	35	Abundance levels, on average are likely to have increased on an annual basis (160% of Reference, but estuary becomes narrower). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 10 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 10. However, during droughts, abundance levels will decrease sharply.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2b. Community composition	35	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (increase). Particularly in the lower estuary. Further upstream, the REI will become more stable and median flows of <5 m ³ /s increasing from 4 to 10 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 10). During droughts (3 in 10 yrs), composition will also change significantly because of relatively high salinity values.	Medium
<i>Macroinvertebrates - hyperbenthos</i>			
1. Species richness	50	Overall, species richness over the year is likely to increase compared to the Reference Condition because of much higher and more stable salinity values.	Medium
2a. Abundance	35	Abundance levels, on average are likely to have increased on an annual basis (160% of Reference), but estuary becomes narrower). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 10 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 10. However, during fairly frequent droughts (3 in 10 yrs), abundance levels will decrease sharply.	Medium
2b. Community composition	35	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (increase), particularly in the lower estuary. Further upstream, the REI will become more stable and median flows of <5 m ³ /s increasing from 4 to 10 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 10). During droughts (3 in 10 yrs), composition will also change significantly.	Medium
<i>Macrocrustacea - benthos</i>			
1. Species richness	50	Overall, species richness over the year is likely to increase compared to the present because of higher and more stable salinity values.	Medium
2a. Abundance	25	Abundance levels, on average are likely to have changed on an annual basis (increase). This is because of the REI becoming more stable and median flows of <5 m ³ /s increasing from 4 to 10 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under the Present State). Species such as <i>Callinassa kraussi</i> and <i>Upogebia africana</i> benefit because of the larger habitat made available through higher salinity values (breeding requirement).	Medium
2b. Community composition	30	Because of the change in salinity distribution over any year, species composition is also likely to have responded to the change (increase), particularly in the lower estuary. Further upstream, the REI will become more stable and median flows of <5 m ³ /s increasing from 4 to 10 months. The REI also penetrates further upstream compared to the Reference Condition (low flow persists for longer and there is also an increase in the residence time under Scenario 10). During droughts (3 in 10 yrs), composition will also change significantly because of higher salinity values.	Medium
Invertebrate Score	25		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	50 (70 %)	Scenario 10 will the same as the Present State. The loss of 4-5 indigenous freshwater species and their replacement by 4 introduced species represents a 26 % loss in species (absolute values). The species richness accorded to the marine, estuarine and estuarine dependent species is likely to have remained unchanged since Reference Conditions. There may be a higher, but still low risk of losing category Ia species (<i>G.aestuaria</i>) from the system.	Medium

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
2a. Abundance	55 (8)	Overall 45 % decrease in abundance from Reference Conditions. Category III marine species have declined by 50 % but their contribution to overall abundance remains low. Category Ib (estuarine & marine breeding populations) species have increased 50 % from reference but have declined 15 % from Present State. In turn, estuarine (G.aestuaria) and obligate estuarine dependent (L.lithognathus) species have undergone a 44 % and 92 % reduction in abundance respectively. Abundance of partially estuarine dependent IIb species 75 % less than Reference Conditions. Note score, 55 refers to a 45 % decrease in overall abundance whereas 8 refer to a 92 % reduction in category IIa obligate estuarine dependent species. For abundance, the complete loss of endemic freshwater species has been ignored.	Medium
2b. Community composition	25	Similar to Present State, indigenous freshwater species replaced by exotics. Category Ia (G.aestuaria) estuarine breeders now 37 % and IIc species (L. richardsonii) now 57 % contribution to overall abundance as opposed to 62 % and 33 % under Reference Conditions respectively. The REI type community will no longer occur and a fish community dominated by species with a preference for 10-30 ppt. will persist throughout the year. In turn, the fish community will now be dominated by a detritivore / benthic grazer (L. richardsonii) as opposed to a filter / selective feeder (G.aestuaria) under reference conditions. As with the Present State, there will also have been a decline in the proportion of piscivorous fish (L.amia & P. saltatrix) and large benthic feeders (L. lithognathus & R. globiceps) but this is likely to be mostly due to the gillnet fishery and the nationwide stock status of these species. Annual recruitment window may be severely reduced for some species. If so, the reduction in recruitment may have as severe as an impact as the gillnet fishery Score based on change in dominance of Ia to IIc species, decline in piscivorous and large bodied benthic feeders, reduced recruitment and almost complete loss of endemic freshwater species.	Medium
Fish Score	25		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	80 (90%)	It is possible that there would be a loss in average instantaneous species richness due to loss of freshwater habitat.	Medium
2a. Abundance	78	Waterbirds numbers are probably significantly more abundant than at present and higher than in the Reference Condition. Invertebrate feeders are more abundant, piscivores are fewer, and herbivores slightly less abundant than the Present State. The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined in the accompanying report (Turpie 2005).	Medium
2b. Community composition	91	Given the changes in different trophic groups outlined above, the community composition is somewhat different from the Reference Condition and from the Present State. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.	Medium
Bird score	78		

4.2.6 Ecological reserve categories (ERC) associated with runoff scenarios

The individual EHI scores, as well as the corresponding ERC for the different scenarios are provided in Table 16.

TABLE 16: EHI score and corresponding ERC for the different runoff scenarios

VARIABLE	WEIGHT	PRESENT	RUNOFF SCENARIO				
			2	7	5	17	10
Hydrology	25	69	77	74	64	61	38
Hydrodynamics/mouth condition	25	100	100	100	100	100	100
Water quality	25	50	61	56	46	41	34
Physical habitat alteration	25	78	78	75	75	70	50

Habitat health score	50	74	79	76	71	68	47
Microalgae	20	70	80	75	70	50	40
Macrophytes	20	58	70	55	49	47	40
Invertebrates	20	65	75	70	55	45	25
Fish	20	40	50	52	40	30	25
Birds	20	95	94	95	95	90	78
Biotic health score	50	66	74	69	62	52	33
Estuarine Health Index Score		70	76	73	67	60	40
Ecological Reserve Category (ERC)		C	B	C	C	D	E

4.3 Recommended Ecological Flow Requirement Scenario

The evaluation of the simulated runoff scenarios is used to derive the recommended Ecological Flow Requirement. The recommended Ecological Flow Requirements is defined as the runoff scenario (or a slight modification thereof) that represents the highest reduction in river inflow that will still protect the aquatic ecosystem of the estuary and keep it in the recommended ERC.

The Olifants Estuary has been targeted as a Desired Protected Area (DWAF, 2004). According to the guidelines for assigning a recommended ERC the estuary, therefore need to be in a Category A or the Best Attainable State (BAS). However, with large dam developments already existing in the catchment (e.g. Clanwilliam Dam) it will be difficult to improve the Olifants Estuary to a Category of A. It was therefore recommended that the Olifants Estuary be improved to the minimum ERC for a 'Highly Important estuary', namely a **Category B**.

Following the guideline above, **Scenario 2**, i.e. the Present inflow scenario plus the Ecological Water Requirement releases of the River ($MAR = 800.3 \times 10^6 \text{ m}^3$) is selected as the recommended Ecological Flow Requirement Scenario for the Olifants Estuary. The flow distribution are summarised in Table 17a.

TABLE 17a: Summary of the flow distribution for the recommended Ecological Flow Requirement (Scenario 2) for the Olifants Estuary

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	48.13	32.08	21.50	37.21	24.46	7.77	96.73	194.20	550.92	472.06	230.02	153.70
90%ile	28.90	9.60	7.24	3.64	3.76	3.85	9.62	80.90	151.71	159.08	126.25	65.58
80%ile	16.05	4.30	2.06	1.75	1.68	2.21	4.85	22.01	93.83	104.19	79.44	48.08
70%ile	12.84	2.93	1.68	1.55	1.38	1.81	3.07	11.18	57.99	78.10	66.22	34.22
60%ile	11.49	2.93	1.51	1.51	1.37	1.46	2.88	8.24	42.45	58.26	50.45	25.66
50%ile	10.11	2.93	1.50	1.51	1.34	1.42	2.84	6.19	37.99	51.82	47.54	22.18
40%ile	9.01	2.49	1.50	1.51	1.34	1.42	2.49	3.57	36.22	39.92	44.77	16.34
30%ile	8.32	1.51	1.50	1.51	1.34	1.42	1.76	3.42	24.20	30.79	33.23	14.73
20%ile	6.36	1.43	1.18	1.51	0.91	1.11	1.41	2.05	15.78	21.17	28.07	11.21
10%ile	4.02	0.83	0.58	0.99	0.85	1.00	1.28	1.15	7.44	9.49	17.41	9.66
1%ile	1.01	0.15	0.00	0.99	0.34	0.00	0.04	0.29	0.82	2.07	5.35	4.04

The workshop highlighted (referring to Table 5) that a significant degree of the modification resulting in the Present State Category C is linked to non-flow related anthropogenic activities such as:

- Nutrient inputs from agricultural activities; and
- Over-exploitation of the fisheries resources (gill net fisheries).

It was therefore concluded that should improved management and control of the above-mentioned activities be achieved, Scenario 7 (raising of the Clanwilliam Dam by 15 m plus the Ecological Water Requirement releases of the River - MAR = $741.5 \times 10^6 \text{ m}^3$) might prove to be sufficient to achieve the recommended Category B. However, this will require cooperation and assistance from the Department of Agriculture and the Department of Environmental Affairs and Tourism (in particular Marine and Coastal Management) (i.e. cooperative governance). The flow distributions of Scenario 7 are summarised in Table 17b.

TABLE 17b: Summary of the flow distribution of an alternative Ecological Flow Requirement (Scenario 7) for the Olifants Estuary (Category B), should management and control of nutrient inputs and over-exploitation be improved

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	38.67	28.63	21.90	37.61	24.80	7.37	96.27	174.77	456.58	471.55	205.43	148.18
90%ile	16.94	8.24	7.64	4.04	4.13	4.07	9.92	69.28	127.88	158.65	111.97	51.47
80%ile	12.56	4.35	2.46	2.15	2.01	2.37	4.92	21.44	88.02	81.43	73.72	35.30
70%ile	10.61	3.29	2.08	1.91	1.77	1.96	3.25	10.60	57.48	67.52	57.21	26.31
60%ile	9.40	3.29	1.90	1.91	1.71	1.77	3.18	7.67	41.29	54.98	48.28	22.32
50%ile	9.33	3.29	1.90	1.91	1.71	1.77	2.86	5.48	38.23	51.94	47.57	16.21
40%ile	9.33	2.72	1.90	1.91	1.71	1.77	2.53	3.65	37.67	47.54	44.17	14.00
30%ile	7.22	1.87	1.90	1.88	1.30	1.26	1.76	3.41	26.23	29.53	34.55	12.50
20%ile	5.69	1.79	1.43	1.88	1.15	1.00	1.68	1.62	15.69	21.31	28.53	10.87
10%ile	4.34	1.13	0.98	0.99	0.88	1.00	1.00	1.21	6.44	7.88	15.28	8.11
1%ile	1.29	0.03	0.00	0.99	0.44	0.15	0.17	0.40	0.90	1.54	4.80	4.26

Although the Present State of the Olifants Estuary currently falls within an Ecological Category C, the estuary is on a negative trajectory of change, because of the extremely low base flows under the Present State ($< 1 \text{ m}^3/\text{s}$) particularly during the summer months. Maintaining the *status quo* is therefore likely to result in continued modification of the Ecological status of the estuary.

It was therefore concluded that to maintain the estuary in the Present State (Ecological Category C) base flows will need to be re-introduced, particularly during the summer period. Scenario 5 showed that by returning some of the base flows during summer, it is possible to maintain the estuary in a Category C, even if the Clanwilliam Dam was raised by 15 m. Scenario 5 was selected as the environmental flow requirements that would maintain the estuary in a Category C (Table 17c).

TABLE 17c: Summary of the flow distribution of the Ecological Flow Requirement (Scenario 5) for the Olifants Estuary to maintain an Ecological Category C

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	42.17	28.76	21.52	37.04	24.33	7.43	95.80	153.56	471.91	470.40	210.01	149.81
90%ile	23.61	7.85	7.27	3.66	3.84	4.07	9.43	66.69	112.14	150.96	116.78	65.34
80%ile	11.33	3.96	2.33	1.62	1.80	2.11	4.34	17.92	72.07	78.37	81.56	40.07
70%ile	7.85	2.16	1.64	1.53	1.46	1.73	2.24	8.84	44.03	53.49	52.19	30.07
60%ile	5.44	1.67	1.52	1.53	1.45	1.39	1.79	4.84	21.61	38.99	33.68	20.61
50%ile	4.36	1.42	1.52	1.53	1.41	1.32	1.23	2.33	14.39	22.60	27.35	13.96
40%ile	3.17	1.36	1.52	1.53	1.41	1.32	1.15	1.65	9.02	12.62	17.14	12.10
30%ile	2.00	1.36	1.52	1.53	1.41	1.32	1.15	0.90	5.01	8.22	11.91	8.78
20%ile	1.70	1.36	1.52	1.53	1.41	1.32	1.15	0.52	2.19	5.28	8.21	5.68
10%ile	1.43	1.36	1.52	1.24	0.95	0.70	0.80	0.43	0.84	2.91	3.92	3.28
1%ile	1.20	1.19	0.89	0.88	0.40	0.22	0.00	0.04	0.32	0.49	0.84	1.59

The consequences of maintaining the Olifants Estuary in an Ecological Category C are considered to be as follows:

- Excessive (or nuisance) macrophyte growth is likely to occur during the late summer months in the upper reaches, particularly if nutrient inputs from agricultural activities continue in the upper reaches. This will have potential negative impacts on water intake systems, recreational usage and aesthetics (i.e. 'loss of value').
- As the flow scenario for an Ecological Category C will result in a reduction of freshwater pulsing to the marine environment (e.g. inflows will be more regulated), this could result in a reduced cueing effect to estuarine dependent invertebrate and fish species.
- Also, more regulated inflow will reduce the variability in abiotic conditions, which in turn may result in changes in community composition (particularly in terms of invertebrates and fish), thus affecting biodiversity.

The above-mentioned are also likely to have a ripple effect on economic good and services provided by the adjacent marine environment, e.g. the marine fisheries. The Olifants Estuary is but one of a few large estuarine systems along the South African west coast where it is considered to play a crucial role in terms of biological functionality to sustain the important fisheries resource. However, the linkages between the estuary, the marine environment and the fisheries resource are still poorly understood. Some of the key aspects that require further research are highlighted later (refer to Section 6.3).

It is therefore strongly recommended that decisions regarding the future state of the Olifants Estuary, carefully consider potential impacts on all uses, both land-based and marine-based activities. This will require effective cooperative governance between the Department of Water Affairs and Forestry, Department of Agriculture and the Department of Environmental Affairs and Tourism (particularly Marine and Coastal Management).

5. ECOLOGICAL SPECIFICATION

Currently the *Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAF, 2004a) does not provide any guidance on the determination of ecological specifications for estuaries. Therefore, the approach that was applied and approved by DWAF as part of the Thukela study was followed (DWAF, 2004b).

Ecological Specifications are clear and measurable specifications of ecological attributes (in the case of estuaries - hydrodynamics, sediment dynamics, water quality and different biotic components) that define a specific ecological reserve category, in this case a **Category B**. The ecological specifications for the Olifants Estuary are listed in Table 18.

Thresholds of potential concern (TPC) are defined as measurable end points related to specific abiotic or biotic indicators that if reached (or when modelling predicts that such points will be reached) prompts management action. In essence, thresholds of potential concern endpoints should be defined such that they provide early warning signals of potential non-compliance to ecological specification (i.e. not the point of 'no return'). In essence, this concept implies that the indicators (or monitoring activities) selected as part of long-term monitoring programme need to include biotic and abiotic components that are particularly sensitive to ecological changes associated with changes in river inflow. The TPCs, associated with each of the ecological specifications are also provided in Table 18.

Table 18: Ecological Specifications and TPC associated with an Ecological Category B in the Olifants Estuary

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
Birds	Retain the species richness, abundance and diversity of the bird community, representative of resident and migrant waders, wading birds and water fowl as under the Present State, except for that there would be an higher abundance of water fowl (increasing by about 10% from Present State numbers)	1.1 Community composition or bird numbers deviates by more than 50% of average seasonal baseline counts for two consecutive summer or winter seasons, focusing on waders, wading birds, terns & water fowl (summer and winter), and specifically red data species which are supported by the system (e.g. Pelican, Oyster catchers, Chestnut banded plover) 1.2 In the case of water fowl densities decline by 20% of average seasonal baseline counts for two consecutive summer or winter seasons	Changes in: - Salinity - Invertebrate biomass/abundance - Fish biomass/abundance in smaller size classes - Vegetation habitats (e.g. reed beds, submerged macrophytes, salt marsh) - Mud flats - Human disturbance (not at moment)
Fish	Retain the following fish assemblages in the estuary: estuarine species (35%), partially estuarine dependent species (50-60%), obligate estuarine dependent (e.g. white steenbras) (>1%) and indigenous freshwater species (>1%). Exotic freshwater species (<0.5%)	2.1 Level of estuarine species drop below 30% of total abundance 2.2 Levels of obligate estuarine dependent species drop below 1% of total abundance 2.3 Levels of partially estuarine dependent species drop below 50% or above 60% of total abundance 2.4 Levels of exotic freshwater species above 0.5% (e.g. Mozambique tilapia out-competing resident species) 2.5 Benthic dwellers species drop below 2% of total abundance in estuary above 18 km from the mouth	Changes in: - Insufficient spawn biomass (national stock – marine) - Spawning failure due to environmental conditions (marine) - Recruitment failure (e.g. no cues reaching the sea from the estuary) - Habitat (macrophytes) - Water column (temperature, salinity, turbidity, dissolved oxygen) - Toxic substances (?) - Food availability (Invertebrate & fish) - Exploitation - Introduction in aliens
	Maintain recruitment of adult and juvenile fish at Reference Condition levels. This requires maintaining sufficient flow for freshwater plume (temperature, salinity and oliphactory gradient) entering the sea. This implies that there should be a significant number of 0 -1 year old fish and no missing year classes.	2.6 There are a missing year class within a species	Blockage of eel migrations due to sand bar at mouth, Bad catchment practises/destruction of habitat, Blockage of migration due to dams.

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
Invertebrates	Retain Present State species richness and mix (low species abundance, high dominance). However, under the present state one or two species are always present at high densities compared to others (e.g. <i>Pseudodiaptomus hessei</i> & <i>Ceratonereis keiskama</i>). For a B Category the higher densities need to be more variable in abundance during the year.	3.1 Species richness is greater than 30 for zooplankton and macroinvertebrates respectively (50% increase)	Changes in: Variability in intra-annual flow, e.g. loss of high flow pulses (>20 m ³ /s) in autumn/spring (salinity) sediment grain size distribution and organic content
	Indicator species such as <i>Capitella capitata</i> , should not dominate benthic species at any site	3.2 <i>Capitella capitata</i> exceeds 50% abundance of benthic species at any site	Increase in pollution (low oxygen high organic loading)
	<i>Calianassa</i> and <i>Upogebia</i> distribution patterns as under Present State	3.3 Abundance levels or areas of distribution decreases by more than 50% (mainly lower sandy reaches)	Changes in sediment characteristics along the estuary
Macrophytes	Maintain the present distribution (summer 2004) and abundance of the different plant community types (<i>Zostera capensis</i> (48 ha), intertidal salt marsh (92 ha), supratidal salt marsh (143 ha), floodplain salt marsh (797 ha), reeds and sedges (60 ha))	4.1 Greater than 20% change in the area covered by different plant community types	Increase in salinity and reduced flooding influencing depth to groundwater and groundwater salinity. Increase in turbidity would reduce submerged macrophyte cover.
	Reduce the areas covered by water weeds in the upper reaches by 50% compared to the Present State (summer 2004). Therefore area covered by invasive waterweeds (<i>Azolla filiculoides</i>), nuisance filamentous algae (e.g. <i>Enteromorpha</i> , <i>Ulva</i> , <i>Cladophora</i>) and pondweed (<i>Potamogeton pectinatus</i>) should be 30 ha (half of channel)	4.2 Upper 15 km of estuary with greater than 50% of estuary water channel covered by invasive waterweeds (<i>Azolla filiculoides</i>), nuisance filamentous algae (e.g. <i>Enteromorpha</i> , <i>Ulva</i> , <i>Cladophora</i>) and pondweed (<i>Potamogeton pectinatus</i>).	Low flow, lack of flushing and reduced current speeds. Reduced flooding that resets the estuary. High nutrient input from agricultural activities and return flow.
	Control the spread of invasive aliens in the riparian zone (e.g. <i>Sesbania punicea</i> and <i>Eucalyptus</i> spp.).	4.3 Greater than 20 % increase in area covered by invasive plants.	Disturbance of riparian zone due to human impacts such as bulldozing and clearing of natural vegetation
	Maintain reed and sedge areas (60 ha) and brackish salt marsh (~10 ha) as for the Present State (summer 2004) (by preventing salinity of 20 ppt to move further upstream than 8.5 km and remain there for greater than 3 months).	4.4 Dieback of reeds and brackish salt marsh at 8.5 km and further upstream from the mouth.	Reduced flow and an increase in saline intrusion.
	Prevent an increase in bareground in the floodplain salt marsh by maintaining groundwater salinity at <70 ppt and depth to the water table at < 1.5 m	4.5 Greater than 20% increase in bare ground in salt marsh.	Reduced flow and flooding, increase in groundwater salinity and depth to groundwater.

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
Microalgae	Maintain a low phytoplankton biomass with a small REI (i.e. 10 ppt to river +1 ppt) zone	5.1 Phytoplankton biomass exceeds 15 µg/l chlorophyll a in summer and 10 ug/l chlorophyll a in winter 5.2 Blue-green algae exceeds 10% of phytoplankton cell counts	Water flow rates falling too low in winter or summer.
	Maintain microalgal group diversity as measured under Present State (2004)	5.3 Flagellates cease to be the dominant group and diatoms become less diverse (<10 taxa per site)	Reduced freshwater inflow rates and high salinity near the upper areas of the estuary.
	Maintain intertidal and subtidal microphytobenthic biomass as measured under Present State (2004).	5.4 Benthic microphytobenthic biomass exceed 40 mg/m ² chlorophyll a	Elevated nutrient in the inflowing freshwater.
	Maintain a low frequency of dinoflagellates	5.5 The frequency of dinoflagellates exceeds 5% of the total phytoplankton counts	Eutrophication of inflowing river water.
Water quality	Salinity intrusion should not to cause exceedence of TPCs for fish, invertebrates, macrophytes and microalgae (see above)	6.1 Salinity greater than 20 ppt for long than 3 months at 7 km upstream from the mouth (brackish saltmarsh, reeds and sedges & invertebrates)	Modification of volume of river inflow Quality of agricultural return flow
		6.2 Salinity of groundwater increases to 50 ppt and depth to water table to 1 m. (flood plain salt marsh)	
		6.3 Total dissolved solids (measure of 'salinity') of river inflow exceeds 3500 mg/l (phytoplankton)	
		6.4 Salinity in estuary exceeds 35 ppt (prevent hyper- salinity) (phytoplankton)	
	System variables (Temperature, pH, turbidity, dissolved oxygen, suspended solids and turbidity) not to cause exceedence of TPCs for biota (see above)	6.5 Salinity greater than 10 ppt occurs above 16 km upstream of the mouth (fish)	Changes in water quality of river inflow at head of estuary and as a result of agricultural return flow along the banks of the upper estuary. Excessive macroalgal/microalgal growth in the estuary
		6.6 River inflow: Summer temp < 20°C pH < 6.5 'Turbid' river inflow (to be determined) Dissolved oxygen < 4 mg/l	
		6.7 Secchi disc reading above 8 km from the mouth is greater than 1 m (proxy for turbidity in estuary)	
		6.8 pH > 8.5 or < 6.5 in river inflow or in estuary	

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
		6.9 Water column DO drops below 4 mg/l (1 m above bottom except in deep holes) (need to investigate DO level at night in dense macrophyte beds)	
	Inorganic nutrient concentrations not to cause exceedance of TPCs for macrophytes and microalgae (see above).	6.10 When average river inflow is less than 5 m ³ /s and average DIN concentrations exceed 100 µg/l in river inflow and DIN concentrations in the upper reaches of the estuary (above 16 km from mouth) exceed 100 µg/l 6.11 During high flow season (flows > 20 m ³ /s) average DIN concentrations exceed 500 µg/l in river inflow and average DIN concentrations in the upper reaches of the estuary (above 16 km from mouth) exceed 500 µg/l 6.12 Average DRP concentration exceed 100 µg/l in river inflow and average DRP concentrations in the upper reaches of the estuary (above 16 km from mouth) exceed 100 µg/l	Changes in water quality of river inflow at head of estuary and as a result of agricultural return flow along the banks of the upper estuary.
	Presence of toxic substances not to cause exceedance of TPCs for biota (see above).	6.13 For pesticides/herbicides baseline studies still need to be undertaken before TPCs can be set (special concern in upper reaches with extensive agricultural activities along banks of estuary)	Inputs from agricultural activities in the catchment and along the banks of the estuary in upper reaches
Hydrodynamics	Maintain a flow regime to create the required habitat for birds, fish, macrophytes, microalgae and water quality	7.1 River inflow distribution patterns differ by more than 5% from that of Scenario 2 (i.e. recommended flow scenario for the Olifants) 7.2 River inflow decreases to below 1.5 m ³ /s at any time 7.3 River inflow below 2 m ³ /s persist for longer than 4 months	Modification to inflow at head of estuary

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
Sediment dynamics	Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) so as not to exceed TPCs for biota (see above)	8.1 River inflow distribution patterns (flood components) differ by more than 10% (in terms of magnitude, timing and variability) from that of the Present State (2004) 8.2 Suspended sediment concentration from river inflow deviates by more than 10% of the sediment load discharge relationship to be determine as part of baseline studies (Present State 2004)	Modification to inflow at head of estuary
	Changes in sediment grain size distribution patterns not to cause exceedance of TPCs in benthic invertebrates (see above).	8.3 The median bed sediment diameter deviates by more than a factor of two from levels to be determined as part of baseline studies (Present State). 8.4 Sand/mud distribution in middle reaches (8-20 km) change by more than 20% from Present State (2004) 8.5 Changes in the channel bathymetry in the upper reaches (above 20 km upstream of the mouth) change by more than 20% from Present State (2004) 8.6 Changes in tidal amplitude below the Lutzville causeway of more than 20% from Present State (2004)	Modification to inflow at head of estuary; Catchment activities

6. RESOURCE MONITORING PROGRAMME

6.1 Baseline Data Requirements

The status of baseline data currently available for different abiotic and biotic components in the Olifants Estuary, after completion of the current ecological reserve determination study, is summarised in the following section. These are compared with the data requirements as specified for an Ecological Reserve determination on a comprehensive level (DWAF, 2004).

6.1.1 Current status

i. Abiotic components

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Series of sediment core samples for the analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) taken every 3 years along the length of an estuary (200 m to 2 km intervals)	Not collected due to budgetary constraints. As part of this study only grab samples were collected (budgetary constraints) Layering and age of sediment to verify numerical modelling, which at this stage is only calibrated from surface grab samples. Also to confirm the assumption that had to be made.
Series of cross-section profiles (collected at about 500 to 1000 m intervals) taken every 3 years to quantify the sediment deposition rate in an estuary	A new data set could not be collected due to budgetary constraints therefore the 1994 data set corrected to MSL was used. However, this data were collected 10 years ago and may no longer be representative of the present state.
Set of sediment grab samples (at cross-section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) need to be taken immediately after a major flood	Only a set of grab samples were collected for the lower 20 km in the estuary.
Aerial photographs of estuary (earliest available year as well as most recent)	No new aerial photographs were collected as part of this study. This is required to set baseline for development in the flood plain and position of mouth. If taken at low spring tide it can also be used to characterize baseline conditions of inter-tidal and flood plain in terms vegetation cover and physical habitat for fauna.
Measured river inflow data (gauging stations) at the head of the estuary over a 5-15 year period	No accurate inflow data was available as the Lutzville gauging station was not calibrated. This is crucial primary baseline data set for estuarine reserve determination. It is also required to re-calibrate the simulated flow data because there are discrepancies between measured and simulated data at present.
Continuous water level recordings near mouth of the estuary	A data record are available for three years, but additional data are required to improve the calibration of the numerical models that was used in the study, as well as to provide information on long-term sedimentation processes.
Water level recordings at about 5 locations along the length of the estuary over a spring and a neap tidal cycle (i.e. at least a 14 day period)	A new data set could not be collected due to budgetary constraints therefore the 1994 data set corrected to MSL was used. Such data is required to improve the calibration of the numerical models that was used in the study.
Longitudinal salinity and temperature profiles (<i>in situ</i>) collected over a spring and neap tide during high and low tide at: - end of low flow season (i.e. period of maximum seawater intrusion)	Salinity and temperature profiles were collected in March 2004 and August 2005 over spring low and high tides. However, because these results could not be correlated to accurate river inflow data (see above) it only incrementally improved the

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
- peak of high flow season (i.e. period of maximum flushing by river water)	confidence of hydrodynamic predictions, i.e. linking river inflow ranges to salinity distribution patterns. Therefore, although a number of historical data sets were available these were mainly for the low flow periods or high flow periods, but the major gap in data is for the transitional flow bands.
Water quality measurements (i.e. system variables and nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and a neap high tide: - end of low flow season - peak of high flow season	pH, turbidity, dissolved oxygen and inorganic nutrient data were collected along the estuary in March 2004 and August 2005 over spring high tides coinciding with the salinity and temperature survey.
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary	Sediment organic content samples were collected at selected sites as part of the invertebrate surveys in March 2004 and August 2004. No data were collected on toxic substances (e.g. pesticides) in sediments of the estuary, excluded mainly due to the high costs of such analyses.
Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary	Electrical conductivity, pH, inorganic nutrient data were available from the DWAF water quality station at the Lutzville causeway (E2H016Q01) for 2 years. However, no data on temperature, turbidity or dissolved oxygen are currently available for river inflow. Also, agricultural activities along the banks of the upper reaches are a diffuse source of inorganic nutrients (and pesticides) to the estuary. Currently no quantitative data are available on such inputs – this needs to be confirmed with a baseline survey.
Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater	No new data were collected, but this data can be derived from published literature.

ii. *Biotic Components*

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Phytoplankton: Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths. Cell counts of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae Measurements must be taken coinciding with typically high and low flow conditions Benthic microalgae: Intertidal and subtidal benthic chlorophyll-a measurements Epipellic diatoms need to be collected for identification These measurements must to be taken coinciding with a typical high and low flow condition	Data were collected in March 2004 and August 2004 at 8 stations along the estuary. The March survey was representative of drought conditions (not a typical low flow period) while the August survey was also not representative of a typical high flow period.
DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the Present State, as well as the Reference Condition (if available) Available orthophotographs 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 Permanent transects:	GIS maps were prepared from 2000 (Present State) and 1937 (Reference Condition). Recent data were available (Bornman 2001). Permanent transects are very important in the

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
- Measurements of percentage plant cover along an elevation gradient - Measurements of salinity, water level, sediment moisture content and turbidity	Olifants Estuary as it has a large supratidal marsh area that is sensitive to changes in water table fluctuations and salinity. Bornman (2001) established baseline conditions for the Olifants Estuary and in March 2004 and August 2004 measurements were repeated at 2 of his sites (lower and middle reaches).

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Collect a set of six benthic samples each consisting of five grabs. Collect two each from sand, mud and interface substrates. If possible, spread sites for each between upper and lower reaches of the estuary. One mud sample should be in an organically rich area. Species should be identified to the lowest taxon possible and densities (animal/m²) must also be determined. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides. Collect two sets of beam trawl samples (i.e. mud and sand). Lay two sets of five, baited prawn/crab traps overnight, one each in the upper and lower reaches of the estuary. Species should be identified to the lowest taxon possible and densities (animal/m²) must also be determined. Survey as much shoreline as possible for signs of crabs and prawns and record observations. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides. Collect three zooplankton samples, at night, one each from the upper, middle and lower reaches of the estuary. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides.	Samples were collected at 10 sampling sites during March 2004 and August 2004 (more sampling sites were included due to the size of the Olifants Estuary). However, the March 2004 (summer) sampling was actually representative of <u>drought</u> conditions (even Aug 2004 [winter] sampling still reflected the influence of a drought year). The 2004 sampling survey therefore actually did not capture <u>typical seasonal</u> responses as required for comprehensive Ecological reserve determination – not even for a typical summer/winter situation (although it did provide valuable information on the system's response during drought periods) .

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Sampling should be representative of small fish (seine nets) and large fish (gill nets). Sampling should be done in all four seasons for the full extent of the system (as far as tidal variation) to allow for predictive capabilities. In a larger estuary (>5 km) sampling can either be at fixed intervals (every 2 km) or have the upper, middle and lower reaches subdivided into at least a further three sections each. The samples should be representative of the different estuarine habitat types, e.g. Zostera beds, prawn beds, sand flats. At least one of the sample sets should be in the 0 to 1 ppt reach of the system.	Two years of bi-monthly sampling (seine and gillnet data) for the lower 5 km were available. The sampling protocol was geared towards simulating the commercial gillnet fishery in the estuary and thus did not adequately sample the juvenile or the non-edible components of the estuarine fish assemblage of the system. Data from one summer and one winter gillnet sampling trip from mouth to Lutzville causeway were also available (winter sampling only comprised of harders). As part of this study, only a winter and summer sampling survey could be undertaken. However, the March 2004 (summer) sampling was actually representative of <u>drought</u> conditions (even Aug 2004 [winter] sampling still reflected the influence of a drought year). The 2004 sampling survey therefore actually did not capture <u>typical seasonal</u> responses as required for comprehensive Ecological reserve determination – not even for a typical summer/winter situation (although it did provide valuable information on the system's response during drought periods)

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Undertake one full count of all water associated birds, covering as much of the estuarine area as possible. All birds should be identified to species level and the total number of each counted. Monthly data sets for at least one year are required. If this is not possible, a minimum of four summer months and one winter month will be required (decisions on the extent of effort required will depend largely on the size of the estuary, extent of shallows present, as well as extent of tidally exposed areas).	Although bi-annual Coordinated Water bird Counts (CWAC) from the Avian Demography Unit at UCT were available for the Olifants Estuary, these data sets only include the <u>lower reaches of the estuary</u> and were therefore not according to protocol requirements. A full count of water birds along the entire estuary was undertaken in April 2004 and August 2004. However, the April 2004 (summer) sampling was actually representative of <u>drought</u> conditions (even Aug 2004 [winter] sampling still reflected the influence of a drought year). The 2004 sampling survey therefore actually did not capture <u>typical monthly variability</u> as required for a comprehensive Ecological reserve determination – not even for a typical summer/winter situation. However, the April 2004 (summer) sampling was actually representative of <u>drought</u> conditions (even Aug 2004 [winter] sampling still reflected the influence of a drought year). The 2004 sampling survey therefore actually did not capture <u>typical seasonal</u> responses as required for comprehensive Ecological reserve determination – not even for a typical summer/winter situation (although it did provide valuable information on the system's response during drought periods).

6.1.2 Additional Baseline Data Requirements

The status of baseline studies currently available for the Olifants Estuary are summarised above. However, although this Ecological Reserve determination study did include a summer (March 2004) and winter (August 2004) sampling surveys, these surveys were actually representative of drought conditions (even the winter sampling still reflected the influence of a drought year). The 2004 sampling survey did therefore not capture typical seasonal responses as required for an Ecological reserve determination – not even for a typical summer/winter situation (although it did provide valuable information on the system's response during drought periods).

The Olifants Estuary, being a complex system, does require (consecutive) seasonal surveys to improve the confidence of the Reserve, as well as to set a suitable and reliable baseline (high confidence) for the different abiotic and biotic components in a long-term monitoring programme. Additional baseline data requirements were recommended based on the generic data requirements stipulated for a Comprehensive Ecological Reserve Determination (DWAF, 2004a) as well as subsequent updates as proposed by Taljaard *et al.* (2003).

Additional baseline data requirements are listed in Table 19 and have been prioritised, using the following criteria:

	High Priority, important for <u>a suitable and reliable baseline</u> (high confidence)
	Medium Priority, will improve the confidence of baseline, and should be added if funding is available
	Low priority, will further improve confidence of baseline, but not considered to be a critical factor in the case of the Olifants Estuary

However, for baseline surveys the quantification of linkages between different abiotic and biotic components are very important, and exclusion of certain components is likely to result in only incremental gain in confidence which may not warrant the effort.

Table 19: Additional baseline data required to increase confidence of Reserve and to set baseline for long-term monitoring in Olifants Estuary

ECOLOGICAL COMPONENT	MONITORING ACTION	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
BIRDS	Undertake counts of all water associated birds. All birds should be identified to species level and total number of each counted.	Monthly surveys during a normal flow year	Entire estuary
FISH	Conduct fish surveys using both seine and gill nets as primary gear.	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season	Entire estuary (15-20 stns)
	Collect samples for larval recruitment.	Summer and winter survey	At mouth
INVERTEBRATES	Zooplankton: Collect quantitative samples using a flow meter <u>after dark</u> , preferably during neap tides (mid to high tide) because currents are less strong and zooplankton will be more active in water column. Sampling to be done at mid- water level, i.e. not surface. (Include chlorophyll a measurements on benthic microalgae and water column chlorophyll as to establish feeding links)	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season	Entire estuary (10-15 stns)
	Benthic invertebrates: Collect (subtidal) samples using a Zabalocki-type Eckman grab sampler with 5-9 randomly placed grabs (replicates) at each station. Collect intertidal samples at spring low tide using core sampling.	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season	Entire estuary (10-15 stns)
	Macrocrustaceans: Collect quantitative samples during neap tides (mid to high tide), at the same stations used for zooplankton, using a benthic sled with flow meter.	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season	Entire estuary (10-15 stns)
	Collect samples for larval recruitment (zooplankton can supplement fish surveys).	Summer and winter survey	At mouth
MACROPHYTES	No additional baseline are data required.	-	-
MICROALGAE	Phytoplankton: Conduct counts of dominant phytoplankton group.	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season.	Entire estuary (8 stns)
	Benthic microalgae: No additional baseline data are required.	-	-
WATER QUALITY	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow.	At least monthly for 3 additional years	At Lutzville causeway
	Water quality measurements of seawater (No additional measurements required - consult available literature on marine water quality in the area).	-	-
	Collected longitudinal salinity & temperature profiles (in situ).	Quarterly for 1 year, coinciding with biotic sampling	Entire estuary (10-15 stns)
	Water quality measurements taken along the length of the estuary (surface and bottom samples) for pH, dissolved oxygen, suspended solids/turbidity and inorganic nutrients.	Quarterly for 1 year, coinciding with phytoplankton and other biotic surveys	Entire estuary (10-15 stns)
	Temperature recordings - large portions of recruitment and behavioural aspects of fish and invertebrates are probably temperature driven on the west coast. Knowledge gained can also be extrapolated to other systems (as this is not considered to be a very costly exercise it is listed here)	Continuous for 1 year	At mouth and 3-5 stns along estuary

ECOLOGICAL COMPONENT	MONITORING ACTION	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
	Baseline data set for pesticides/herbicides accumulation in sediments	Once, at end of low flow period also taking into consideration when spraying occurred	Focus on depositional areas
HYDRODYNAMIC	Water level recordings	Continuous	Near mouth 15 km from mouth 36 km from mouth
	Flow gauging	Continuous	Near Lutzville causeway
	Aerial photographs of estuary (recent photograph at spring low tide)	Once-off	Entire estuary
	Water level recordings along the length of the estuary (done at the same time as cross section profile survey) (if the additional water level recorders cannot be installed)	Once of during a spring and neap tidal cycle (2 wks each)	Near mouth 15 km from mouth 36 km from mouth
	Near-shore wave data records (only if available)	-	-
SEDIMENT DYNAMICS	Bathymetric survey: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but more detailed in the mouth (vertical accuracy better than 300 mm)	Once-off (to define Present State)	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	Once off	Entire estuary 200 m to 2 km intervals
	Series of sediment core (3 m) samples for the analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) along the length of estuary (200 m to 2 km intervals). Recommend that isotope analysis in carried out on selected sample to determine the age of sediments	Once-off	Entire estuary 200 m to 2 km intervals
	Velocity cross section data during a neap and spring tide (the same period as the cross section profiles)	Once-off	200 m from mouth
	Daily sampling of suspended sediment (and organic matter) - Required to quantify actual sediment and organic yield and variability entering the estuary from the catchment. (Although sampling of organic input to the estuary from the catchment is not included in current estuarine protocol it is important and this means of quantifying it)	Daily for 5 years	DWAF monitoring station at Sishen-Saldanha train bridge

6.2 Long-Term Resource Monitoring Programme

The purpose of long-term monitoring programmes, in this context, is to assess (or audit) whether the Ecological Specifications (defined as part of the Ecological Reserve determination process) are being complied with after implementation of the Reserve. In addition, these programmes can also be used to improve and refine the Ecological Reserve measures (including the Resource Quality Objectives), in the longer-term through an iterative process (Taljaard *et al.*, 2003).

Although baseline studies and long-term monitoring programmes have different purposes, it is extremely important that long-term monitoring programmes follow on from similarly structured baseline studies. In essence, the monitoring activities selected for the long-term monitoring programme should be derived from the monitoring activities conducted as part of the baseline studies, but implemented on less intensive spatial and/or temporal scales (Taljaard *et al.*, 2003).

Abiotic and biotic indicators considered relevant for a long-term monitoring programme on the Olifants Estuary is listed in Table 20. Should the components within the programme need to be prioritised prior to the completion of the baseline studies (when higher confidence will allow for a sensible prioritisation), it was concluded that the emphasis should be placed on monitoring of the abiotic 'driver' components.

Table 20: Long-term resource monitoring programme proposed for the Olifants Estuary after implementation of the Reserve

ECOLOGICAL COMPONENT	MONITORING ACTION	RELATED TPC (see Table 17)	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
BIRDS	Undertake counts of all water associated birds. All birds should be identified to species level and total number of each counted.	1.1 – 1.2	Winter and summer survey, yearly	Entire estuary
FISH	Conduct fish surveys using both seine and gill nets as primary gear.	2.1 – 2.6	Two years after implementation conduct summer and winter survey, followed by summer and winter survey every 3 years thereafter	Entire estuary (10-15 stns)
INVERTEBRATES	Zooplankton: Collect quantitative samples using a flow meter <u>after dark</u> , preferably during neap tides (mid to high tide). Sampling to be done at mid- water level, i.e. not surface. (Include chlorophyll a measurements on benthic microalgae and water column chlorophyll as to establish feeding links)	3.1	Same as for fish	Entire estuary (10-15 stns)
	Benthic invertebrates: Collect (subtidal) samples using a Zabalocki-type Eckman grab sampler with 5-9 randomly placed grabs (replicates) at each station. Collect intertidal samples at spring low tide using core sampling.	3.2	Same as for fish	Entire estuary (10-15 stns)
	Macrocrustaceans: Collected quantitative samples during neap tides (mid to high tide), at the same stations used for zooplankton, using a benthic sled with flow meter.	3.3	Same as for fish	Entire estuary (10-15 stns)
MACROPHYTES	Use aerial photographs to quantify area covered by different plant community types and produce a vegetation map. Conduct ground survey to: 1) verify areas covered by different plant community types, 2) check the spread of alien vegetation, 3) check the spread of aquatic weeds and algae in the upper estuarine reaches 4) check the extent of bareground in the floodplain salt marsh, depth to groundwater and groundwater salinity. 5) check the distribution of reeds, sedges and brackish salt marsh up the length of the estuary in relation to the longitudinal salinity gradient.	4.1 – 4.5	Same as for fish	Entire estuary
MICROALGAE	Phytoplankton: Conduct water column chlorophyll a measurements and counts of dominant phytoplankton group.	5.1 – 5.3, 5.5	Same as for fish	Entire estuary (8 stns)
	Benthic microalgae: Conduct benthic chlorophyll a measurements	5.4	Same as for fish	Entire estuary (8 stns)
WATER QUALITY	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow	6.6, 6.7 & 6.8	At least monthly	At Lutzville causeway
	Monitor inorganic nutrient inflow from agricultural return flow in upper reaches (e.g. bore hole sampling)	6.6, 6.7 & 6.8	At least monthly	3-5 stns along upper banks

ECOLOGICAL COMPONENT	MONITORING ACTION	RELATED TPC (see Table 17)	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
	Collected longitudinal salinity & temperature profiles (<i>in situ</i>)	6.1 – 6.5	To be measured when biotic surveys require information for interpretation	Entire estuary (10-15 stns)
	Water quality measurements taken along the length of the estuary (surface and bottom samples) for pH, dissolved oxygen, suspended solids/turbidity and inorganic nutrients.	6.7 – 6.9		Entire estuary (10-15 stns)
	Baseline data set for pesticides/herbicides accumulation in sediments	6.13	Every 3 – 6 years	Focus on depositional areas
HYDRODYNAMICS	Water level recordings	8.6	Continuous	Near mouth
	Flow gauging	7.1 – 7.3 & 8.1	Continuous	Near Lutzville causeway
	Aerial photographs of estuary (spring low tide)	4.1 – 4.4 & 8.5	Annually	Entire estuary
SEDIMENT DYNAMICS	Bathymetric survey: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but more detailed in the mouth (vertical accuracy better than 300 mm)	8.5	Every 3-6 years, depending on time scale of dominant sedimentation/erosion processes in an estuary, as well as after flood events.	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	8.3 - 8.4		Entire estuary
	Daily sampling of suspended sediment (and organic matter)	8.2	Daily	Sishen-Saldanha train bridge

A proposed Monitoring Decision Support System to be applied in the long-term resource monitoring of estuaries, as part of the RDM process, is illustrated in Figure 11 (DWAF, 2004b).

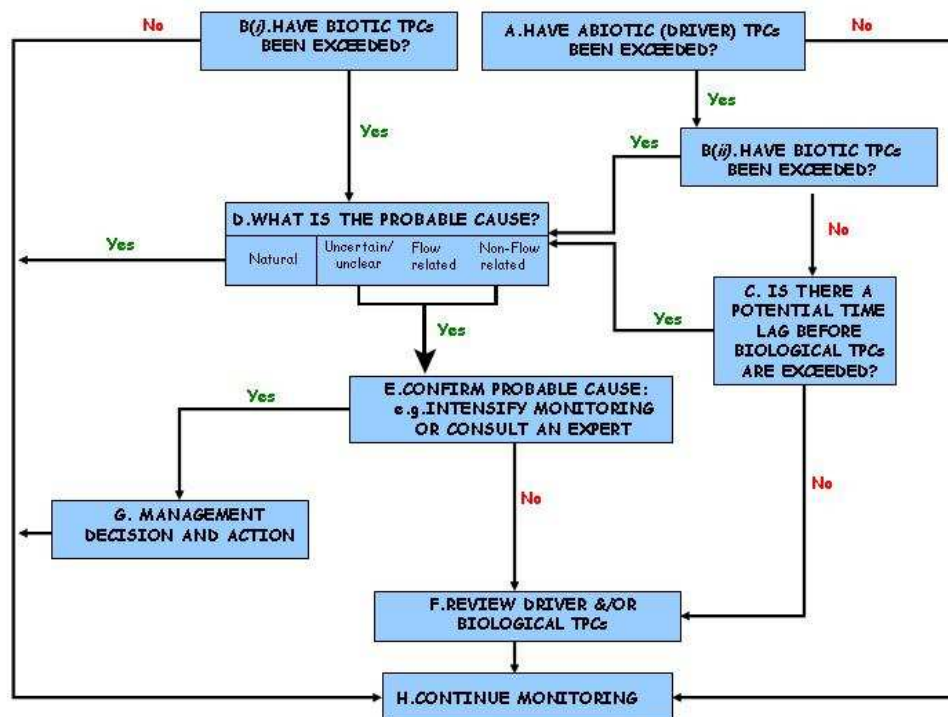


Figure 11: Proposed Monitoring Decision Support System to be applied in the long-term resource monitoring of estuaries

6.3 Recommended Research Studies to support RDM in Estuaries

The following have been recommended as worthwhile research studies to be undertaken in support of the RDM process for estuaries. As these should provide generic understanding, it is recommended that they rather be funded as research projects, e.g. through Water Research Commission (WRC) or National Research Fund (NRF):

- The role of remineralisation in the inorganic nutrient cycle of South African estuaries (this research topic will be addressed as part of the CERM: Intermittently Open Estuaries Study (K5/1581) of the WRC using the East Kleinemonde Estuary as case study).
- The ecological relevance of flagellates in South African estuaries. A probable approach would be to initiate a survey of a representative set of estuaries on the east, south and west coast to determine the proportions of flagellates relative to the other groups.

Historically, in RSA, information has been collected on phytoplankton and benthic microalgae using diatoms as the focus group. The reasons for selecting diatoms were:

- Diatoms were the focus microalgal group in the surf-zone work undertaken in Algoa Bay – viz. *Anaulus australis*.
- Diatoms are the major micro-algal group responsible for bloom formation in oceanic systems (e.g. the Benguela System).
- Diatoms were found to be a major group in both the benthic and phytoplankton groups in South African Estuaries on the south coast between Port Elizabeth and Cape Town.
- Diatoms were the focus of attention of earlier microalgal specialists, i.e. Cholnoky, Schoeman, Archibald and Giffen.
- Diatoms are still considered to be the major microalgal group upon which focus should be paid with respect to bioassessment of water quality in South Africa and in many other countries around the world, e.g. the Diatom Index System for water quality assessment.

As a result, there has been a greater development in the understanding of diatoms, both at the taxonomic and ecological level, by comparison with the other microalgal groups, e.g. Cyanophytes, Chlorophytes, Dinophytes, Euglenophytes.

In the case of the Olifants Estuary, the standard phytoplankton count analysis has produced data showing that flagellates made up 95% of the population in the March 2004 sampling and 66% in the August 2004 sampling sessions. Because of the dominance of flagellates in this west coast estuary, the diatom data lose some of their relevance, leaving a lack of information on the other groups as a serious shortcoming. The inability to interpret those data should be used to motivate for additional research.

- Biotic (in particular fish and invertebrate) exchange patterns between estuaries and the marine environment under variable freshwater inflow patterns along the west coast of South Africa. For example, the role of highly contrasting temperature between river and seawater (particularly in summer) on cueing effects (provided by freshwater inflow) should be investigated. In particular, the affect of reduction in freshwater inflow on such exchanges should be investigated.

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DEPARTMENT:
DIRECTORATE:

WATER AFFAIRS AND FORESTRY
RESOURCE DIRECTED MEASURES

**OLIFANTS/DORING CATCHMENT
ECOLOGICAL WATER REQUIREMENTS
STUDY**

**Appendices to RDM Report
on Estuarine Component**

FEBRUARY 2006

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APPROVED BY SOUTHERN WATERS ER & C cc

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APPROVED BY DEPARTMENT OF WATER AFFAIRS AND FORESTRY: DIRECTORATE RESOURCE DIRECTED MEASURES

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DIRECTOR

APPENDIX A

SUMMARY OF AVAILABLE DATA FOR THIS STUDY

**(measured against requirements specified for a
Comprehensive level determination)**

Data availability on sediment dynamics, hydrodynamics and water quality:

DATA REQUIRED	AVAILABILITY	COMMENT
Simulated monthly runoff data (at the head of the estuary) for present state, reference conditions and the selected future runoff scenarios over a 50 to 70 year period	Provided by Mr A Sparks, Ninham Shand Consulting engineers for a 70-year period	The confidence in the runoff data are <u>very low</u> as no accurate flow data was available for lower Olifants catchment
Simulated flood hydrographs for present state, reference conditions and future runoff scenarios: • 1:1, 1:2, 1:5 floods (influencing aspects such as floodplain inundation) • 1:20, 1:50, 1:100, 1:200 year floods (influencing sediment dynamics)	Flood peaks calculated for 10-year period. No flood hydrographs.	No info on floods larger than 1:20
Series of sediment core samples for the analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) taken every 3 years along the length of an estuary (200 m to 2 km intervals).	Grab samples (2004) at 1000 to 1500 m intervals	
Series of cross-section profiles (collected at about 500 to 1000 m intervals) taken every 3 years to quantify the sediment deposition rate in an estuary ¹ .	CSIR (1994), CSIR (1997)	
Set of cross-section profiles and a set of sediment grab samples for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations), need to be taken immediately after a major flood.	None	
Aerial photographs of estuary (earliest available year as well as most recent)	1942, 1958, 1966, 1976, 1979, 1980, 1981, 1987, 1998	CSIR
Measured river inflow data (gauging stations) at the head of the estuary over a 5-15 year period	None	A water level recorder was installed at the low water bridge at Lutzville, but it was not calibrated for flow
Continuous water level recordings near mouth of the estuary	Available from 2003	
Water level recordings at about 5 locations along the length of the estuary over a spring and a neap tidal cycle (i.e. at least a 14 day period).	CSIR (1997)	Collected in 1994, but only for one tidal cycle and by visual observation techniques
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 (i.e. period of maximum seawater intrusion) • peak of high flow season (i.e. period of maximum flushing by river water)	Eagle and Bartlett (1984); Morant (1984); CSIR (1990a & 1990b); CSIR (1997a); CSIR (1997b); CSIR (1999); CSIR (2000); Surveys conducted during March and August 2004 as part of this study	Data on the high flow season was limited
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	Eagle and Bartlett (1984) Morant (1984) CSIR (1997a) CSIR (unpublished data) Surveys conducted during March and August 2004 as part of this study	Data on the high flow season was limited
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary.		Removed from TOR by DWAF due to budgetary constraints
Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary	Monthly measurements on EC and inorganic nutrients were available from DWAF for 2003 – 2005 measured at the Lutzville causeway and Bill Harding (2004)	No data on suspended solid inputs
Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater	Data were derived from available literature (DWAF, 1995)	

Data availability on microalgae:

DATA REQUIRED	AVAILABILITY	COMMENT
Chlorophyll-a measurements taken at 5 stations at the surface, 0.5 m and 1 m depths. Cell counts of dominant phytoplankton groups i.e. flagellates, dinoflagellates, diatoms and blue-green algae. Measurements must be taken coinciding with typically high and low flow conditions.	Chlorophyll-a data is available for March and August 2004 corresponding to low and high flows. Counts of "other" phytoplankton available for March & August 2004.	Data reported in microalgae report.
Intertidal and subtidal benthic chlorophyll-a measurements taken at 5 stations (at least). Epipellic diatoms need to be collected for identification. These measurements must to be taken coinciding with a typical high and low flow condition (in temporarily closed estuaries measurements must include open as well as closed mouth conditions).	Five stations sampled in March 2004. Eight stations sampled in August 2004. Five stations also sampled in 2001 for benthic diatom ID. Data available for comparison. Low and high flow conditions complied with.	Data in report including interpretations from 2005 data at St Lucia.
Simultaneous measurements of flow, light, salinity, temperature, nutrients and substrate type (for benthic microalgae) need to be taken at the sampling stations during both the phytoplankton and benthic microalgal surveys.	Chlorophyll-a data reported as $\mu\text{g chl-a.gdry sediment}^{-1}$ but with comparisons from other estuaries.	Substrate type not identified. No basis for comparison available.

Data availability on macrophytes

DATA REQUIRED	AVAILABILITY	COMMENT
Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the reference condition (if available) Available orthophoto maps	1942, 1958, 1966, 1976, 1979, 1980, 1981, 1987, 1998	All of these photographs were used to map the distribution of the macrophytes and assess changes over time.
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.	Morant (1984) Bornman (2002) Bornman et al. (2002) Bornman et al. (2004)	Map and description of main plant community types. Seasonal data on distribution and cover of macrophytes along transects (1999-2001).
Permanent transects: - Measurements of percentage plant cover along an elevation gradient - Measurements of salinity, water level, sediment moisture content and turbidity	Bornman (2002) Bornman et al. (2002) Bornman et al. (2004)	Seasonal data on distribution and cover of macrophytes along transects and elevation gradients (1999-2001). Measurements of sediment salinity, moisture content, particle size, depth to groundwater and groundwater conductivity.

Data availability on invertebrates:

DATA REQUIRED	AVAILABILITY	COMMENT
Compile a detailed sediment distribution map of the estuary Obtain a detailed determination of the extent and distribution of shallows and tidally exposed substrates. During each survey, collect sediment samples for analysis of grain size and organic content at the six benthic sites.	Sediment samples collected in March and August 2004 for particle size analysis. Organic content also analysed.	Good data set collected during both field trips. See specialist report.
Surveys to determine salinity distribution pattern along the length of the estuary, as well as other system variables (e.g. temperature, pH and dissolved oxygen and turbidity) are required for different seasons and for different	System variables recorded in March and August 2004. One survey per trip at the ten sites.	Good data set collected during both field trips. See specialist report.

DATA REQUIRED	AVAILABILITY	COMMENT
states of the tide. Seasonal (i.e. quarterly) physico-chemical data are also required for each of the six benthic sampling sites		
Collect a set of six benthic samples each consisting of five grabs. Collect two each from sand, mud and interface substrates. If possible, spread sites for each between upper and lower reaches of the estuary. One mud sample should be in an organically rich area. Species should be identified to the lowest taxon possible and densities (animal/m ²) must also be determined. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides.	Subtidal benthic samples collected at ten sites. Nine replicates per site for each of the two field trips.	Good data set collected during both field trips. See specialist report.
Collect two sets of beam trawl samples (i.e. mud and sand). Lay two sets of five, baited prawn/crab traps overnight, one each in the upper and lower reaches of the estuary. Species should be identified to the lowest taxon possible and densities (animal/m ²) must also be determined. Survey as much shoreline as possible for signs of crabs and prawns and record observations. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides.	Benthic sled samples collected at the ten sites. Two replicates per site. Collected March and August.	Good data set collected during both field trips. See specialist report
Additional trip(s) may be required to gather data on the occurrence/recruitment and emigration of key species such as <i>Varuna litterata</i> , <i>Callinassa</i> and <i>Upogebia</i> which require a connection to the marine environment at specific times of the year.		
Collect three zooplankton samples, at night, one each from the upper, middle and lower reaches of the estuary. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides.	Ten zooplankton sites samples, two replicates per station. Collected March and August.	Good data set collected during both field trips. See specialist report

Data availability on fish:

DATA REQUIRED	AVAILABILITY	COMMENT
In a small estuary (<5km) collect at minimum three sets of samples from the lower, middle and upper reaches of the estuary. The samples should be representative of the different estuarine habitat types, e.g. <i>Zostera</i> beds, prawn beds, sand flats. At least one of the sample sets need to be in the 0 to 10 ppt reach of the estuary. Sampling should be representative of small fish (seine nets) and large fish (gill nets). In a larger estuary (>5km) sampling can either be at fixed intervals (every 2km) or have the upper, middle and lower reaches subdivided into at least a further three sections each. The samples should be representative of the different estuarine habitat types, e.g. <i>Zostera</i> beds, prawn beds, sand flats. At least one of the sample sets should be in the 0 to 1 ppt reach of the system. Sampling should be representative of small fish (seine nets) and large fish (gill nets). Sampling should be done during both the low and the high flow season for the full extent of the system (as far as tidal variation) to allow for predictive capabilities.	The Olifants Estuary was sampled during February (Summer) and August (Winter) 2004. The data comprises 18 seine samples, spaced 1-2 km apart and 6 gillnet samples spaced 4-6 km apart from the mouth to the Lutzville causeway. Additional data includes that obtained from 6 bimonthly sampling trips during 1996 – 1997, a two day gillnet survey during 1994 Commercial catch return data 2004 – 2005 from the gillnet fishery.	The data are good but lacking in that there were no Autumn or Spring samples for comparison. These data meet the requirements of an intermediate but not a comprehensive reserve. The 1996-1997 seine & gillnet samples are confined to the lower 6 km of the system. Good catch & effort data (2 700 net-days) but limited by under-reporting of non-target & illegal species.

Data availability on birds:

DATA REQUIRED	AVAILABILITY	COMMENT
Undertake one full count of all water associated birds, covering as much of the estuarine area as possible. All birds should be identified to species level and the total number of each counted. Monthly data sets for at least one year are required. If this is not possible, a minimum of four summer months and one winter month will be required (decisions on the extent of effort required will depend largely on the size of the estuary, extent of shallows present, as well as extent of tidally exposed areas).	Existing count data: 1975 Summer, Waders only (Summers et al. 1976) 1980 Summer, Lower 3km of estuary only (Underhill & Cooper 1984) 1996-2005 Summer & Winter counts, Lower 3km of estuary only (unpublished Co-ordinated Water Count (CWAC) data, University of Cape Town) 2004 Summer, Winter, whole estuary – this study Other literature: Turpie (1997) Morant (1984)	None of the existing counts cover all taxa over the entire estuary. This study provided a winter and a summer count, whereas a comprehensive study should ideally use monthly count data, or at least five comprehensive counts of the estuary. There are no ornithological studies available for this estuary

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APPENDIX B

PROPOSED CHANGES TO THE RDM METHODOLOGIES FOR ESTUARIES

After each Specialist workshop a list of possible improvements to the Ecological Reserve Determination methodology for estuaries is provided. The following list was recorded at the Olifants Estuary Specialist Workshop in July 2005:

Data Requirements

1. Secchi disc depth readings could be collected as a routine operation together with turbidity readings. Turbidity versus Secchi disc plots can be used to correlate visibility to turbidity readings. These relationships are usually site specific.
2. If the summer and winter fish data for this study had not been augmented by the Gillnet fishery data (collected by Marine and Coastal Management) it would have been very inaccurate as the fish species composition in the Olifants Estuary was found to be very different in spring and autumn. To obtain the required level of confidence, it is therefore important that quarterly samples are collected for Comprehensive reserve assessments.
3. To allow for comparison between different abiotic and biotic components, it should be stressed that 'Distance from mouth' be used for the identification of sampling stations.

Estuarine Health Index (EHI)

4. The possible breakdown of biotic components into different sub-components needs to be investigated. For example, it may be more appropriate to sub-divide the fish score into the five major categories of fishes which utilize South African estuaries (after Whitfield 1994)
5. In the biotic health index the use of Productivity versus Biomass (one of the components that are scored), needs to be investigated and clarified.
6. Investigate the possibility of capturing the Estuarine Health Index (EHI) scoring and motivation process in a spreadsheet format. This digital record combined with the detail findings of the Present State, Reference Conditions and recommended Ecological scenario(s) in the workshop report would then represent the Record of decision. It might even be possible to develop a programme that would populate the reserve templates automatically based on the final scores and motivations (i.e. spreadsheet) of the workshop. This could be a tremendous timesaving development and would assist in the verification of the ecosystems interactions (cross checking the cascade effects of the biological components.)

APPENDIX C

SPECIALIST REPORT: ABIOTIC COMPONENTS

**(HYDRODYNAMICS, SEDIMENT DYNAMICS
AND WATER QUALITY)**

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1. BRIEF

The CSIR was commissioned by Southern Waters ER & C to coordinate and conduct the estuarine component on the Reserve determination which forms part of a the larger Ecological Flow Requirement study on the Olifants/Doring Catchment commissioned by the Department of Water Affairs and Forestry.

This report contains the results from the Abiotic specialist studies (i.e. sediment dynamics, hydrodynamics and water quality). A brief summary of requirements in terms of these abiotic components is provided below:

i. Sediment dynamics

One detailed field survey was conducted to do a grading analysis of bed sediment samples. A hydrodynamic model with sediment transport modules was used to analyse the long-term equilibrium of the estuary under natural, present (with dam development) and possible future runoff and catchment development conditions.

The hydrodynamic model was calibrated on the recorded water level, river flow and tidal data. Sediment input from the river could be based on a suspended sediment rating curve if data are available, or the sediment transport capacity of the river could be calibrated against the catchment sediment yield to obtain a time series of sediment load. A hydrodynamic model with sediment transport modules was used to analyse the long-term equilibrium of the estuary under natural, present (with dam development) and possible future runoff and catchment development conditions.

ii. Hydrodynamics

For verification of the numerical model, longitudinal salinity profiles were collected on two occasions, representative of summer and winter flow conditions. Profiles were collected on high tide and low tides.

iii. Water quality

During the summer (low flow) and winter (high flow) water quality data will be collected along the estuary (high tide) for:

- System variables (salinity, temperature, turbidity/SS, DO and pH)
- Dissolved nutrients distribution (nitrite, nitrate, ammonia, phosphate and silicate)

Field data on toxic substances (e.g. trace metals) in sediments were not be included as part of this study as the estuary is not located in close proximity of industrial zones.

It was assumed that the water quality of river inflow would be provided by the river component (see assumptions). Seawater quality for the area was derived from available literature.

2. ASSUMPTION AND LIMITATIONS

The brief was undertaken based on the following assumptions and limitations:

- Due to budgetary constraints, the complete estuarine field data set, as recommended for a comprehensive ecological reserve determination, could not be collected as part of this project (i.e. only summer and winter surveys instead of quarterly surveys). It, therefore, should be noted that the confidence of the ecological reserve determination, may be lower than required for a comprehensive determination (even so, due to the size and complexity of the Olifants Estuary, the generic data requirements recommended for a Comprehensive Ecological Reserve determination may not have given the desired confidence in any way)
- Accurate inflow data on the magnitude and duration of floods in Olifants/Doring System was not available. Flood hydrographs representative of inflows into the Olifants Estuary for both the Reference Condition and Present State were not provided to the CSIR. As part of the sediment dynamics evaluation (University of Stellenbosch) some flood hydrographs were generated, but this needs to be improved on in future studies.
- The overall confidence in the hydrology is **very low** as only limited accurate baseflow data was available to base the hydrological and hydrodynamic assessments on. Summer baseflow comprises river flow, leaks from the Bulshoek Weir (though some of this is currently intercepted and pumped back into the irrigation system), return flows from the irrigators, and possibly inflow from springs (e.g. near Kapel). The baseflow is difficult to determine because:
 - The accuracy of the stage measurements at the bridge downstream of Lutzville depends on how well the bridge is cleaned of the debris that blocks the bridge culverts
 - The leaks from Bulshoek have been reduced and were estimated to be about 0.5 m³/s in April 2002 and since then the Lower Olifants River Water User Association (LORWUA) have pumped leakage water back into the canal or Bulshoek
 - An unknown proportion of the return flows may have been intercepted by irrigators further downstream
 - Future use of drip irrigation may further reduce return flows
 - There are unconfirmed reports of contributions from springs at say Kapel
 - Flows observed during the summer of 2004/5 at the Lutzville Bridge occurred during a drought when the irrigators may have been forced to take additional water from the river to supplement the water from the canal.
- Variable leakage from the Bulshoek Dam also hindered the estimation of flows that reach the estuary. Total leakage of water from Bulshoek was estimated to be 1.2 m³/s (26 January 1994) of which leakage through the foundation was estimated as about 0.7 m³/s, while the rest was from excessive leakage from the crest gates at the time and leakage from the canal.

Thereafter some work was done on the foundation of the Bulshoek Dam by DWAF: Worcester, with the effect that the leakage was much less, for some time. The leakage however gradually increased again and on 11 April 2002 it was estimated to be about 0.5 m³/s.

Thereafter DWAF: Construction did some major repair work (new concrete apron) to stabilize the foundation which unfortunately did not improve the situation, because the leakage is estimated to be about the same. Some groutwork still needs to be done, and that will potentially resolve the problem. In the mean time the Lower Olifants River Water User Association (LORWUA), at their own costs, recently installed pumps downstream of the dam wall, pumping leakage water back into either the irrigation canal or the dam. (Mr F van Heerden, pers comm.).

- The catchment of the Doring is by far the largest with about 24000 km². The Olifants catchment up to the confluence of the Doring and Olifants is much smaller with only about 2900 km². However, the two rivers have approximately the same mean annual runoff under natural conditions. The Sout on the other hand produces very little runoff (approximately 2% of the total MAR of the Olifants), and for this reason, together with the fact that there is very little gauging data, it was decided to exclude this area from the modelling and analysis.
- Water quality data from the Department of Water Affairs and Forestry (DWAf) at their routine monitoring station on the Olifants River at Lutzville causeway (E2H016Q01) (representative of the quality of river inflow to the estuary) were only available from December 2002 to January 2005. Reference Conditions were derived from the DWAf routine water quality monitoring station on the Doring River [Melkboom - E2H003] for the years 1980 to 1986.

3. STUDY AREA

The Olifants Estuary is approximately 250 km north of Cape Town and forms the generally accepted southern boundary of Namaqualand (Morant, 1984).

The estuary receives freshwater inflow from the Olifants/Doring systems which has a catchment of approximately 49 000 km² which makes it one of the largest catchments in South Africa. The naturalised mean annual run off (MAR) of $1070 \times 10^6 \text{ m}^3$, however, only contributes about 2% to the country's MAR. The Olifants River is approximately 250 km long and arises in the Agter Witzenberg, which is a winter rainfall area. The area drains hard, well-leached sandstone and quartzites of the Table Mountain Group. The Doring River drains the eastern slopes of the Cedarberg, the Swarttruggens and the western Roggeveldberge. This sub-catchment lies in the more arid Ceres Karoo. It drains mainly soft, leachable shales and thus has a different chemical characteristics to those of the main stem. The Doring River joins the Olifants river near Klawer. The Doring River, as it nears the confluence flows strong enough during winter to support a white-water rafting industry, but is reduced to a series of pools in summer (low flow period) (DWAf, 1997).

At present the main stem of the Olifants River has two major dams, namely the Clanwilliam Dam (with a capacity of $127 \times 10^6 \text{ m}^3$) and the Bulshoek Dam (with a capacity of $7.5 \times 10^6 \text{ m}^3$).

The Olifants Estuary is a permanently open system. The mouth is situated between a large sand spit on the south and a rocky bluff on the northern side. The position is fixed in the north by a reef (Morant, 1984). Just upstream of the mouth the estuary widens to about 400 m with water depths in a typical range of between 3 – 5 m. Prior to 1925, the lower reaches of the Olifants Estuary comprised a large swampy island encompassed by two channels which combined to form a common mouth. However, after a violent storm in 1925 the southern channel became blocked with marine sand (Morant, 1984). From about 15 km upstream of the mouth the estuary becomes narrower (100 – 200 m) and shallower with water depths of around 2 – 3 m. The head of tidal intrusion is approximately 36 km upstream at a low water bridge/causeway near Lutzville. Although the causeway has been constructed over a natural rocky obstruction in the system, tidal intrusion under natural conditions probably extended further upstream.

For the purposes of the study, the geographical boundaries for the Olifants Estuary are as follows (Figure 3.1):

- Downstream boundary: Estuary mouth (31° 42'S; 18° 11.34'E)
- Upstream boundary: Extent of tidal influence, i.e. the causeway at Lutzville - about 36 km from the mouth (31° 33.8'S; 18° 19.78'E)

- Lateral boundaries: 5 m contour above MSL along each bank.

The 5 m contour above MSL is indicated on the provided on 1:10 000 orthophotos (Olifants River Estuary spans about 10 1:10 000 orthophotos). Although the 1:10 000 orthophotos are electronically available, the 5 m contour above MSL is not yet available on the electronic versions.

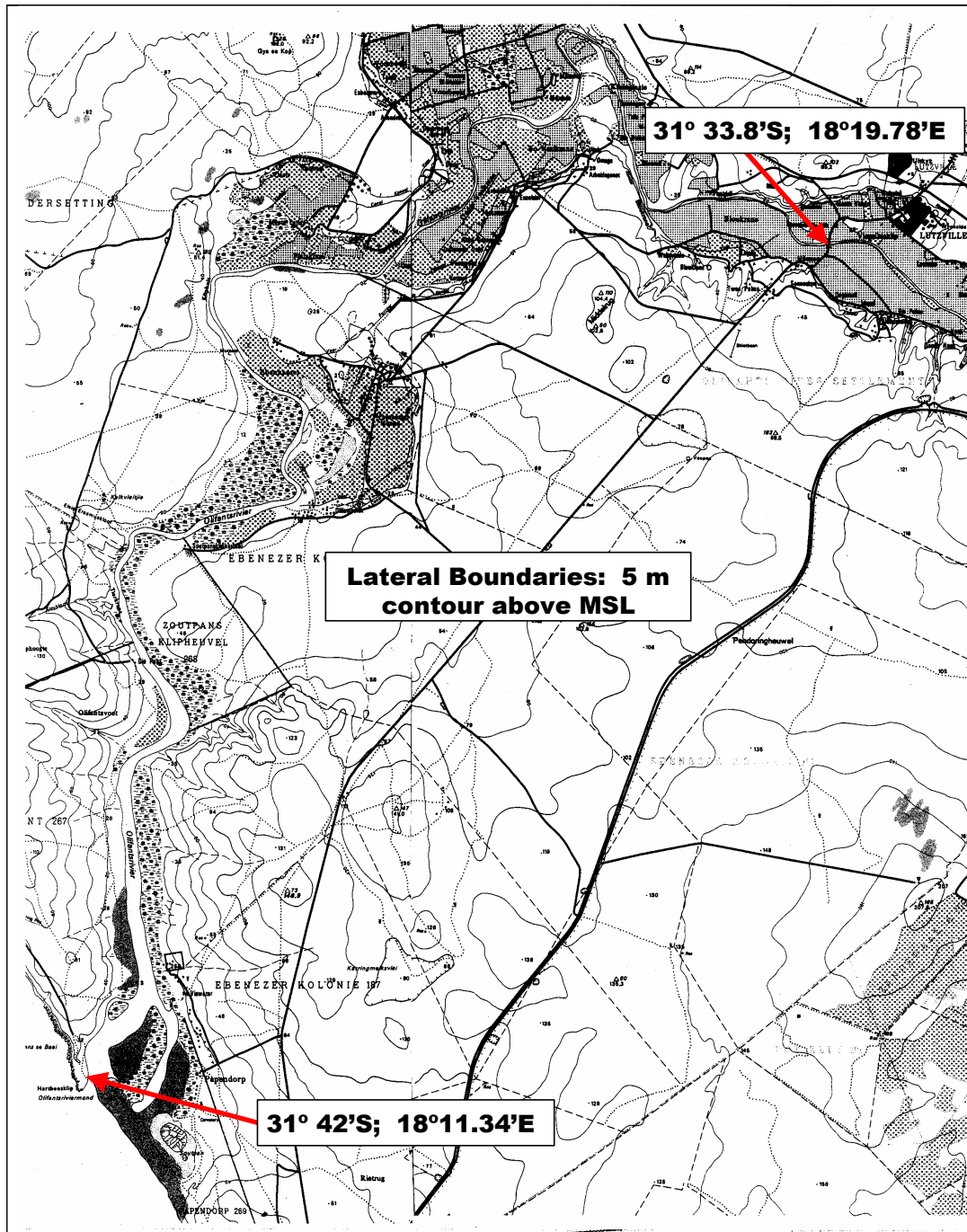


Figure 3.1: Geographical boundaries for the Olifants Estuary

4. AVAILABLE FIELD DATA

Available literature on the Olifants Estuary, related to its Abiotic characteristics are summarised Table 1.

TABLE 1: Summary of available literature on the Olifants Estuary: Abiotic components

REFERENCE	PERIOD	PARAMETERS	DETAILS
Eagle and Bartlett (1984)	1976 and 1977	Salinity, Temperature, pH, Dissolved oxygen, Inorganic nutrients	Once off surveys conducted during February 1976 and July 1977
Morant (1984)	1983	Salinity, Temperature, pH, Transparency (Secchi disc)	Limited data collected during an once-off survey conducted in winter of 1983
CSIR (1990a & 1990b)	1990	Salinity, Temperature	Logitudinal profile data collected in January and February 1990 (5 occasions)
CSIR (unpublished data)	1994	Salinity, temperature	Logitudinal profile data collected in January and March 1994 (2 occasions)
CSIR (1997a)	-	Salinity, Temperature, pH, Dissolved oxygen, Inorganic nutrients, Turbidity/Suspended solids	Overview of existing information and data on water quality that were available at the time
CSIR (1997b)	-	Topography, run off, water levels, evaporation, salinity, temperature	Synopsis of existing information and data related to the hydrodynamics that were available at the time
CSIR (1999)	1999	Salinity, Temperature	Once off surveys conducted on 2 occasions in in June 1999
CSIR (2000)	-	-	Preliminary rapid RDM assessment based on available information (unofficial)
CSIR (unpublished data)	1999	Inorganic nutrients	Once off survey conducted by the CSIR in June 1999
Present study	2004	Salinity, Temperature	Logitudinal profile data collected during March and August 2004 (high and low tides)
Present study	2004	pH, Dissolved oxygen, Inorganic nutrients, Turbidity/Suspended solids	Once-off surveys conducted during March and August 2004 (surface and bottom samples along the length of the estuary).
Bill Harding (2004)	-	Inorganic nutrients	Predicted monthly concentrations of inorganic nutrients entering the Olifants Estuary at the Lutzville causeway under Present and Reference Conditions

For this study, salinity and temperature profiles, as well as other water quality data (refer to Table 1) were collected from the Olifants Estuary on 2/3 March 2004 and 10/11 August 2004 (Figure 4.1).

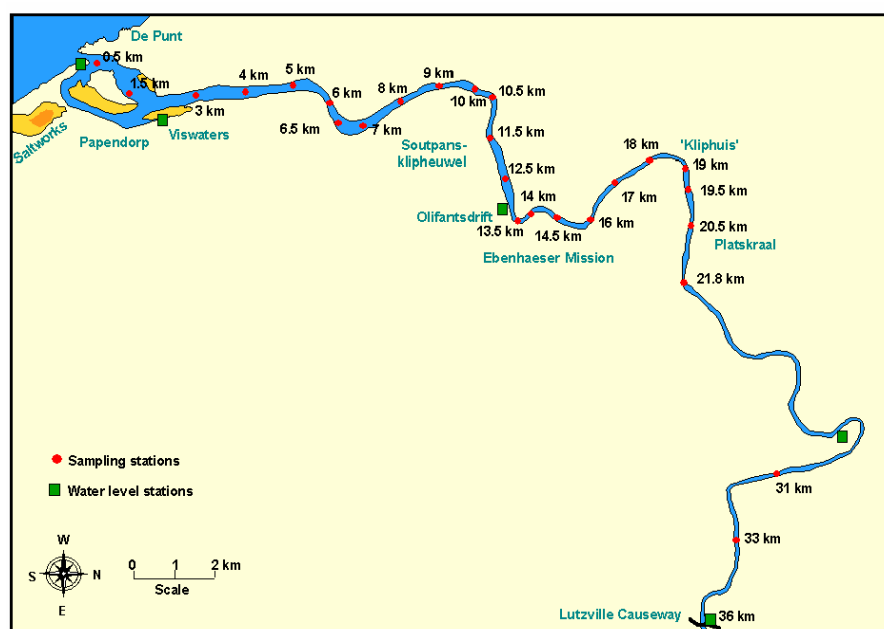


Figure 4.1: Map showing sampling locations in the Olifants Estuary (including location of water level stations referred to in modelling section)

5. HYDRODYNAMIC CHARACTERISTICS

5.1 Circulation Processes

i. Mouth dynamics

The mouth of the Olifants River estuary is permanently open and because of the strong tidal flows, protected outflow channel and the relatively high run-off of the system, it is considered highly unlikely that the mouth will close under present day conditions.

ii. Topography of the estuary

A summary of widths and depths of cross-sections at intervals of approximately one km along the Olifants Estuary is presented in Table 5.1. These data were collected as part of a monitoring programme of estuaries undertaken by the CSIR for the Department of Environment Affairs and Tourism and are presented in a separate report (CSIR, 2000)

These data show that the estuary is up to 545 metres wide near the mouth and gradually becomes narrower further upstream with a width of 19 metres just below the low water bridge at Lutzville. The depths are mostly between 2 and 3 metres below mean sea level (MSL). A maximum depth of - 6.6 m MSL is observed at 18.5 km from the mouth.

TABLE 5.1: Maximum depths and widths at MSL in the Olifants Estuary

Cross-section no	Chainage (km)	Depth (m) MSL	Width(m) MSL
1	0.0	3.6	108
2	1.0	2.6	545
3	1.7	3.6	440
4	3.0	1.6	222
5	4.0	1.8	240
6	5.0	2.2	196
7	5.5	2.7	235
8	6.0	2.2	139
9	6.5	5.0	178
10	7.0	2.6	237
11	8.0	2.1	134
12	9.0	3.1	102
13	10.0	4.3	68
14	11.0	4.1	66
15	12.0	3.3	73
16	12.8	2.8	93
17	13.5	3.1	80
18	14.5	3.9	68
19	15.5	3.0	74
20	16.5	3.1	60
21	17.5	3.6	58

Cross-section no	Chainage (km)	Depth (m) MSL	Width(m) MSL
22	18.5	6.6	47
23	19.0	2.3	77
24	19.5	2.2	63
25	20.0	3.0	63
26	21.0	2.9	51
27	22.0	2.5	48
28	23.0	2.5	47
29	24.0	2.3	81
30	25.0	2.4	36
31	26.0	4.2	46
32	27.0	1.9	47
33	28.0	2.4	36
34	29.0	1.7	33
35	30.0	1.3	33
36	31.0	1.9	34
37	32.0	2.0	32
38	33.0	2.3	29
39	34.0	2.4	28
40	35.0	2.2	19
41	35.9	0.9	22

iii. Water levels and Tidal prism

Water level variations were measured in 1994 by visual observations from gauging staffs at five positions in the estuary (Figure 4.1), as part of a CSIR research project. The results collected during a neap tide and for a springtide are presented in Figure 5.1a and 5.1b.

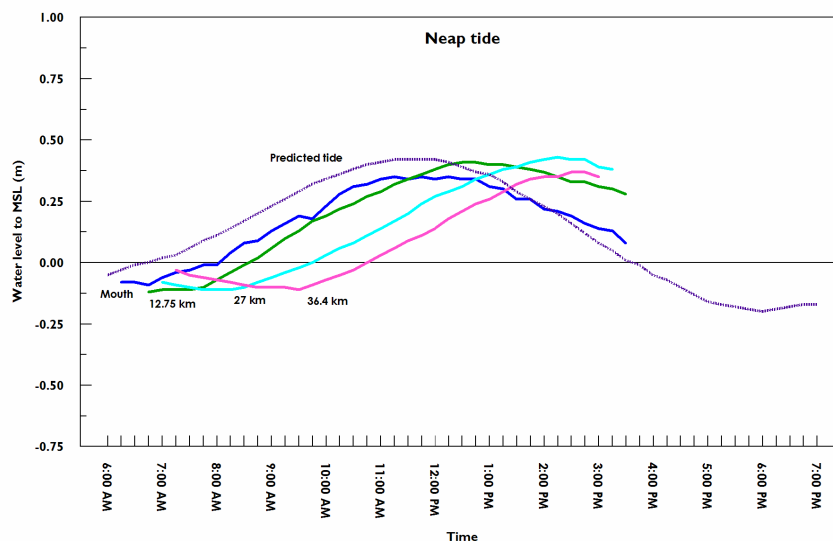


Figure 5.1a: Measured waterls in the Olifants estaury for a neap tide (22 Janunary 1994)

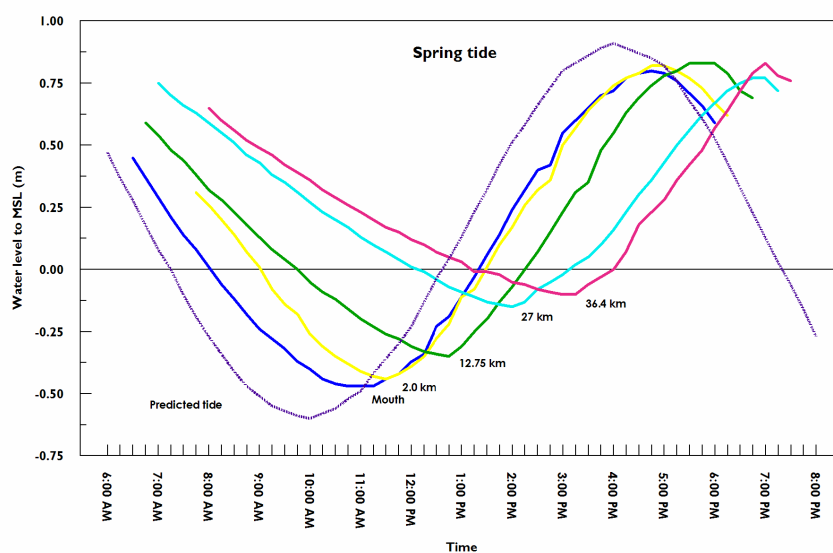


Figure 5.1b: Measured waterls in the Olifants estaury for a spring tide (28 January 1994)

The results show the existence of strong vertical tidal variations along the whole estuary and, for example, a water level variation of almost one metre at springtide below the low water bridge at Lutzville.

iv. Evaporation

Information on average evaporation, obtained from the Department of Agriculture of the University of Stellenbosch and based on data collected at Lutzville, are summarised in Table 5.2. These data show maximum average evaporation of 10.1 mm/day in December and 10.2 mm/day in January and a minimum average evaporation of 3.4 mm/day in July.

TABLE 5.2: Evaporation rates in the Olifants Estuary

<i>Month</i>	<i>mm/day</i>	<i>m³/s</i>
<i>Jan</i>	10.2	0.4920
<i>Feb</i>	9.5	0.4583
<i>Mar</i>	8.0	0.3859
<i>Apr</i>	5.8	0.2798
<i>May</i>	4.3	0.2074
<i>Jun</i>	3.6	0.1737
<i>Jul</i>	3.4	0.1640
<i>Aug</i>	4.2	0.2026
<i>Sep</i>	5.5	0.2653
<i>Oct</i>	7.3	0.3521
<i>Nov</i>	9.3	0.4486
<i>Dec</i>	10.1	0.4872

iv. Volume

To give an indication of the available water column habitat along the length of the estuary, the volume of water was calculated for every 5 kilometres for spring and neap tides (at high and low water conditions) during the low flow period (see Table 5.3). The maximum and minimum volumes achieved during the modeling sequence are also summarised. Figure 5.1 provides a graphic illustration of the accumulative volumes for spring and neap tides (low and high water conditions).

The spring tidal prism is about $4.2 \times 10^6 \text{ m}^3$, with the volumes at spring high and low tide being about $8.9 \times 10^6 \text{ m}^3$ and $4.7 \times 10^6 \text{ m}^3$ respectively. This is nearly 50% more than the neap tidal prism of about $2.1 \times 10^6 \text{ m}^3$, with volumes at neap high and low tide being $7.4 \times 10^6 \text{ m}^3$ and $5.3 \times 10^6 \text{ m}^3$ respectively.

What is also clear from these calculations is that more 50% of the estuary's water column habitat occurs in the lower 10 kilometres, and between 65 and 76% in the lower 15 kilometres of the system. About 90% of the water column habitat is in the lower 25 kilometres of the estuary. Therefore, changes in the salinity distribution in the lower reaches of the estuary will have significant consequences for the estuarine biota dependent on water column habitat, e.g. microalgae biomass and fish distribution.

TABLE 5.3: Estimated volumes (m^3) for 5 km reaches of the Olifants Estuary

<i>Chainage (km)</i>	<i>Volume at Spring tide (m^3)</i>			<i>Volume at Neap tide (m^3)</i>			<i>Maximum</i>	<i>Minimum</i>
	<i>High tide</i>	<i>Low tide</i>	<i>Average</i>	<i>High tide</i>	<i>Low tide</i>	<i>Average</i>		
5.00	3 589 057	1 393 930	2 491 494	2 892 703	1 804 623	2 348 663	3 862 359	1 276 464
10.00	1 765 801	868 384	1 317 092	1 419 942	947 919	1 183 931	1 891 573	767 971
15.00	1 121 132	758 370	939 751	973 115	780 803	876 959	1 178 303	677 819
20.00	841 589	600 856	721 222	737 170	607 416	672 293	904 913	514 711
25.00	600 803	465 389	533 096	537 541	460 931	499 236	690 876	372 018
30.00	412 099	352 485	382 292	382 483	345 861	364 172	504 392	276 548
35.00	245 665	228 473	237 069	234 949	221 394	228 171	350 153	168 283
36.40	34 121	31 820	32 970	32 548	30 564	31 556	51 118	21 049
Side channel	258 060	45 855	151 957	169 912	54 454	112 183	297 558	31 485
Total	8 868 327	4 745 562	6 806 945	7 380 364	5 253 966	6 317 165	9 731 243	4 106 348

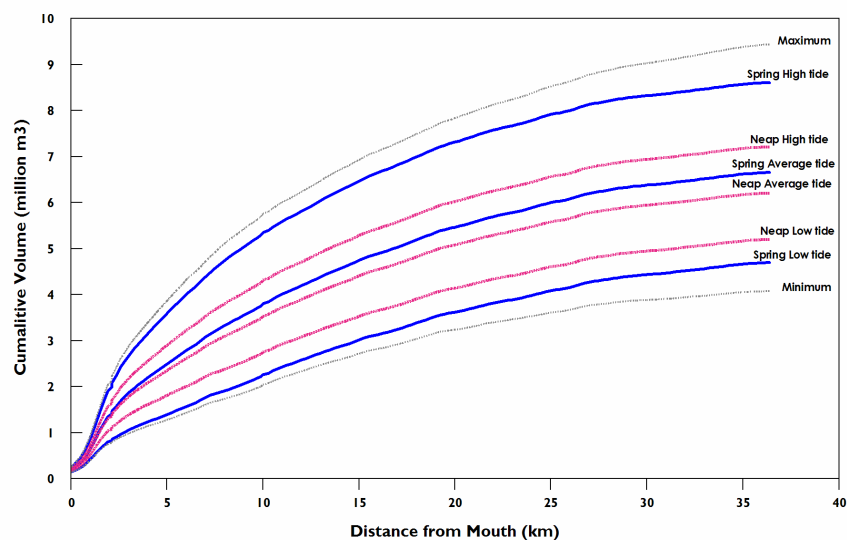


Figure 5.2: Graphic summary of the accumulative volume in the olifants Estuary for spring and neap tides (high and low tides) and the maximum and minimum volumes

5.2 River Inflow versus Salinity Distribution

5.2.1 Measured salinity distribution

In addition to the salinity data that were recorded as part of this study, the longitudinal salinity structure of the Olifants Estuary has been investigated extensively over the past years.

For the purposes of the Ecological Reserve determination, it is important to be able to correlate any measured salinity structure to specific river inflow patterns. Unfortunately measured inflow data at the head of the estuary (i.e. the Lutzville low water bridge) were often not available. Such information was therefore either derived from measured inflow data from gauging stations further upstream (e.g. Melkboom and Bulshoek) or estimated from simulated runoff data.

Historical data sets and measurements taken as part of this study were, however, interpreted as best possible to extract the necessary information to support predictions on the salinity characteristics of the Olifants Estuary under different river inflow ranges.

The earliest salinity distribution data that could be obtained for the Olifants Estuary was that collected by Eagle and Bartlett in February 1976 (Eagle and Bartlett, 1984). Only surface salinities were measured at 6 stations along the lower estuary. Simulated average monthly inflows to the Olifants Estuary in February 1976 was estimated around 8 m³/s during these measurements.

The combined measured inflow of the Olifants/Doring catchment varies between 28 m³/s and 6 m³/s for the weeks preceding the data collection, with the Doring catchment contributing about 20m³/s and the Olifants on average 6m³/s. Note, that there are significant losses down stream from the Olifants/Doring confluence, especially in summer when irrigation is at its peak. The simulated results were therefore judged to be representative of the flow for that period. The estimated salinity distribution, as derived from those limited measurements are illustrated in Figure 5.3.

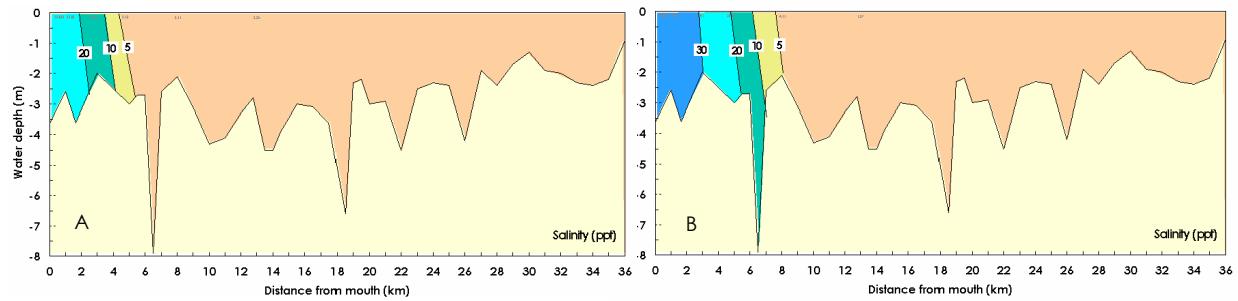


Figure 5.3: Estimated salinity distribution patterns (based on surface salinities) measured in the Olifants Estuary on 24 February 1976 on A. Low tide and B. High Tide

Based on surface salinities measured in the Olifants Estuary in July 1977 (Eagle and Bartlett, 1984), the estuary appeared to be completely fresh, with salinities throughout the system below 3 ppt, during both a low and high tide (Figure 5.4). Based on simulated runoff data, the average monthly runoff into the Olifants Estuary in July 1977 was about 170 m³/s, representative of flood conditions.

Measured riverflows from the Doring catchment indicate repeated freshettes of up to 300m³/s for June 1977. The Olifants had a flow of about 1m³/s during that period. This correlated well with the measured data.

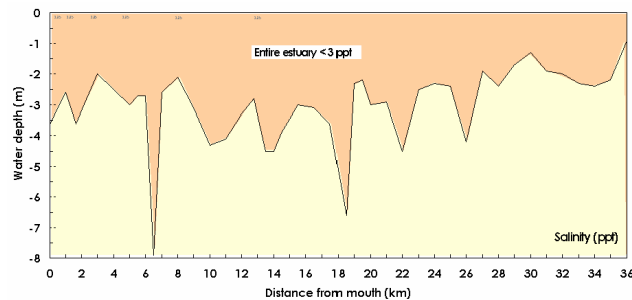


Figure 5.4: Estimated salinity distribution patterns (based on surface salinities) measured in the Olifants Estuary on 10/11 July 1977 (both low and high tide)

In 1990, a series of longitudinal salinity profiles were collected from the Olifants Estuary during summer (January and February) (Figure 5.5 and 5.6).

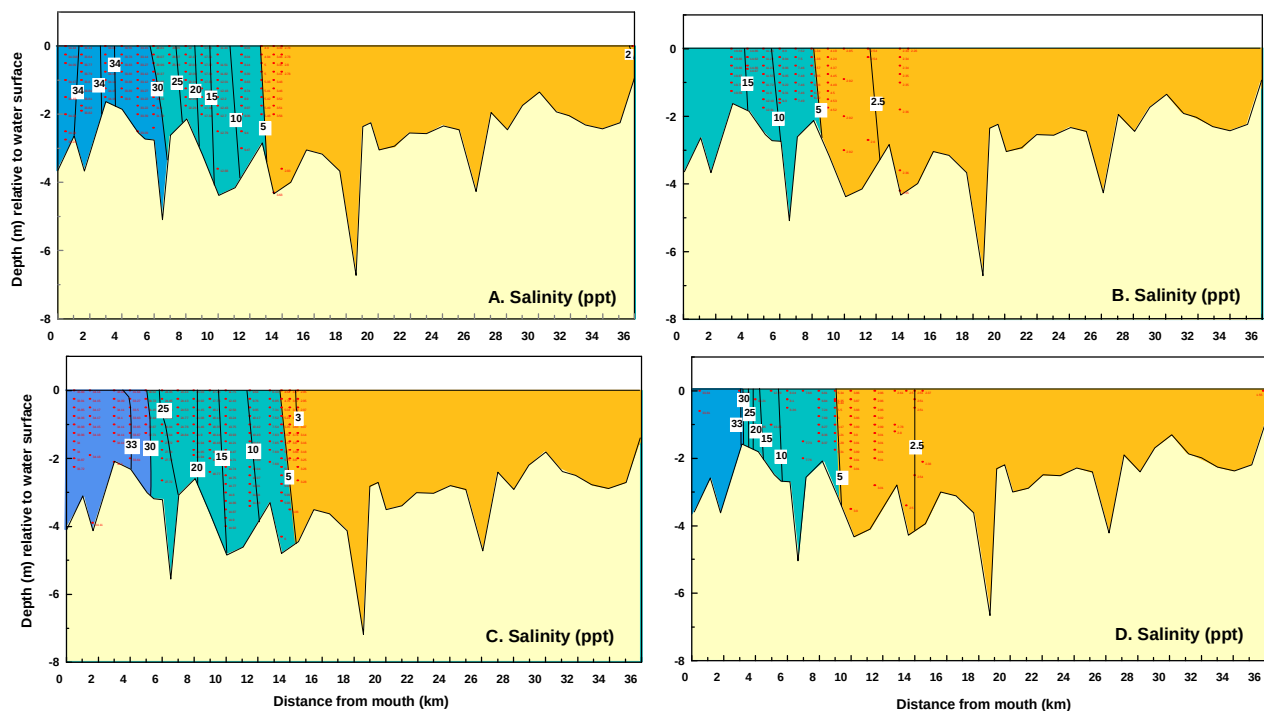


Figure 5.5: Salinity distribution patterns measured in the Olifants Estuary on A. 27 January 1990 during a spring high tide (flood), B. 28 January 1990 during a spring low tide (ebb), C. 28 January 1990 during a spring high tide (flood) and D. 29 January 1990 during a spring low tide (ebb)

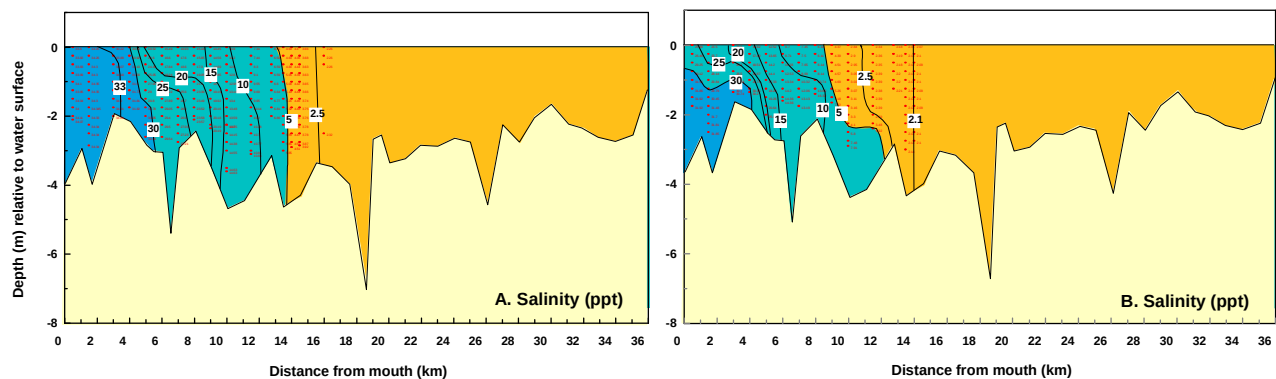


Figure 5.6: Salinity distribution patterns measured in the Olifants Estuary on 4 February 1990 on a A. neap high tide (flood) and B. neap low tide (ebb)

For both the January and February 1990 surveys, the average monthly inflow to the estuary, based on simulated data, is estimated at about $1.5 \text{ m}^3/\text{s}$. (Simulated Present state flows were augmented with about $0.75 \text{ m}^3/\text{s}$ to compensate for the loss of the Bulshoek Dam leakage.) Flows of about $7 \text{ m}^3/\text{s}$ were measured in the Olifants catchment, the difference is the reduction due to abstraction, evaporation and return flow.

During high (flood) tides, a strong horizontal gradient developed in the system ranging from $> 30 \text{ ppt}$ at the mouth to 5 ppt about 14 km upstream of the mouth. No marked vertical stratification was evident during high tides. During low (ebb) tides, a strong horizontal salinity gradient remained in the system

with the 5 ppt contour moving seaward to about 10 km from the mouth. Limited vertical stratification developed in the middle reaches of the estuary during the ebb tides.

In April 1991, a longitudinal salinity profiles was measured during a neap high tide, when river inflow to the system was about $1.4 \text{ m}^3/\text{s}$ (based on average monthly simulated data) (Figure 5.7). Measured flows in the Olifants catchment were about $6 \text{ m}^3/\text{s}$. The distribution of salinity was much the same as for January 1990, with a strong horizontal gradient existed in the system ranging from $> 30 \text{ ppt}$ at the mouth to 5 ppt about 14 km upstream of the mouth.

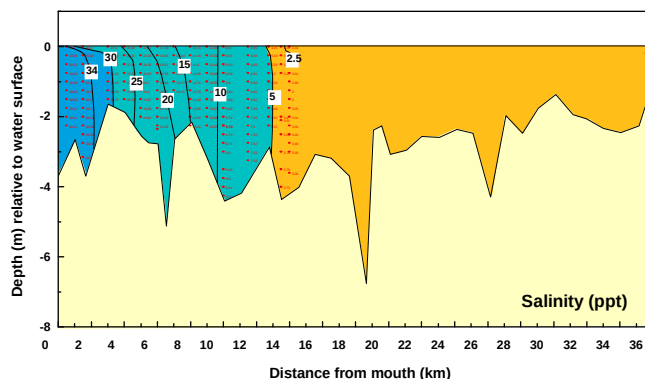


Figure 5.7: Salinity distribution patterns measured in the Olifants Estuary on 30 April 1991 during a neap high tide (flood)

In January 1994, when simulated monthly runoff to the estuary averaged around $1.7 \text{ m}^3/\text{s}$ (Measured $6 - 7 \text{ m}^3/\text{s}$ in Olifants/Doring catchment during sampling period), salinity distributions were similar to that observed during the same time in 1990 - the estuary showed a strong horizontal salinity gradient ranging from $>30 \text{ ppt}$ at the mouth to 5 ppt about 14 km upstream of the mouth during the high tide (Figure 5.8). Limited vertical stratification also developed during the low (ebb) tide.

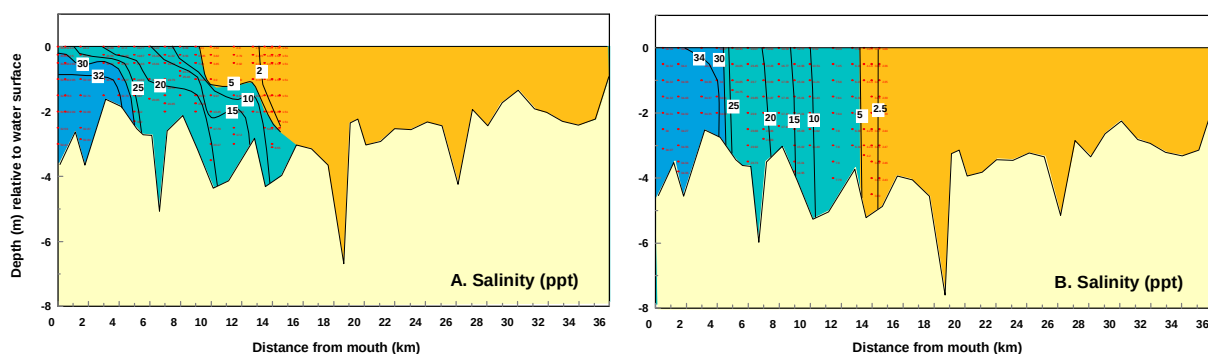


Figure 5.8: Salinity distribution patterns measured in the Olifants Estuary on A. 20 January 1994 during a neap low tide (ebb) and B. 27 January 1994 during a spring high tide (flood)

In March 1994, which was probably at the end of the low flow period for that year, salinity distribution measured on a neap low tide (ebb), also showed limited vertical stratification in the middle reaches, but the horizontal gradient now penetrated further upstream, with the 5 ppt contour at around 18 km from the mouth (Figure 5.9). Simulated monthly runoff is estimated at $2.3 \text{ m}^3/\text{s}$ (between $4 - 7 \text{ m}^3/\text{s}$ was measured in the Olifant/Doring catchment).

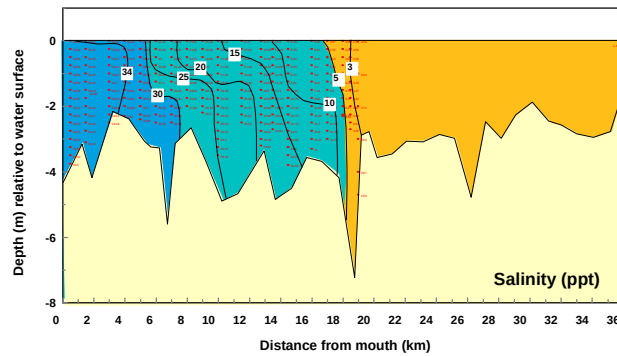


Figure 5.9: Salinity distribution patterns measured in the Olifants Estuary on 22 March 1994 during neap low tide (early ebb)

Salinity distribution patterns measured on 21/22 June 1999, at the end of a lower flow period during that year, also showed a similar picture – a strong horizontal gradient ranging from > 30 ppt at the mouth with the 5 ppt contour at about 18 km from the mouth (Figure 5.8). Measured flow was estimated at $2.4 \text{ m}^3/\text{s}$.

Immediately after this survey, the winter rains commenced increasing runoff to about $12.6 \text{ m}^3/\text{s}$ (simulated runoff for this period reflects a average value of $9.5 \text{ m}^3/\text{s}$). These increased flows started to push saline water from the estuary, albeit quite slowly. On 29 June 1999, the 5 ppt contour was only down to about 16 km from the mouth compared to 18 km a week earlier (Figure 5.10).

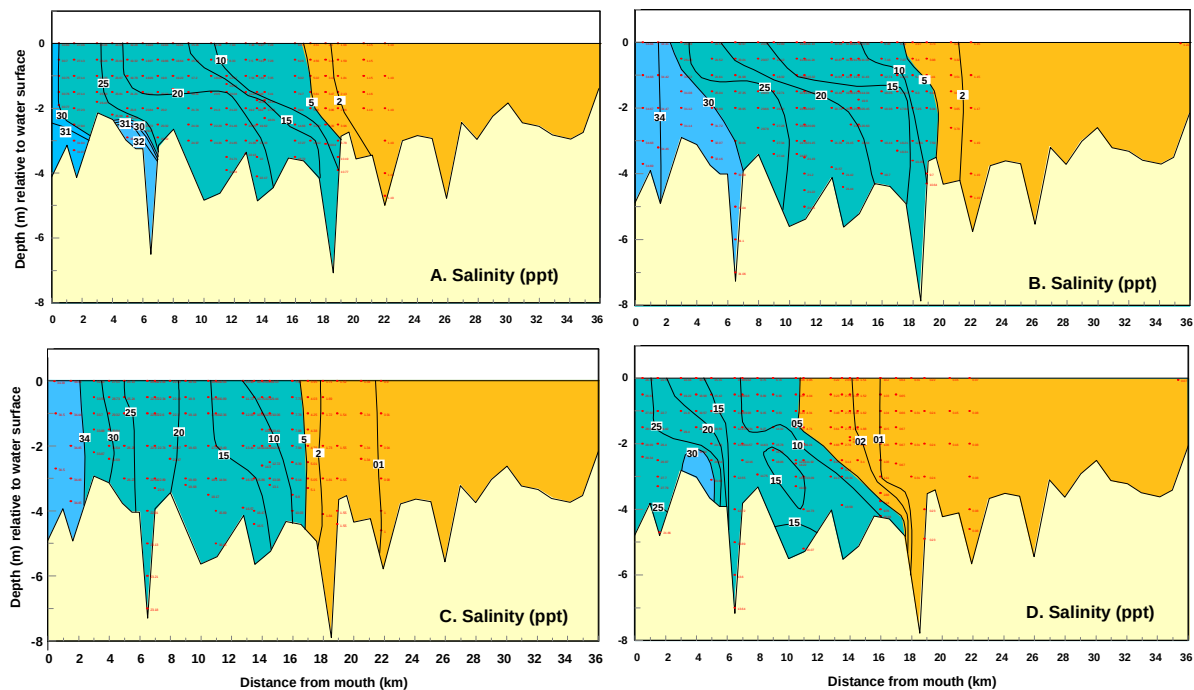


Figure 5.10: Salinity distribution patterns measured in the Olifants Estuary on A. 22 June 1999 during a neap low tide (ebb), B. 23 June during a neap high tide (flood), C. 28 June 1999 during a spring high tide (flood) and D. 29 June 1999 during a spring low tide (ebb)

In early March 2004 (as part of this study), salinity distribution patterns were measured in the estuary, at the time of an extended low flow period (i.e. where inflow to the estuary was $1.8 \text{ m}^3/\text{s}$ for a few months) (Figure 5.11).

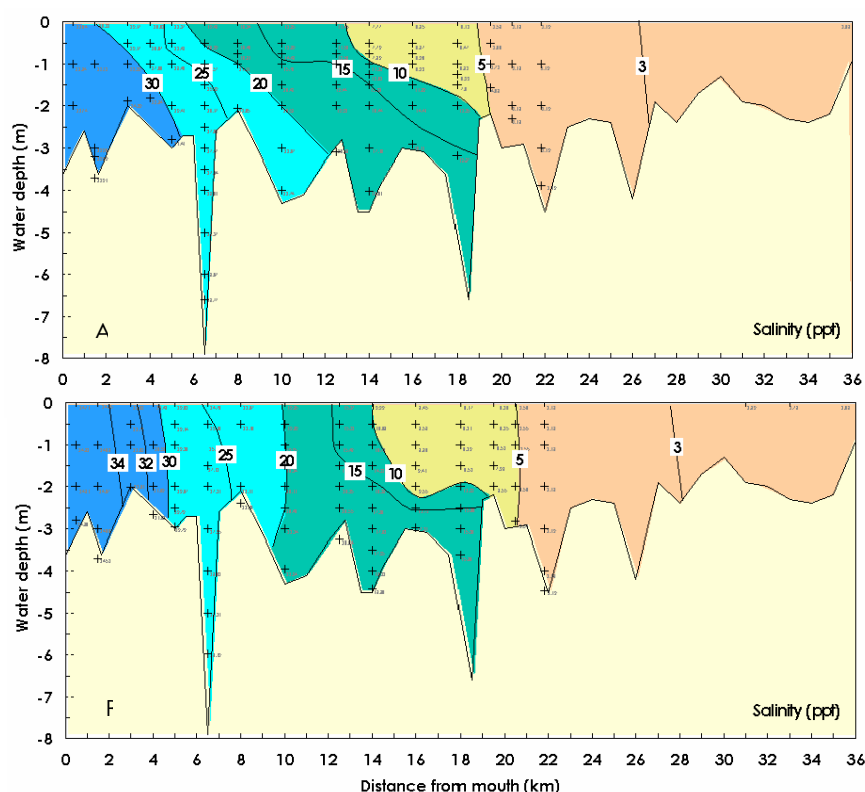


Figure 5.11: Salinity distribution patterns measured in the Olifants Estuary on 3 March 2004 during a spring tide A. Low tide and B. High tide

As with all the other surveys, the most dominant feature was the strong horizontal salinity gradient (with limited vertical stratification in the middle reaches). During this survey, as a result of the prolonged period of low river inflow, the 5 ppt contour penetrated to about 20 km upstream of the mouth during high tide.

In August 2004, when inflows to the estuary averaged around $16.8 \text{ m}^3/\text{s}$ (the bulk of the inflow was from the Doring catchment), this stronger river inflow resulted in marked vertical stratification developing in the system with salinities near the mouth ranging from about 5 ppt in surface water to >30 ppt in bottom waters (Figure 5.12).

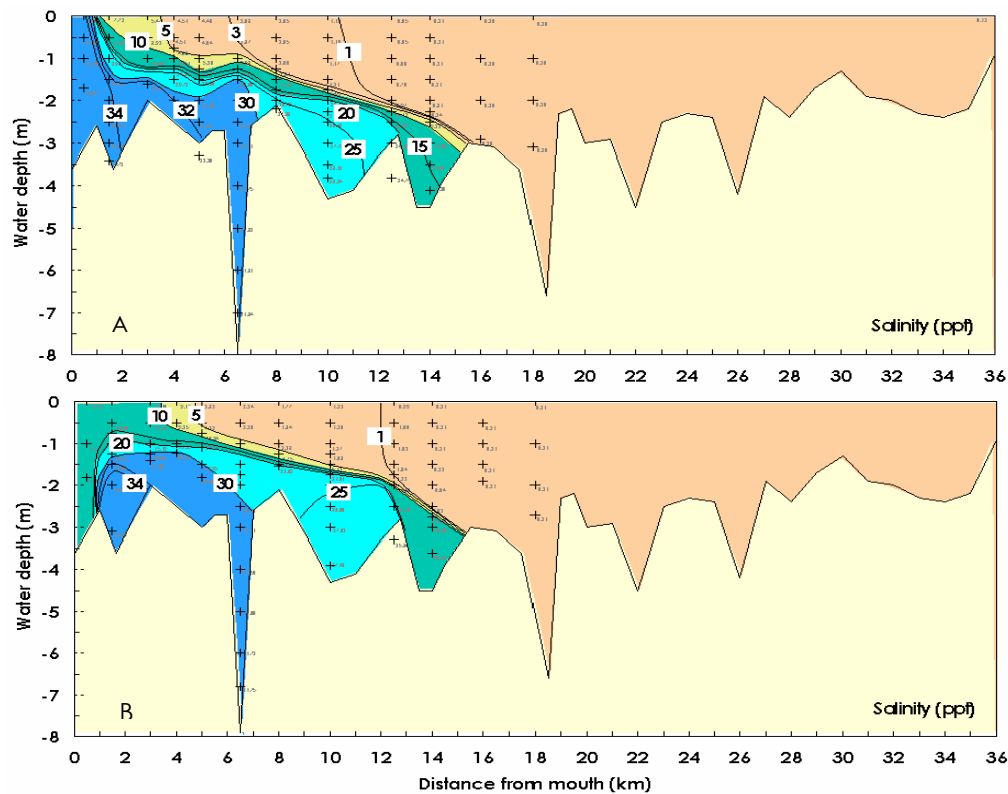


Figure 5.12: Salinity distribution patterns measured in the Olifants Estuary on A 10 August 2004 during a spring high tide and B. 11 August 2004 during a spring low tide

5.2.2 Numerical modelling of salinity distribution

A major result of development (e.g. impoundments and direct abstraction) in the catchment of a permanently open estuary is that a reduction in lower baseflow and increase in the duration of the low flow periods could result in increased salinities upstream in the estuary.

A mathematical model utilizing the Mike 11 modelling system was therefore applied to the estuary to simulate the effects of low flow conditions on the salinities.

The Mike 11 modelling system, which was developed in the 1970's at the Danish Hydraulics Institute and is regularly upgraded, has been applied worldwide in various investigations. It is an advanced and user-friendly one-dimensional dynamic modelling system for rivers and estuaries. The hydrodynamic module is the basic module in Mike 11; additional modules can be used for simulations of transport dispersion, water quality and sediment transport among others.

The hydrodynamic and transport-dispersion modules were used in the investigations described in this report.

Modelling results indicated the following:

- At flow of more than 20 m³/s limited saline intrusion occurs in the lower reaches of the Olifants Estuary, i.e. saline penetration is ~ 7.0 km or less on the high tide and negligible on the low tide.
- At a flow of less than 20 m³/s saline intrusion on the low tide becomes more persistent
- At flows of less than 5 m³/s there is a significant salinity intrusion into the lower reaches of the estuary.
- At flows of about 2 m³/s the salinity profile is still reasonable stable, with only limited additional intrusion if the simulation period is extended from 2 months to 6 months, i.e. ~2 – 3 km.
- At flows of about 1 m³/s the salinity profile becomes very sensitive to the duration of the simulations and extending the period of the simulation from 2 to 6 months, increases the extent of salinity penetration by 4 km (10ppt) and 7 km (0.5 ppt).
- At flows of 0.5 m³/s salinities rapidly increase to 32 km upstream of the mouth.

Numerical modelling results:

FLOW RANGE	DISTANCE FROM MOUTH (km)							
	HIGH TIDE				LOW TIDE			
	<30ppt	<20ppt	<10ppt	<0.5 ppt	<30ppt	<20ppt	<10ppt	<0.5 ppt
50m ³ /s	2.5	3.3	4	5.8	-	-	0 (1.4 ppt)	2.0
30m ³ /s	3.2	4.2	4.9	6.8	-	-	0 (5.7 ppt)	2.2
20m ³ /s	3.5	4.6	5.4	7.3	-	0 (11.7ppt)	0.25	2.3
10m ³ /s	4.1	5.2	6.2	8.4	0 (22.7ppt)	0.25	1.6	3.8
5m ³ /s	4.7	5.9	7.2	9.9	0 (28.9ppt)	1.6	2.6	6.5
2m ³ /s	5.8	7.5 – 9.2	9.2 -11.1	14.8 – 17.5	1.0	3	5.4	12.5
1m ³ /s	8	8.7- 11	10.4 -14.2	16.0 - 23.3	1.0	3.2	7	18.4
0.5m ³ /s	8.8-10.4	14.1 – 15.3	19.1 – 21.0	31.0- 32.0	2.6	7.8	14.1	28.12

Figure 5.13 illustrates some of the modelling results for a 3-month period.

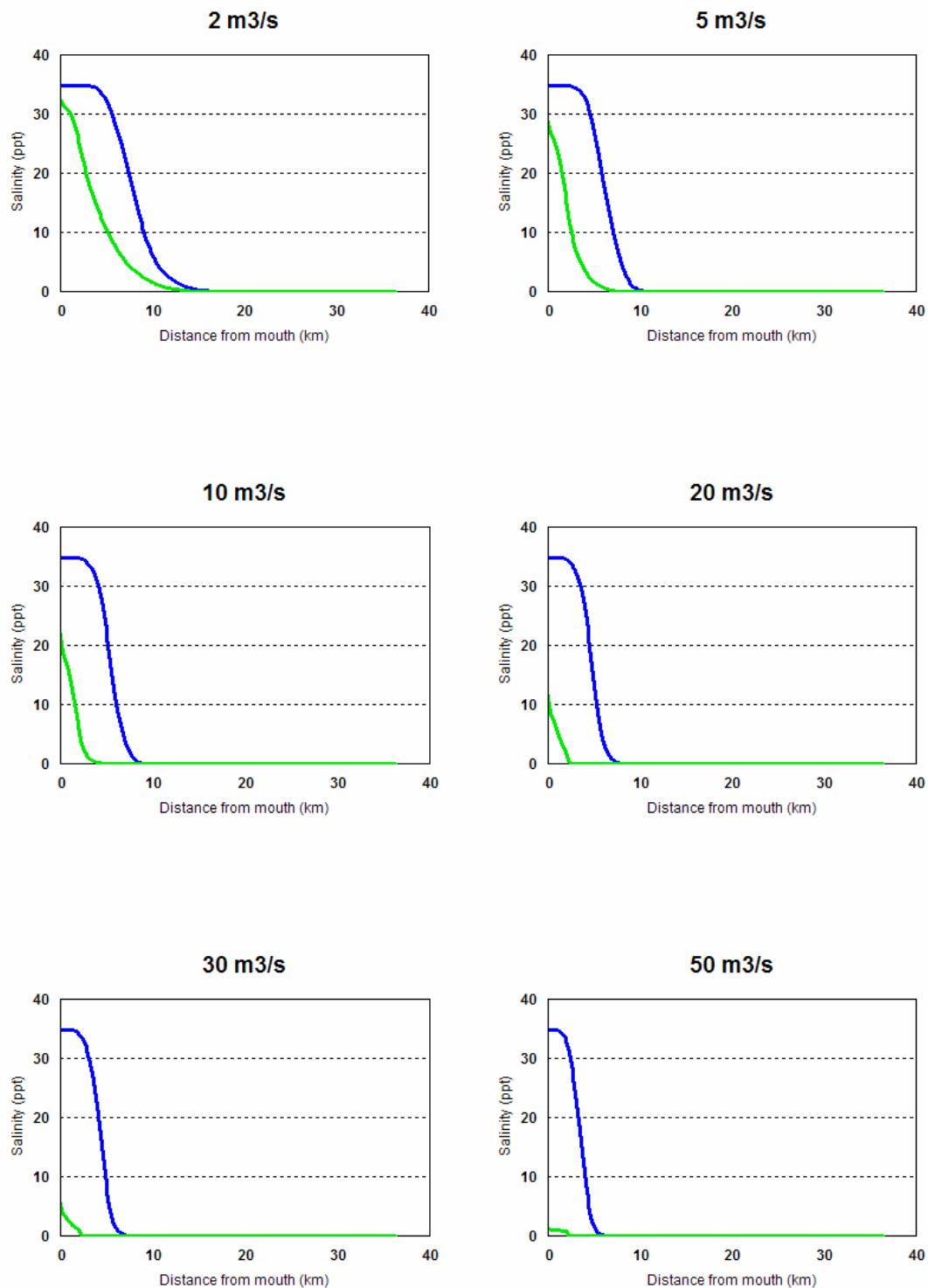


Figure 5.13 Illustrations of some of the numerical modelling results for a 3-month period (Blue = high tide; Green = low tide)

6. WATER QUALITY CHARACTERISTICS

The water quality assessment considered the following variables:

- System variables (temperature, pH, dissolved oxygen and turbidity/suspended solids)
- Inorganic Nutrients (inorganic nitrogen, reactive phosphate and reactive silicate)
- Toxic substances (only discussed briefly, as this was not within the scope of this study).

6.1 System Variables

6.1.1 Temperature

Most of the water quality studies on the Olifants Estuary included temperature measurements (Table 1). A plot of these data sets against salinity is provided in Figure 6.1.

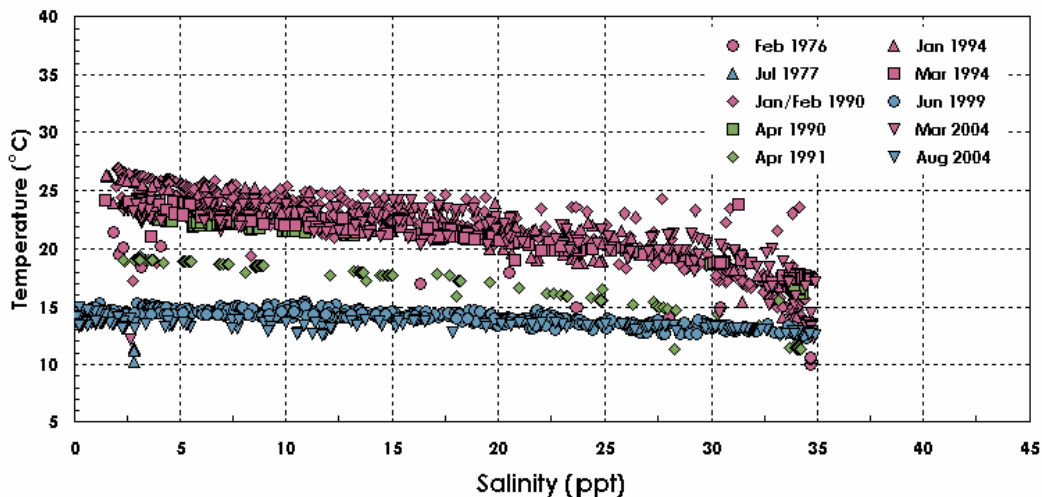


Figure 6.1: Temperature versus salinity distribution measured in the Olifants Estuary from 1976 to 2004

The results show a distinct seasonal signal in the temperature regime of the Olifants Estuary: During summer the temperatures in the estuary can be as low as 10°C near the mouth to around 25 °C in the upper reaches, while in winter the range is much narrower, ranging from about 13°C near the mouth to around 15 °C in the upper reaches. Interesting to note is the temperature regime during April 1991, indicative of the transition (autumn signal) developing between the typical summer and winter signals.

Temperatures in the lower reaches of the estuary are influenced largely by conditions at sea. Upwelling is a common feature along this section of coast where the temperatures of newly upwelled waters typically range between 9 – 14 °C, depending on the strength of the upwelling event (DWAf, 1995). The upwelling season is generally between August and May (Monteiro and Largier, 1999). Along the west coast, these events are largely driven by the onset of S/SE winds which appears to have mean periodicity of 6 days in spring/summer and 10 days in winter/autumn (Walker, 1984), with the actual event persisting for a few days within the period.

Further upstream the variation in temperature between summer and winter follows typical seasonal trends in atmospheric temperature.

An illustration of the typical summer and winter temperature distribution patterns expected for the Olifants Estuary, based on data collected during March 2004 (summer) and August 2004 (winter), are provided in Figure 6.2.

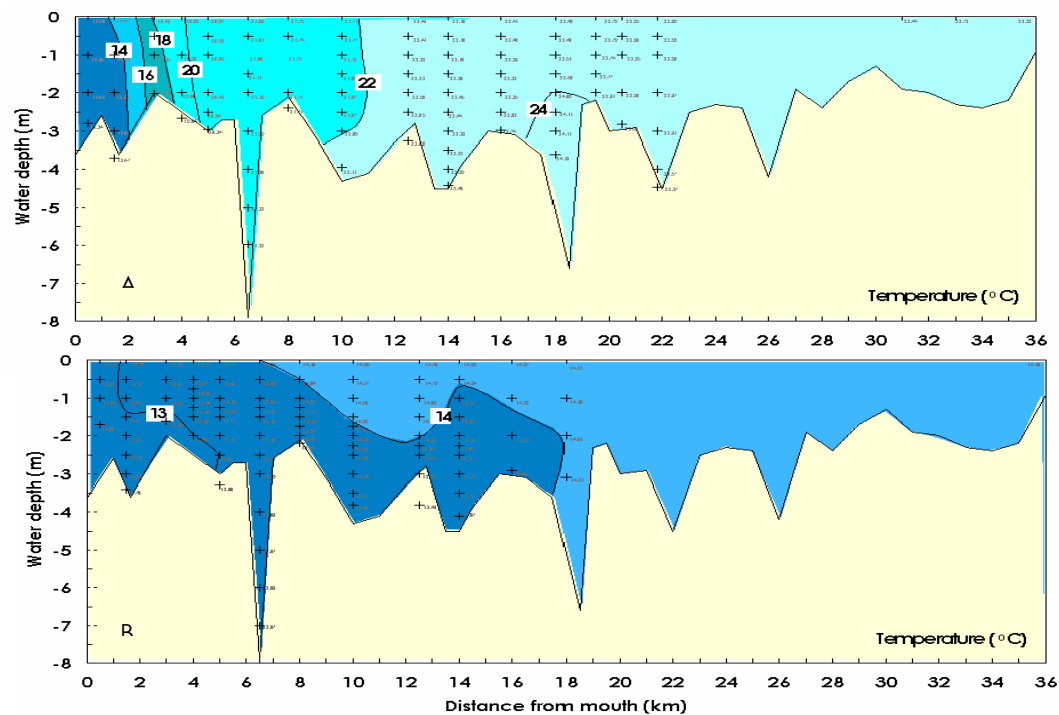


Figure 6.2: Longitudinal temperature distribution patterns measured in the Olifants Estuary on A. March 2004 (representative of summer conditions) and B 10 August 2004 (representative of winter conditions)

6.1.2 pH

Historical data on the pH characteristics of the Olifants Estuary, as well as data collected as part of this study, revealed no distinct patterns or trends and levels typically ranged between 7.3 and 8.5 throughout the system, as illustrated in Figure 6.3.

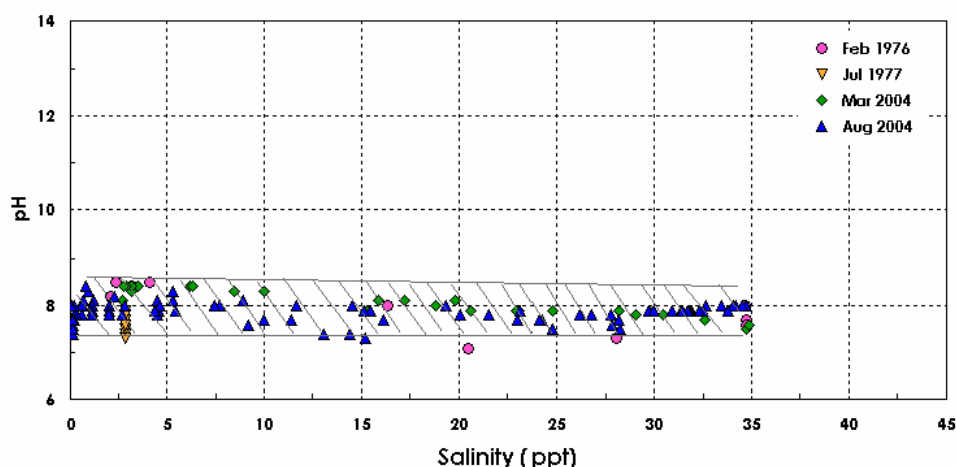


Figure 6.3: Measured data on pH versus salinity distributions measured in the Olifants Estuary

As expected the above range falls within the range measured in the inflowing river water (based on data collected by the Department of Water Affairs and Forestry [DWAF] at their routine monitoring station on the Olifants River at Lutzville causeway - E2H016Q01) (Figure 6.3) and that of seawater (between 7.9 and 8.2) (DWAF, 1995). The range also falls within that which is predicted for river inflow to the estuary under Reference Condition (~7.3) (Harding, 2004).

Although it was expected for the pH from the main stem (i.e. Olifants) to be relatively low, draining hard, well-leached sandstone and quartzites of the Table Mountain Group, data collected from the Bulshoek dams from 1997 to 2000 showed median values of 7.1 with a minimum value of 6.5 (refer to www.dwaf.gov.za/IWQS/water_quality/NCMP/olifantsdoorn.htm). Therefore, this suggests that even under scenarios where inflow to the estuary will be dominated by water from the Olifants river, it is unlikely markedly alter the pH regime in the estuary.

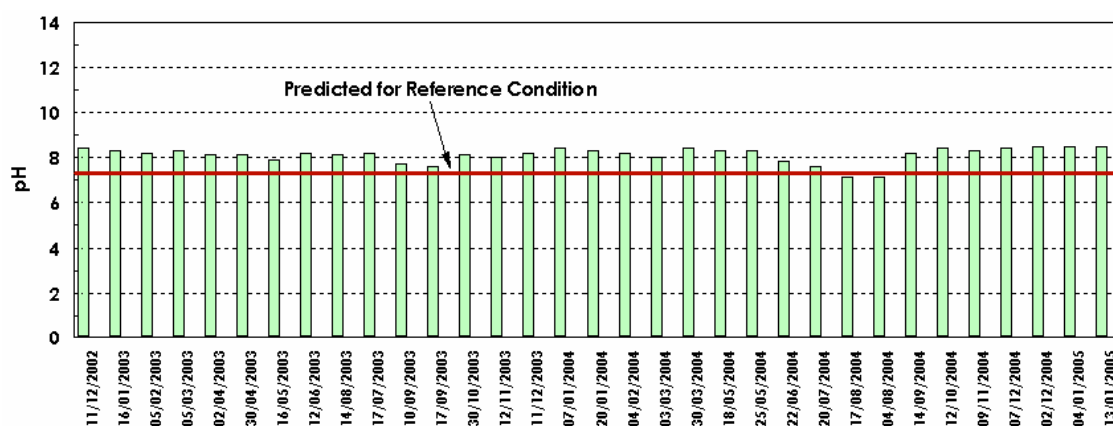


Figure 6.3: pH levels measured in the Olifants River at the DWAF routine monitoring station at Lutzville causeway (E2H016Q01) from 2002 to 2005. Also indicated is the predicted level under the Reference Condition

6.1.3 Dissolved Oxygen

Limited data on the dissolved oxygen characteristics of the Olifants Estuary are available prior to 2004. As part of this study, dissolved oxygen data were collected during both the March and August 2004 surveys and results are provided in Figure 6.4.

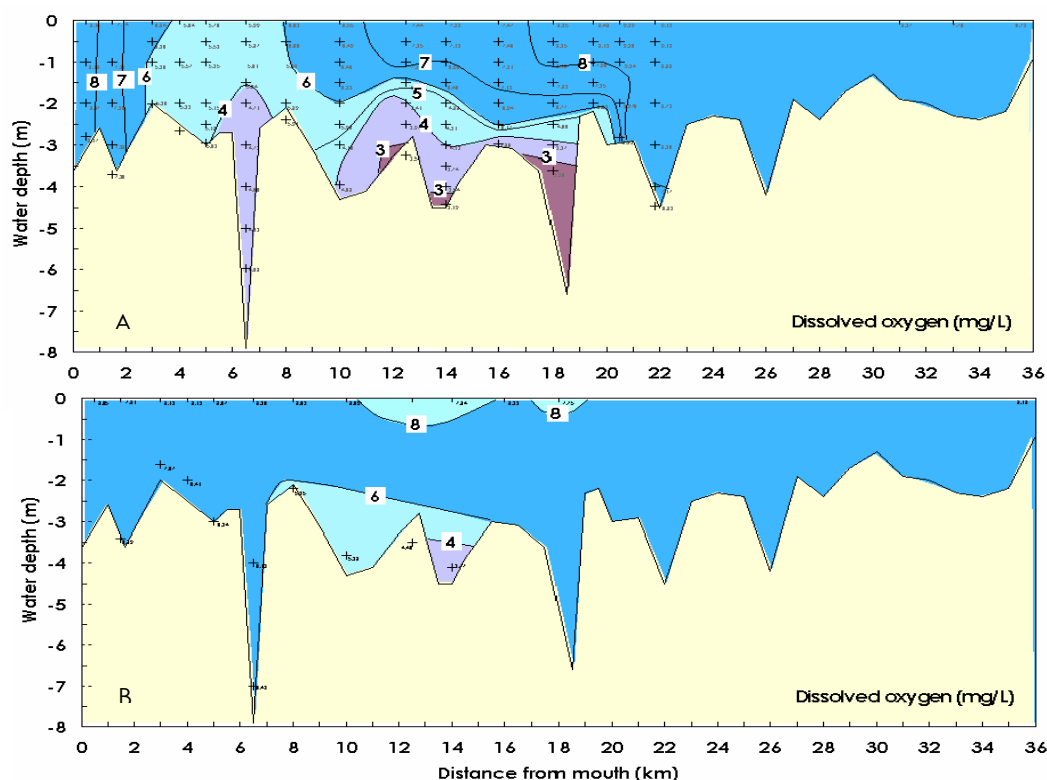


Figure 6.4: Longitudinal distribution of dissolved oxygen concentrations measured in the Olifants Estuary on A. 3 March 2004 and B. 10 August 2004

The March 2004 survey was conducted during a prolonged low flow period in summer. As a result water in the estuary, particularly in the middle reaches, was subject to long residence times. Although wind mixing was probably the main driver in sustaining dissolved oxygen concentrations (above 6 mg/l) in the surface waters, dissolved oxygen levels in bottom waters (below 3 m water depth) showed reduced oxygen levels (below 4 mg/l) as a result of these longer residence times.

During the August 2004 survey, which coincided with the onset of the high flow period, the system became well-oxygenated, with only a small section of bottom waters (below 3 m water depth) in the middle reaches having lower oxygen concentrations (~ 4 mg/l). The latter was probably still a remnant of the older water from the low flow season, in the process of being flushed from the system with the onset of this high flow period.

Therefore, during low flow periods, when the residence time of water in the estuary will be longer, it can be expected that dissolved oxygen concentration in bottom waters (below 3 m water depths) of the middle, and possibly also the upper reaches, could drop below 4 mg/l. Wind mixing it is expected to sustain well-oxygenated conditions (above 6 mg/l) in surface waters (above 3 m water depths). In the lower reaches, strong tidal flushing is expected to sustain well-oxygenated conditions throughout the water column (up to about 8 km from the mouth).

During high flow periods, freshwater flushing together with tidal exchange is expected to maintain well oxygenated conditions throughout the estuary (above 6 mg/l).

(NOTE: Dissolved oxygen concentrations are also dependent on the prevailing salinity and temperature regime. Under saturated or near-saturated conditions, dissolved oxygen concentrations are higher in fresher and/or colder waters compared with saline and/or warmer waters).

6.1.4 Turbidity/Suspended solids

The Olifants Estuary receives freshwater inflow from the Olifants/Doring systems, where the main stem (Olifants River) is fairly clear (draining hard, well-leached sandstone and quartzites of the Table Mountain Group) in contrast to the Doring River and other tributaries further downstream being more turbid (draining mainly soft, leachable shales – Karoo formations) (DWAF, 1997). Therefore, the source of river inflow, either from the Olifants main stem or from the Doring and other tributaries draining mainly soft, leachable shales is a key determinant in the turbidity characteristics of the Olifants Estuary. In comparison to river inflow, turbidity levels in seawater in the area is considered to be very low (i.e. 'clear').

Historical data on turbidity levels in the Olifants Estuary were limited to a few samples collected in the lower reaches during January 1994 (Harrison et al., 1994). For the purposes of this study, assessments are therefore based on data collected in March and August 2004. Turbidity versus salinity plots are provided in Figure 6.5.

The March 2004 survey was conducted at the end of an extended low flow period. Due to limited river inflow and long residence times, turbidity levels throughout the estuary were low (< 5 NTU), except in the upper reaches where the influence of some river flow was evident in slightly elevated turbidity (>20 NTU). The rapid decrease with increase in salinity can probably be attributed to flocculation. Suspended solid concentrations measured in the estuary during the same period were also considered to be low (around 5 mg/l) (Figure 6.5). The higher values that were measured at the stations 5 and 6.5 km upstream of the mouth could not be explained.

During the August 2004 survey (which coincided with the onset of a high flow period) the stronger influence of turbid river water (presumably originating from the Doring River) was clearly evident (Figure 6.5). Turbidity levels showed a sharp increase with decrease in salinities ranging from 25 – 50 NTU in the upper reaches (~0 ppt) to between 2 -15 NTU near the mouth (~34 ppt). Secchi disc depths were also recorded at the time and results showed a good correlation with turbidity levels (data obtained from Prof J Adams, Nelson Mandela Metropolitan University – estuarine vegetation component), as illustrated in Figure 6.6.

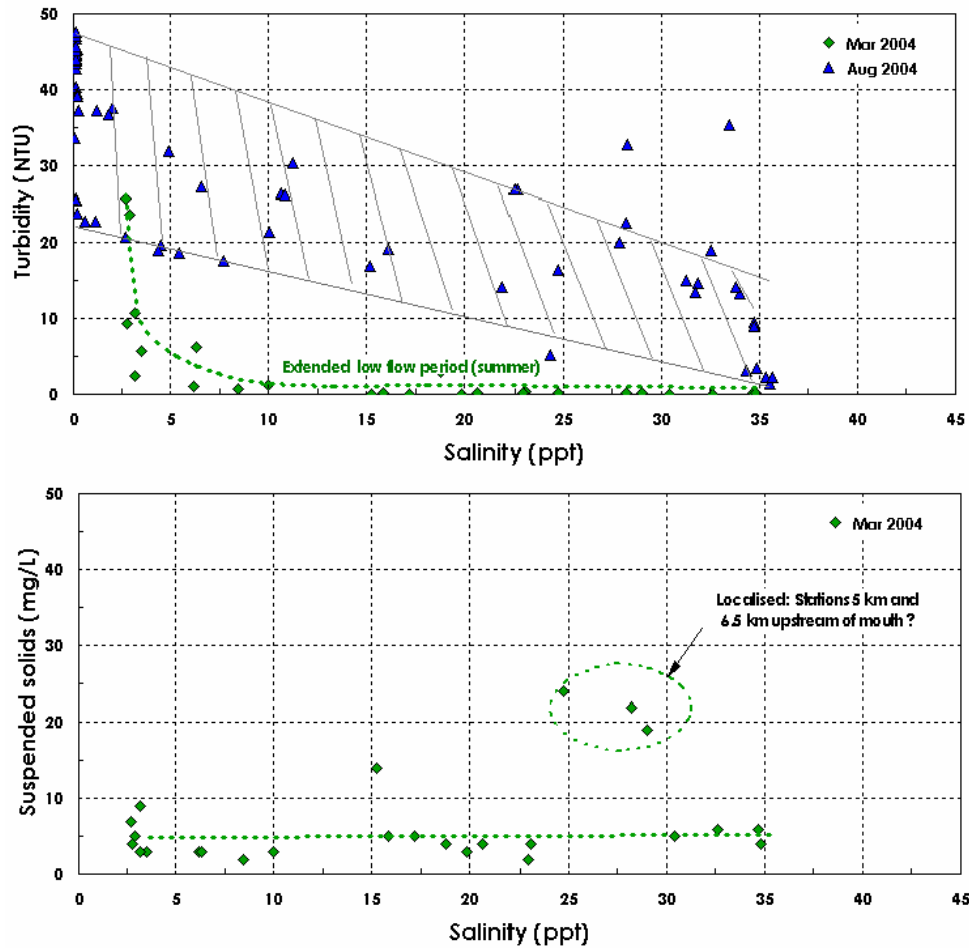


Figure 6.5: Turbidity and suspended solid concentrations versus salinity measured data in Olifants Estuary

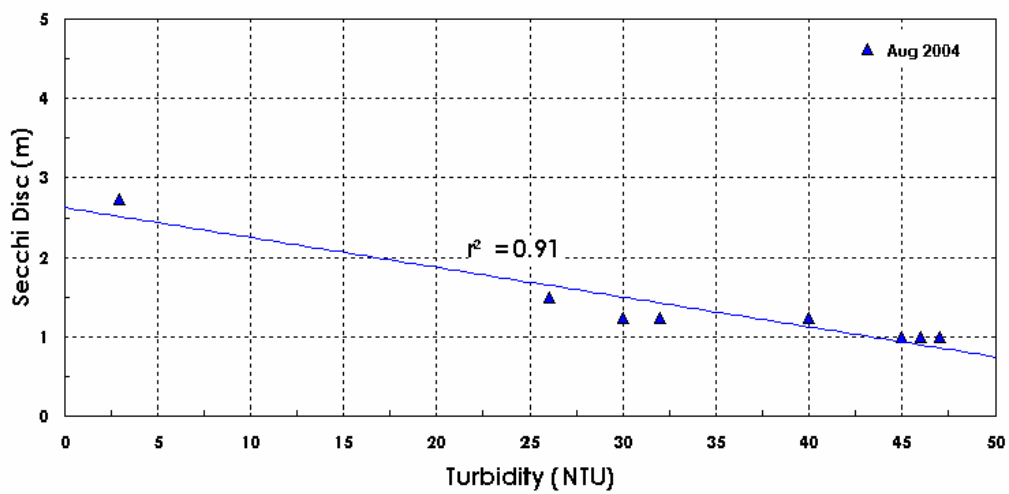


Figure 6.7: Relationship between Secchi disc depth and turbidity levels measured in the Olifants Estuary in August 2004

Based on the above, it is predicted that during periods of low flow, turbidity levels in the estuary probably remain low, with Secchi disc depths greater than 1 m, and even more, moving towards the lower reaches where the influence of clear seawater becomes more pronounced. However, limited river inflow may still result in relatively turbid waters in the upper reaches.

During periods of high river inflow, particularly when the source of inflow originates from the Doring and other tributaries draining soft, leachable shales (Karoo formations) the system becomes much more turbid. As tidal intrusion still introduces clearer seawater into the lower reaches, a strong horizontal gradient can be expected, ranging from between 25-50 NTU (Secchi disc depth typically less than 1 m) in the upper reaches to <15 NTU (Secchi disc depth typically greater than 1 m) near the mouth.

6.2 Dissolved Inorganic Nutrients

The inorganic nutrient concentrations in an estuary are largely a function of the concentrations in the source waters, i.e. the river and the sea, as well as any physical (e.g. evaporation) or biochemical processes (e.g. biological uptake and re-mineralisation) that occur within the estuary. The extent to which these processes affect inorganic nutrient characteristics in the Olifants Estuary is discussed below.

To assess spatial and temporal variations in the nutrient distribution patterns, the relationship between nutrient concentrations versus salinity was used. Salinities of river and seawater (i.e. the two major water sources of estuaries) are distinctly different. As salinity is usually a conservative parameter, the relationship between this and nutrient concentrations can be used as a means of characterising the distribution and fate of inorganic nutrients within an estuary. To orientate oneself in terms of the spatial distribution of nutrient concentrations along the estuary, the nutrient versus salinity plots should be compared with corresponding longitudinal salinity profiles provided in Section 5.2.

6.2.1 Dissolved Inorganic Nitrogen

Currently, dissolved inorganic nitrogen (DIN) inputs introduced to the Olifants Estuary via the river are largely influenced by agricultural activities. It has been documented that nitrification in the Olifants systems has become a problem, particularly downstream of Lutzville (which probably also includes areas long the banks of the Olifants Estuary – upper reaches). In this area drip irrigation is widely used. Although this technique results in substantial water saving per unit area, it tends to build up levels of nitrophosphates and other fertilizers due to irregular ‘flushing’ (unlike overhead sprinklers systems). As a result, nutrients accumulate in soils and are flushed into the river during rains, in particular the DIN (Seshoka *et al.*, unknown). This phenomenon is illustrated clearly in the ‘winter peaks’ (coinciding with the wet periods) observed in $\text{NO}_x\text{-N}$ and total dissolved inorganic nitrogen ($\text{NO}_x\text{-N}$ plus $\text{NH}_4\text{-N}$) concentrations measured at the DWAF routine monitoring station at Lutzville causeway (Figure 6.8).

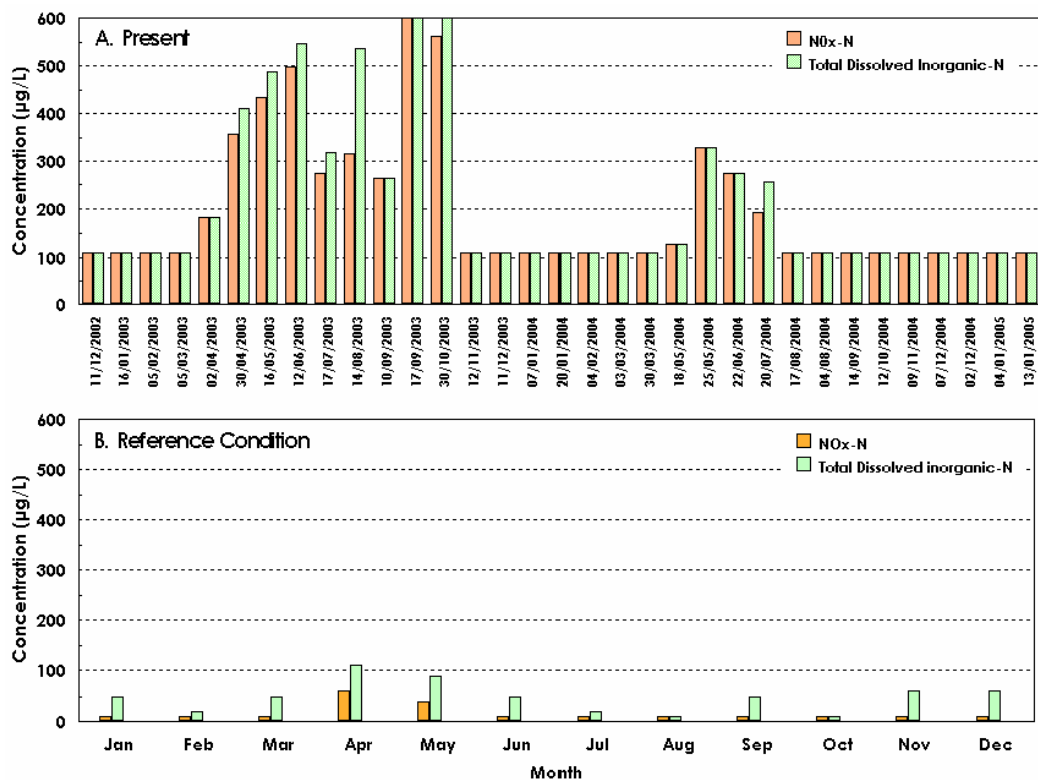


Figure 6.8: Dissolved inorganic nitrogen concentrations measured in the Olifants River at the DWAF routine monitoring station at Lutzville causeway (E2H016Q01) from 2002 to 2005 representative of A. Present (detection limit 100 µg/ℓ) and B. Reference Condition

DIN concentrations for the Reference Condition (derived from DWAF routine water quality monitoring station on the Doring River [Melkboom - E2H003] for the years 1980 to 1986), appeared to have been much lower compared to the present, particularly in terms of 'winter peaks' (about 3 to 6 times less than present). It is more difficult to predict the change for other months, since the detection limit for the present data was quite high (110 µg/ℓ).

Upwelling is common feature along this section of coast and plays an important role in determining the nutrient inputs that enters the Olifants Estuary from the sea. The upwelling season along the west coast usually occurs between August and May and is largely driven by the onset of S/SE winds. These winds appear to have mean periodicity of 6 days in spring/summer and 10 days in winter/autumn, with the actual event persisting for a few days within the period (Walker, 1984; Monteiro and Largier, 1999). Upwelling results in a marked increase in DIN concentrations (i.e. nitrate-N) with the size of the increase depending on the 'strength' of the event (Monteiro, *et al.*, 1998).

Historical data on DIN characteristics in the Olifants Estuary were limited to once off surveys in February 1976, July 1977 and June 1999 (Eagle and Bartlett, 1984; CSIR, unpublished data). For this study, once off surveys were undertaken in March and August 2004. The relationship between DIN and salinity, observed on these different occasions, are illustrated in Figure 6.9. Results indicate that the bulk of the DIN are present as NO_x-N (mainly nitrate), illustrated by the similarity in the distribution patterns between that of DIN and total dissolved inorganic nitrogen versus salinity (Figure 6.9).

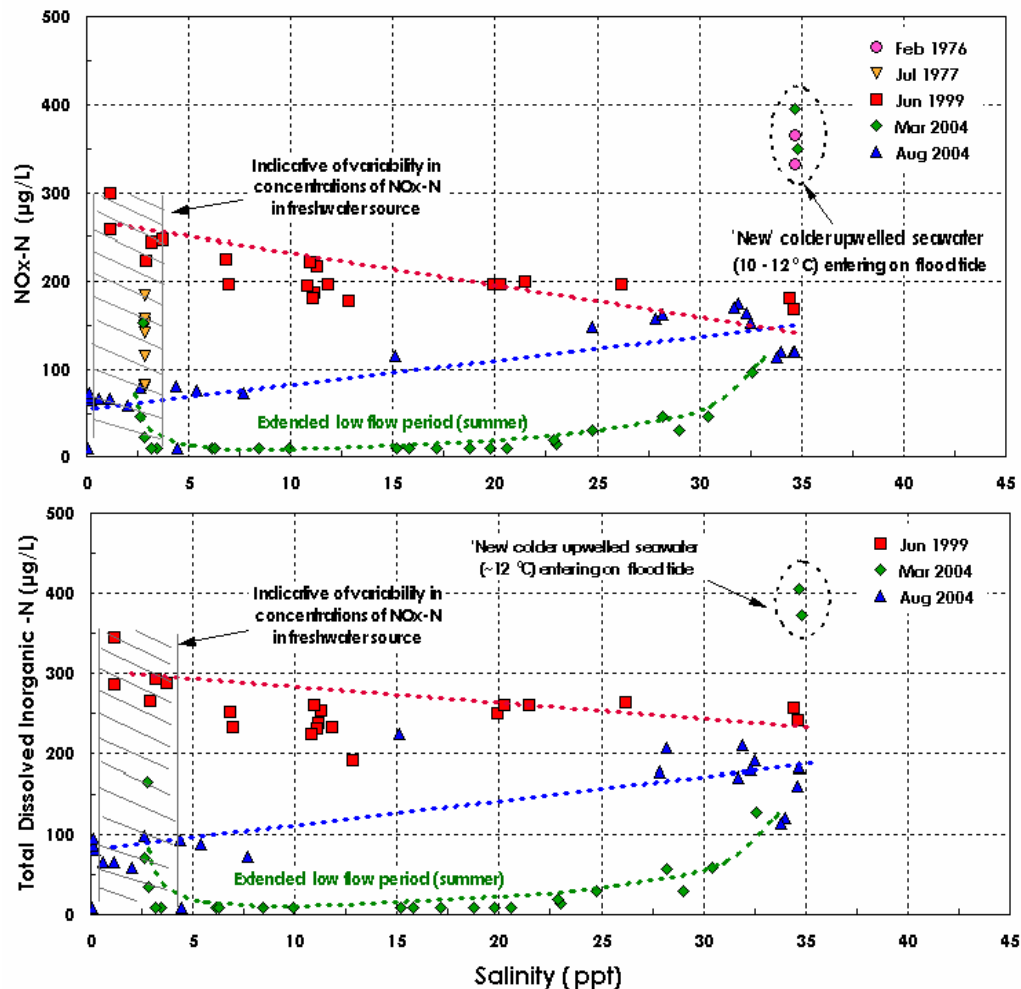


Figure 6.9: Relationship between $\text{NO}_x\text{-N}$ and total dissolved inorganic-N concentrations versus salinity measured in the Olifants Estuary

The following were derived from the distribution graphs for DIN (Figure 6.9):

- Results from the June 1999 (end of a lower flow period) and August 2004 (initial stages of a high flow period) surveys shows a fairly good linear trend between DIN concentrations and salinity. This suggests that in the Olifants Estuary, the concentration of DIN is largely determined by the concentrations in the inflowing sea- and river water.
- However, during the March 2004 survey, which was at the end of an extended period of low flows ($< 2 \text{ m}^3/\text{s}$), results indicate that waters with salinities between 5 and 25 ppt (middle reaches - section between 8 – 20 km from mouth), were basically depleted of DIN. Higher levels were measured in waters above 5 ppt (upper reaches - section above 20 km from mouth), suggesting that river inflow and, possibly also discharges from agricultural activities along the banks, still introduced DIN to the system. Similarly, tidal intrusion near the mouth (lower reaches - up to about 8 km from mouth) introduced DIN (in particular nitrate) from the sea.
- At the time of the March 2004 survey, the estuary supported very dense beds of submerged macrophytes between 20 and 30 km upstream of the mouth. This phenomenon was not observed in any of the previous surveys and it was concluded that the consistent low velocities and

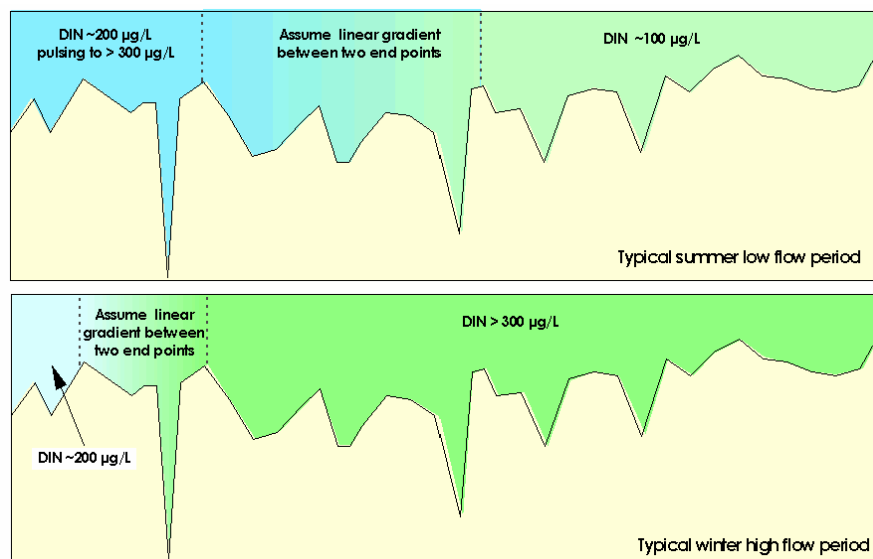
improved light penetrations associated with an extended low flow period ($< 2 \text{ m}^3/\text{s}$), created a favorable habitat for these submerged macrophytes in this section of the estuary. Uptake of DIN by these dense macrophytes beds was considered the most likely reason for the depleted status measured at the time (DIN considered the limiting nutrient in these systems).

- The influence of upwelling was evident in the high DIN concentrations that were observed near the mouth during the June 1976 and March 2004 surveys. Water temperature of between 10 and 12 °C suggested that these higher values were the result of upwelling. Although this phenomenon was only observed on these two occasions, the periodicity of conditions that result in upwelling (i.e. occurrence of S/SE winds) suggest that, on average pulses of high DIN (in particular nitrate), could be entering the lower reaches of the estuary for a few days, every 6 to 10 days, during the upwelling season (August to May).
- The range of DIN concentrations measured in lower salinity waters of the Olifants Estuary (indicative of river inputs and possibly also from agricultural activities along the banks in the upper reaches) reflected large variability (hatched area in Figure 6.9). Comparing these results with measurements from the Olifants River at Lutzville (Figure 6.8), it tends to follow similar patterns, i.e. values during winter (June/July) are generally higher compared with summer (March). Although one would have expected results from the August 2004 survey to be higher (winter), the corresponding results on the Olifants River, for that particular year, were also low.

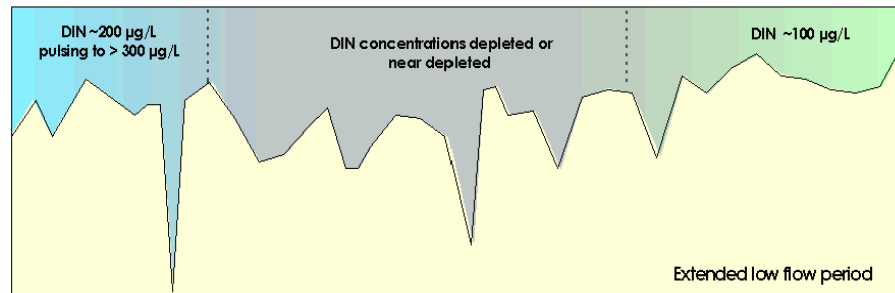
For the purposes of this Ecological Reserve Study, the distribution of DIN concentrations in the Olifants Estuary is estimated to be as follows:

- During periods of where river inflow is $> 2 \text{ m}^3/\text{s}$, a salinity gradient develops in the estuary, where the extent of saline intrusion is determined by the volume of river inflow. During these periods, assume that a linear relationship exists between DIN concentrations and salinity, where concentrations along the estuary are largely a function of the extent of mixing between river- and seawater, as well as the DIN concentrations in these sources (River $\sim 100 \text{ } \mu\text{g}/\text{L}$; Seawater $\sim 200 \text{ } \mu\text{g}/\text{L}$). However, the concentration in the river and sea can vary markedly as a result of upwelling at sea (pulses of higher DIN concentrations $> 300 \text{ } \mu\text{g}/\text{L}$) and the 'winter peak' phenomenon (DIN concentrations $> 300 \text{ } \mu\text{g}/\text{L}$) observed in river inflow.

Typical summer (low flow) and winter (high flow) distributions under this condition are schematically illustrated below:



- During extended low flow periods ($< 2\text{m}^3/\text{s}$), consistent low velocities and improved light penetration, create a favourable habitat for dense beds of submerged macrophytes to develop, depleting DIN concentrations in the estuary. However, river inflow and, possibly also inputs from agricultural activities along the banks, still introduced some DIN into the upper reaches the system, while tidal intrusion introduce DIN (in particular nitrate) to the lower reaches. As this conditions is likely to only develop in summer or late summer, DIN concentrations in freshwater inflows is expected to remain around $100\text{ }\mu\text{g/L}$ (higher concentrations are typically associated with wetter periods - usually in winter). However, concentrations introduced to the lower reaches from the sea can vary markedly as a result of upwelling (i.e. pulses of higher DIN concentrations $>300\text{ }\mu\text{g/L}$). This conditions is sschematically illustrated as follows:



6.2.2 Dissolved Reactive Phosphate

Dissolved reactive phosphate (DRP) concentration measured in river inflow at the DWAF routine monitoring station at Lutzville causeway is provided in Figure 6.10.

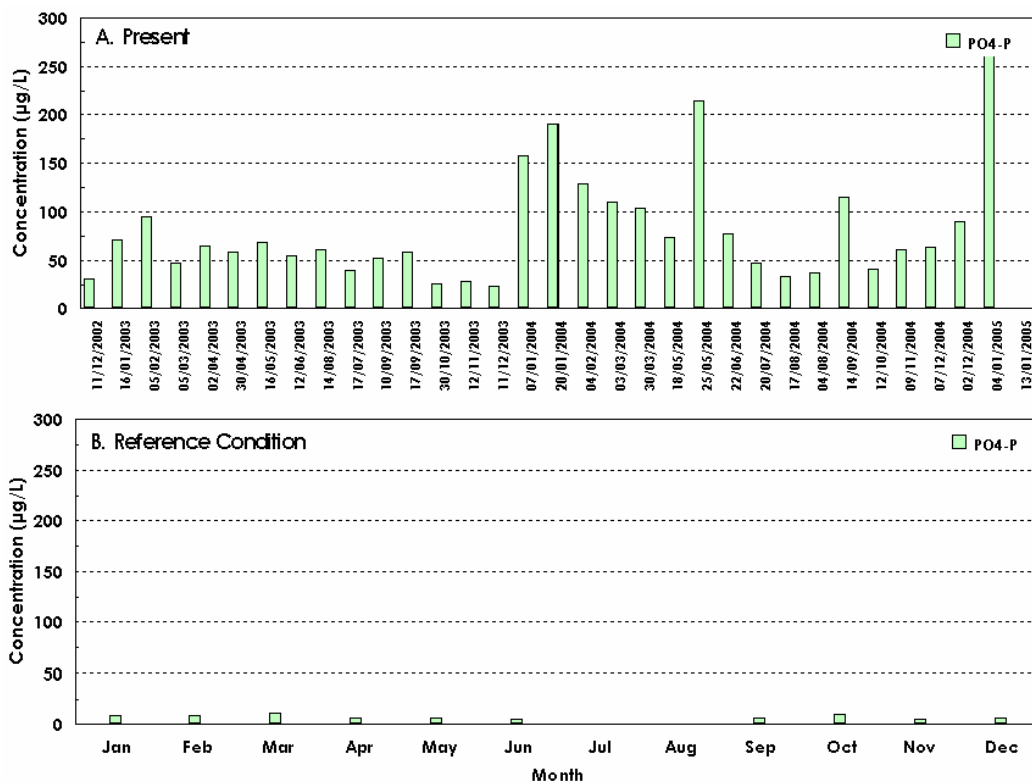


Figure 6.10: Dissolved reactive phosphate concentrations measured in the Olifants River at the DWAF routine monitoring station at Lutzville causeway (E2H016Q01) from 2002 to 2005 representative of A. Present and B. Reference Condition

In contrast to the trend observed for DIN, DRP concentrations tend to show 'summer peaks'. This could not be explained, except that this may be partly as a result of high evaporation in the area during summer. DRP concentrations under the Reference Condition (derived from DWAF routine water quality monitoring station on the Doring River [Melkboom - E2H003] for the years 1980 to 1986), appeared to have been much lower compared to the present - generally below 20 µg/l (Figure 6.10).

Unlike the situation with DIN, upwelling does not appear to significantly increase DRP concentrations in seawater, which along the west coast average around 50 µg/l (DWAF, 1995).

Historical data on DRP concentrations in the Olifants Estuary were limited to a once off data sets collected in June 1999 (CSIR, unpublished data). For this study, once off surveys were undertaken in March and August 2004. The relationship between DRP and salinity, observed on these different occasions, are illustrated in Figure 6.11.

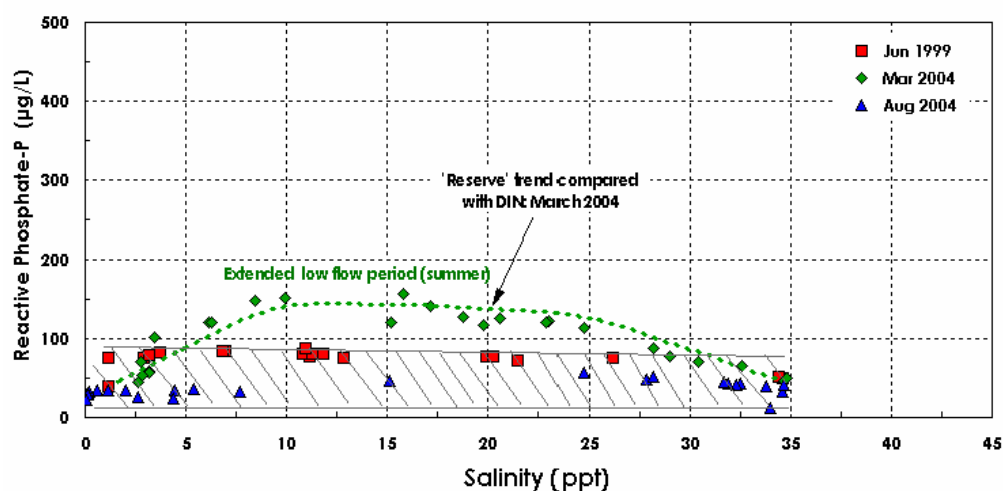


Figure 6.11: Relationship between Dissolved reactive phosphate concentrations versus salinity measured in the Olifants Estuary

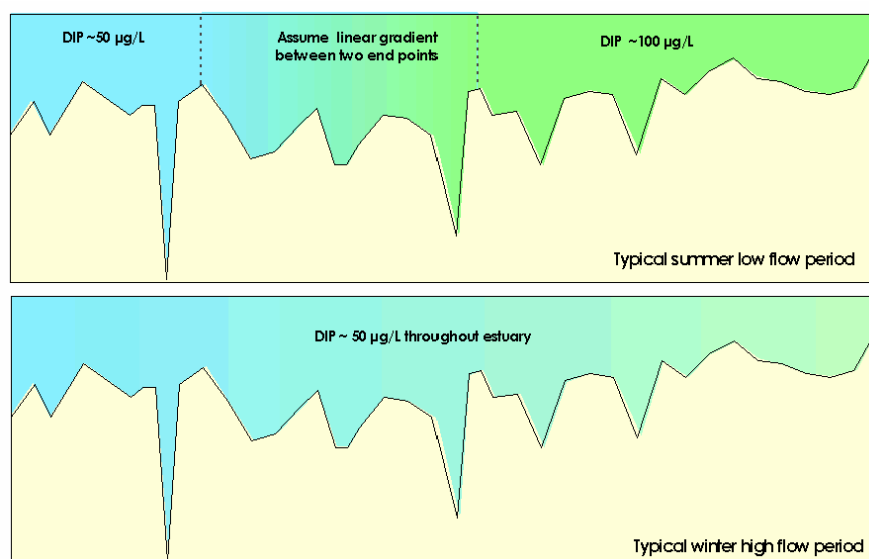
The following were derived from the distribution graphs for DRP (Figure 6.11):

- There were no marked trends in the DRP concentrations throughout the estuary during both the June 1999 and August 2004 surveys, suggesting that the levels in both the river and seawater were similar (~ 50 µg/l).
- However, during the March 2004 survey, which was at the end of an extended period of low flows (< 2 m³/s), results indicate that waters with salinities between 5 and 25 ppt (middle reaches), were elevated to above 100 µg/l, while levels in the upper reaches (below 5 ppt) and lower reaches (above 25 ppt) remained in the 50 µg/l range. A possible explanation for this phenomenon was accumulation of DRP due to evaporation and/or re-mineralisation, not being the limiting nutrient in estuaries, as for example DIN (which, at the time, became depleted in this same section on the estuary).
- Measurements in the estuary did not reflect the 'summer peak' phenomenon that was evident in the river inflow data (Figure 9.10), but this does not necessarily imply that it cannot occur (only one summer survey were conducted).

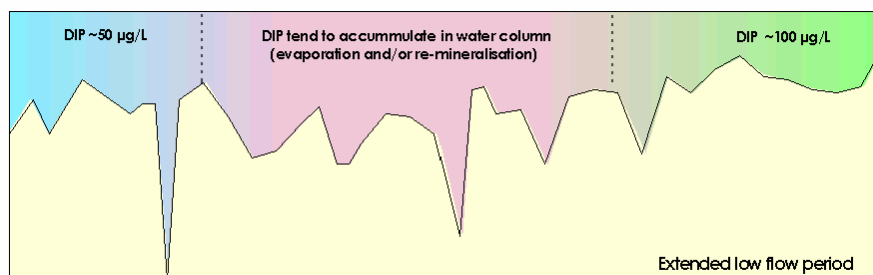
For the purposes of this Ecological Reserve Study, the distribution of DRP concentrations in the Olifants Estuary is estimated to be as follows:

- During periods of where river inflow is $> 2 \text{ m}^3/\text{s}$, a salinity gradient develops in the estuary, where the extent of saline intrusion is determined by the volume of river inflow. During these periods, assume that a linear relationship exists between DIN concentrations and salinity where concentrations along the estuary are largely a function of the extent of mixing between river- and seawater, as well as the DRP concentrations in these sources (river and seawater $\sim 50 \text{ } \mu\text{g}/\text{l}$). However, the concentration in the river could increase during summer based on the 'summer peak' phenomenon observed in river inflow data (DIP concentrations $\sim 100 \text{ } \mu\text{g}/\text{l}$).

Typical summer (low flow) and winter (high flow) distributions under this condition are schematically illustrated below:



- During extended low flow periods ($< 2 \text{ m}^3/\text{s}$), consistent long residence time results in an accumulation of DRP concentration in the middle reaches, possibly due to evaporation and/or re-mineralisation. As this state is likely to occur during summer, concentrations introduced by freshwater inflow in the upper reaches could increase to $\sim 100 \text{ } \mu\text{g}/\text{l}$ ('summer peak' phenomenon). Concentrations introduced to the lower reaches from the sea are likely to remain around $50 \text{ } \mu\text{g}/\text{l}$. Conditions are schematically illustrated as follows:



6.2.3 Dissolved Reactive Silicate

Dissolved reactive silicate (DRS) concentrations measured in river inflow at the DWAF routine monitoring station at Lutzville causeway is provided in Figure 6.12.

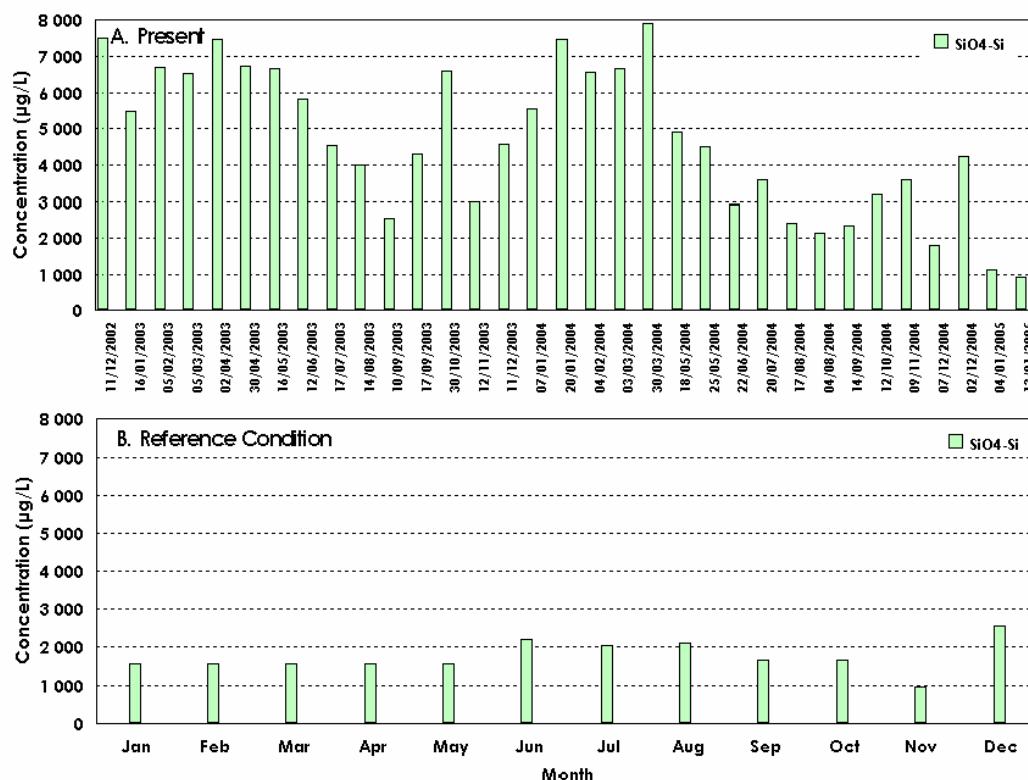


Figure 6.12: Dissolved reactive silicate concentrations measured in the Olifants River at the DWAF routine monitoring station at Lutzville causeway (E2H016Q01) from 2002 to 2005 representative of A. Present and B. Reference Condition

Similar to the DRP concentrations (and in contrast to the trend observed for DIN), DRS concentrations tended to show 'summer peaks'. This could not be explained and it is thought that evaporation played a role in this regard (although this still needs confirmation). DIP concentrations under the Reference Condition (derived from DWAF routine water quality monitoring station on the Doring River [Melkboom - E2H003] for the years 1980 to 1986), appeared to have been much compared to the present - generally between 1000 and 2000 µg/l (Figure 6.10).

Unlike the situation with DIN, upwelling does not appear to significantly increase DRS concentrations in seawater, which along the west coast average around 400 µg/l (DWAF, 1995).

Historical data on DRS concentrations in the Olifants Estuary were limited to a once off data sets collected in February 1976, July 1977 and June 1999 (Eagle and Bartlett, 1984; CSIR, unpublished data). For this study, once off data sets were collected in March and August 2004. The relationship between DRS and salinity, observed on these different occasions, are illustrated in Figure 6.13.

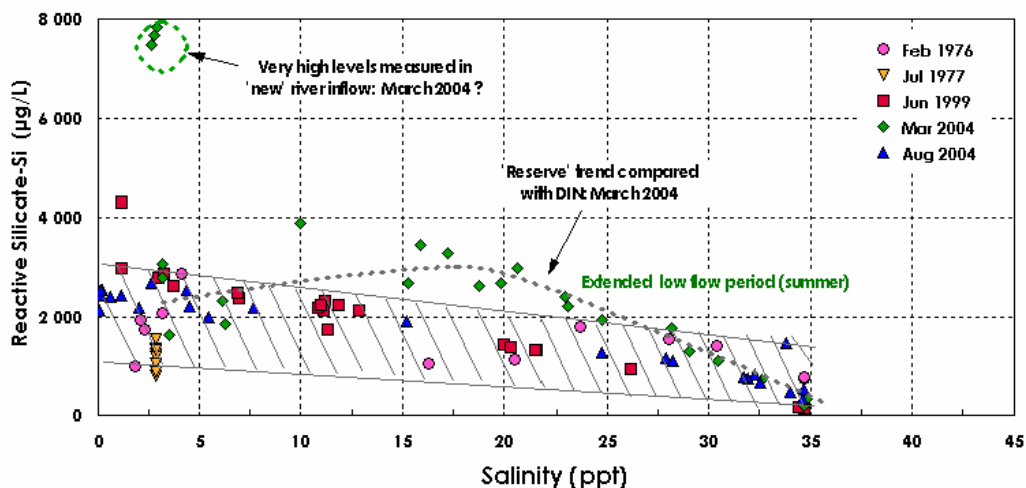


Figure 6.13: Relationship between dissolved reactive silicate concentrations versus salinity measured in the Olifants Estuary

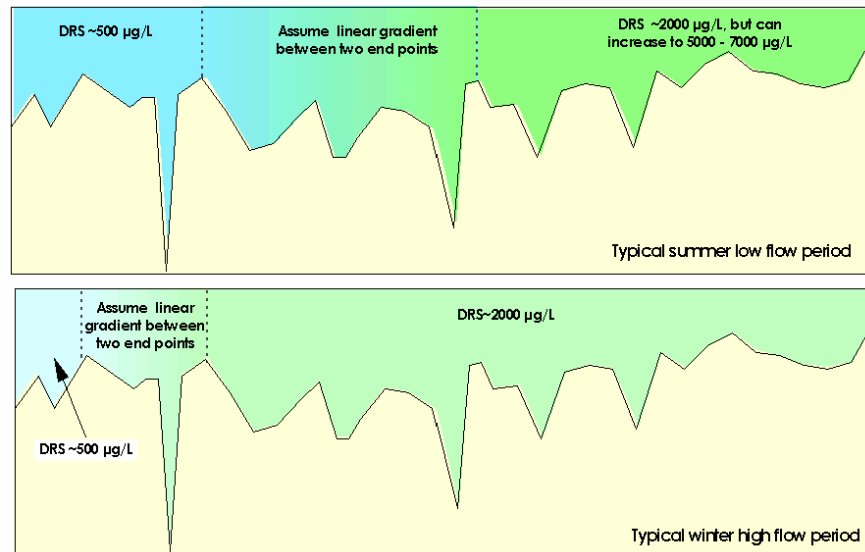
The following were derived from the distribution graphs for DRS (Figure 6.13):

- In all studies, DRS concentrations increased with decrease in salinity, from ~500 µg/l in high salinity water (~34 ppt) near the mouth to ~2000 µg/l in low salinity water (< 5 ppt) near the head of the estuary. This indicated that concentrations in the fresh river water was generally higher than those in seawater, as would be expected (it has been documented that, depending up on catchment characteristics, high reactive silicate concentrations often occur in terrestrial [fluvial] run-off - Eagle and Bartlett, 1984).
- However, during the March 2004 survey, which was at the end of an extended period of low flows (< 2 m³/s), results indicate that waters with salinities between 5 and 25 ppt (middle reaches), were elevated to around 3000 µg/l, higher than levels measured in the lower reaches (above 25 ppt) and even upper reaches (<5 ppt). A explanation for this phenomenon was accumulation of DRS due to evaporation, not being a limiting nutrient, as for example DIN (which, at the time, became depleted in this same section on the estuary).
- During the March 2004 survey, measurements in the estuary did reflect the 'summer peak' phenomenon observed in the river data; Concentrations as high as 7000 µg/l were recorded in the upper reaches. This corresponded well with the high levels that were also measured at the DWAF monitoring station at the Lutzville causeway at the time (Figure 6.12).

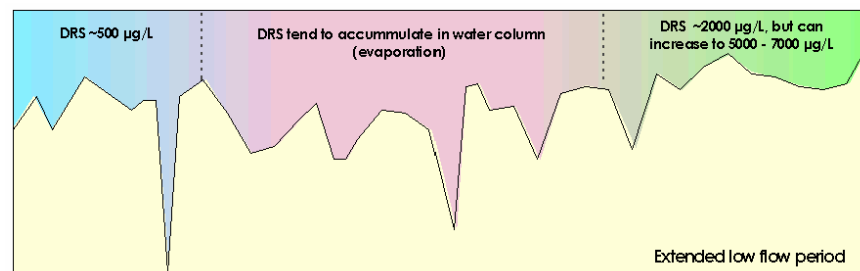
For the purposes of this Ecological Reserve Study, the distribution of DRS concentrations in the Olifants Estuary is estimated to be as follows:

- During periods of where river inflow is > 2 m³/s, a salinity gradient develops in the estuary, where the extent of saline intrusion is determine by the volume of river inflow. During these periods, assume that a linear relationship exists between DRS concentrations and salinity where concentrations along the estuary are largely a function of the extent of mixing between river- and seawater, as well as the DRS concentrations in these sources (River ~2000µg/l and seawater ~500 µg/l). However, the concentration in the river could increase during summer based on the 'summer peak' phenomenon observed in river inflow data (increasing to 5000 - 7000 µg/l).

Typical summer (low flow) and winter (high flow) distributions under this condition are schematically illustrated below:



- During extended low flow periods ($< 2\text{m}^3/\text{s}$), consistent long residence time result in an accumulation of DIP concentration in the middle reaches, possibly attributed to evaporation. As this state is likely to occur during summer, concentrations introduced by freshwater inflow in the upper reaches could increase to between 5000-7000 $\mu\text{g}/\text{l}$ ('summer peak' phenomenon). Concentrations introduced to the lower reaches from the sea is likely to remain $\sim 500 \mu\text{g}/\text{l}$. This conditions is schematically illustrated as follows:



6.3 Toxic Substances

As the estuary is not located in close proximity of major industrial areas, toxic substances (e.g. trace metals) were not included within the scope of this study. The catchment of the Olifants River, however, is extensively used for agriculture and toxic substances such as herbicides and pesticides may be of concern. Although this aspect will not be further addressed as part of the current ecological reserve study, the potential of the presence of such toxic substances will be acknowledged in the allocation of the present status of the system.

7. ABIOTIC STATES OF OLIFANTS ESTUARY

Based on the assessments and evaluations conducted for this specialist report, three Abiotic States were derived for the Olifants Estuary, of which the occurrence and duration varies depending on river inflow rate these states are:

State 1: Marine dominated	< 2 m ³ /s
State 2: Saline penetration extend to middle reaches	2 – 5 m ³ /s
State 3: Saline penetration limited to lower reaches	5 – 20 m ³ /s
State 4: Freshwater dominated	> 20 m ³ /s

7.1 State 1: Marine Dominated

Typical flow patterns. Flows are usually less than 2 m³/s and occur during summer months. Under the Reference Condition this state seldom occurred, and if so, only for short periods during droughts. However, under the Present State, and some of the Future Runoff Scenarios, it now typically occurs from November to April.

State of the mouth. The mouth is permanently open

Flood plain inundation patterns. At these flows inundation of the flood plain will be limited, probably on spring high tides.

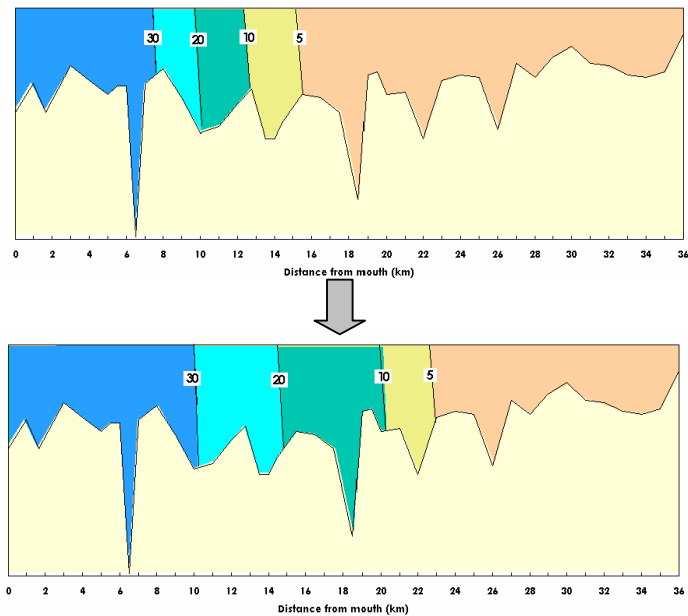
Amplitude of tidal variation. During neap tides the vertical water level variation is approximately 0.3 m. This variation is very similar trough out the estuary to the top at the Lutzville low water bridge. During spring tides, the tidal variation increases to about 1.30 m at the mouth and reduces upstream to almost 1.0 m just upstream of the low water bridge at Lutzville.

Retention times of water masses. The residence time in the lower estuary is estimated to be 1 - 10 days, depending on the distance from the mouth. The closer to the mouth, the more effective tidal flushing will be and the less the residence time. Most of the lower estuary will be flushed during a spring-neap tidal cycle from the marine side, so retention is not expected to be more than 2 weeks in the lower reaches.

In the middle to upper reaches the residence time is expected to be longer than > 4 weeks . In sections where the estuarine bathymetry is deeper than -2.0 m MSL, retention time is expected to be longer (> 6 weeks) as flushing is less effective in these deeper areas.

Estimated (maximum) tidal velocities along the estuary. Approximately 1 m/s at springtide near the mouth and gradual reduced velocities further upstream. The tidal velocities are 0 m/s at the causeway at Lutzville.

Salinity distributions in the estuary. The average salinity distribution under State 1 is illustrated below. However, in instances where flows of < 2 m³/s persist for more than 5 months or when flow decrease to <1 m³/s, marked saline penetration can occur even further upstream (as illustrated on the following page).

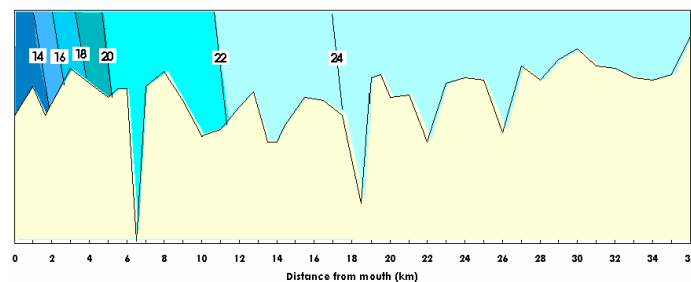


Under State 1 saline intrusion occurs in the lower 15 – 18 km of the estuary during the average low flow conditions. During period of extended low flows, the salinity intrusion can extend more than 30 km upstream from the mouth.

Total volume per salinity range:

SALINITY ZONE	AVERAGE LOW FLOWS (~ 3 MONTHS)		EXTENDED PERIODS OF LOW FLOW	
	Distance from mouth (km)	Volume (m ³)	Distance from mouth (km)	Volume (m ³)
30 ppt	7.0	2 921 000	10.0	3 612 200
20 ppt	10.0	691 100	15.0	908 400
10 ppt	13.0	562 800	20.0	696 800
5 ppt	15.0	345 500	23.0	306 900
0.5 ppt	20.0	696 800	32.0	667 400

Temperatures. As State 1 occurs during summer the temperature distribution along the estuary is as follows:

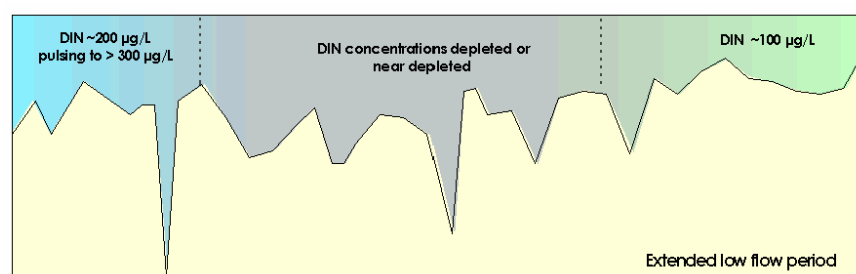


pH. Levels is likely to ranged between 7.3 and 8.5 throughout the system

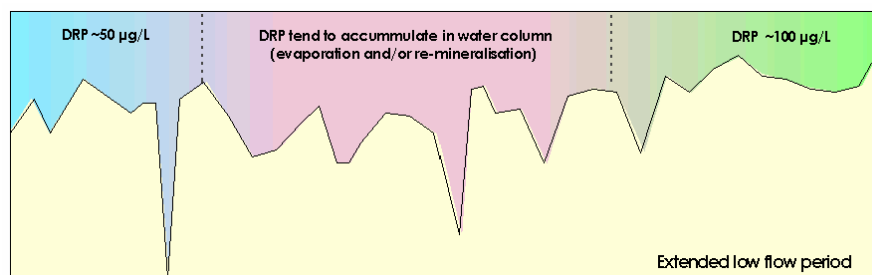
Dissolved oxygen. During State 1 (low flow period in summer), residence time of water in the estuary will be longer and dissolved oxygen concentration in bottom waters (below 3 m water depths) of the middle, and possibly also the upper reaches, could drop below 4 mg/l. Wind mixing should sustain well-oxygenated conditions (above 6 mg/l) in surface waters (above 3 m water depths). In the lower reaches, strong tidal flushing is expected to sustain well-oxygenated conditions throughout the water column (up to about 8 km from the mouth).

Turbidity/Suspended solids. During State 1 (low flow period in summer) turbidity levels in the estuary will probably remain low, with Secchi disc depths greater than 1 m, and even more, moving towards the lower reaches where the influence of clear seawater becomes more pronounced. However, limited river inflow may still result in relatively turbid waters in the upper reaches. Wind mixing in the shallower reaches of the lower estuary may also increase turbidity levels at times.

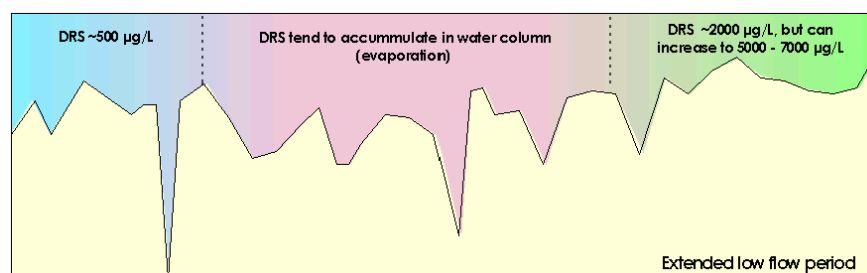
Dissolved inorganic nitrogen (DIN). The distribution of DIN concentrations in the estuary during State 1, in particular when the state occurs for extended periods or flow become very low, is follows:



Dissolved reactive phosphate (DRP). The distribution of DRP concentrations in the estuary during State 1, in particular when the state occurs for extended periods or flow become very low, is follows:



Dissolved reactive silicate (DRS). The distribution of DRS concentrations in the estuary during State 1, in particular when the state occurs for extended periods or flow become very low, is follows:



7.2 State 2: Saline penetration to middle reaches

Typical flow patterns. Flows range between 2 and 5 m³/s. This flow range typically occurs in summer (December to March). However, under the Present State and some of the Future Runoff Scenarios, it could extend into autumn (April to May).

State of the mouth. The mouth is permanently open

Flood plain inundation patterns. At these flows inundation of the flood plain will be limited, probably on spring high tides.

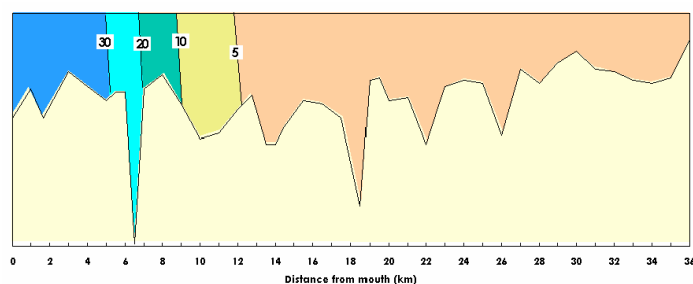
Amplitude of tidal variation. During neap tides the vertical water level variations is approximately 0.3 m. This variation is very similar through out the estuary to the top at the Lutzville low water bridge. During spring tides, the tidal variation increases to about 1.30 m at the mouth and reduces upstream to almost 1.0 m just upstream of the low water bridge at Lutzville.

Retention times of water masses. The residence time in the lower estuary is estimated to be 1 - 5 days, depending on the distance from the mouth. The closer to the mouth the more effective tidal flushing will be.

In the middle to upper reaches the residence time can vary between 1 to 4 weeks. In sections where the estuarine bathymetry is deeper than -2.0 m MSL, retention time is expected to be longer (> 4 weeks) as flushing is less effective in these deeper areas.

Estimated (maximum) tidal velocities along the estuary: Approximately 1 m/s at springtide near the mouth and gradual reduced velocities further upstream. The tidal velocities are 0 m/s at the causeway at Lutzville.

Salinity distributions in the estuary: The average salinity distribution under State 2 is illustrated below:

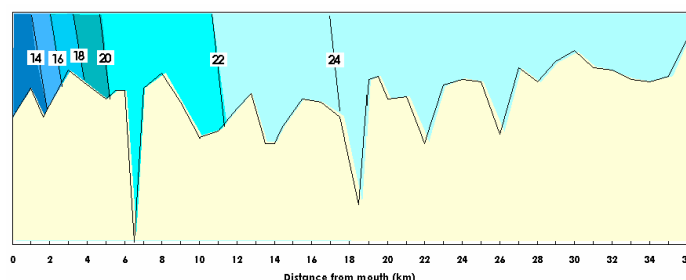


Under State 2 saline intrusion occurs in the lower 10 – 17.5 km of the estuary.

Total volume per salinity range:

SALINITY ZONE	DISTANCE FORM MOUTH (km)	VOLUME(m ³)
30 ppt	5.8	2 290 600
20 ppt	7	630 500
10 ppt	9	446 500
5 ppt	13	807 500
0.5 ppt	16	488 700

Temperatures. As State 2 mainly occurs during summer the temperature distribution along the estuary is as follows:

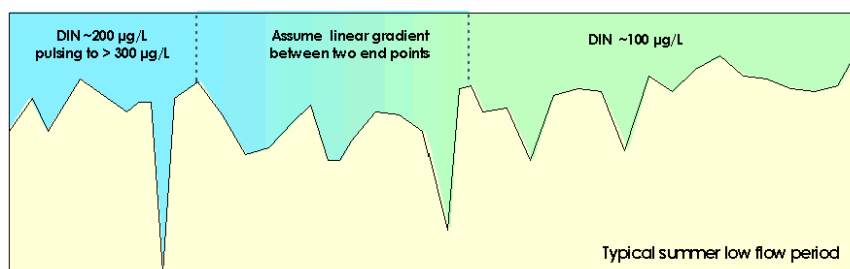


pH. Levels is likely to ranged between 7.3 and 8.5 throughout the system

Dissolved oxygen. During State 2 (also considered a low flow period), residence time of water in the estuary will be longer and dissolved oxygen concentration in bottom waters (below 3 m water depths) of the middle, and possibly also the upper reaches, could drop below 4 mg/l. Wind mixing should sustain well-oxygenated conditions (above 6 mg/l) in surface waters (above 3 m water depths). In the lower reaches, strong tidal flushing is expected to sustain well-oxygenated conditions throughout the water column (up to about 8 km from the mouth).

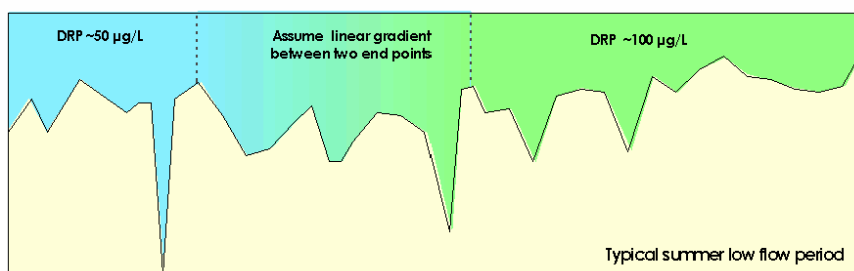
Turbidity/Suspended solids. During State 2 (also considered a low flow period) turbidity levels in the estuary will probably remain low, with Secchi disc depths greater than 1 m, and even more, moving towards the lower reaches where the influence of clear seawater becomes more pronounce. However, limited river inflow may still result in relatively turbid waters in the upper reaches. Wind mixing in the shallower reaches of the lower estuary may also increase turbidity levels at times.

Dissolved inorganic nitrogen (DIN). The distribution of DIN concentrations in the estuary during State 2 is estimated as follows:



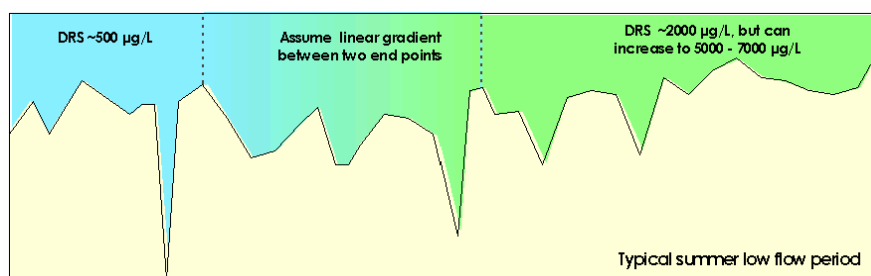
Where State 2 occurred under the Reference Condition, the DIN concentrations in the upper reaches were probably markedly lower (~50 µg/l), based on the predicted Reference Condition for DIN in river inflow. As a result DIN concentrations in the estuary showed a linear gradient between that present in the upper reaches (~50 µg/l) and that typically measured in lower reaches – characteristics of seawater (50-300 µg/l). In future scenarios where agricultural return flows are expected to increase, it is likely that DIN concentrations entering the estuary in the upper reaches will also increase (>100 µg/l) under State 2.

Dissolved reactive phosphate (DRP). The distribution of DRP concentrations in the estuary during State 2 is estimated as follows:



Where State 2 occurred under the Reference Condition, the DRP concentrations in the upper reaches were probably markedly lower ($<20 \mu\text{g/l}$), based on the predicted Reference Condition for DRP in river inflow. As a result DRP concentrations in the estuary showed a linear gradient between that present in the upper reaches ($<20 \mu\text{g/l}$) and that typically measured in lower reaches – characteristics of seawater ($\sim 50 \mu\text{g/l}$).

Dissolved reactive silicate (DRS). The distribution of DRS concentrations in the estuary during State 2 is estimated as follows:



Where State 2 occurred under the Reference Condition, the DRS concentrations in the upper reaches probably remained in the $2000 \mu\text{g/l}$ range based on the predicted Reference Condition for DRS in river inflow.

7.3 State 3: Saline penetration limited to lower reaches

Typical flow patterns. Flows are usually between $5 - 20 \text{ m}^3/\text{s}$. These flow ranges usually only occur for relatively short periods (e.g. a few weeks to a month) during the transition periods between summer and winter, i.e. autumn (April - May) and spring (October to December).

State of the mouth. The mouth is permanently open

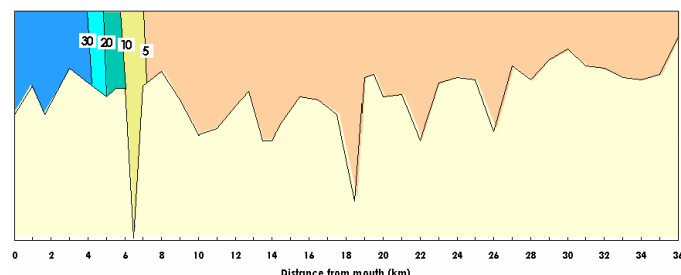
Flood plain inundation patterns. At these flows inundation of the flood plain will be limited, probably on spring high tides.

Amplitude of tidal variation. During neap tides the vertical water level variations is approximately 0.3 m. This variation is very similar through out the estuary to the top at the Lutzville bridge. During spring tides, the tidal variation increases to about 1.30 m at the mouth and reduces upstream to almost 1.0 m just upstream of the low water bridge at Lutzville.

Retention times of water masses. The residence time in the lower estuary is estimated to be 1- 3 days. In the middle to upper reaches the retention time can be a few days to about a week. In sections where the estuarine bathymetry is deeper than -2.0 m MSL, residence time is expected to be longer (1 - 2 weeks) as the estuary often stratify during this transition state especially in the case of Autumn flows following protracted low flows in summer.

Estimated (maximum) tidal velocities along the estuary: Approximately 1 m/s at springtide near the mouth and gradual reduced velocities further upstream. The tidal velocities are 0 m/s at the causeway at Lutzville.

Salinity distributions in the estuary. The average salinity distribution under State 3 is illustrated below:

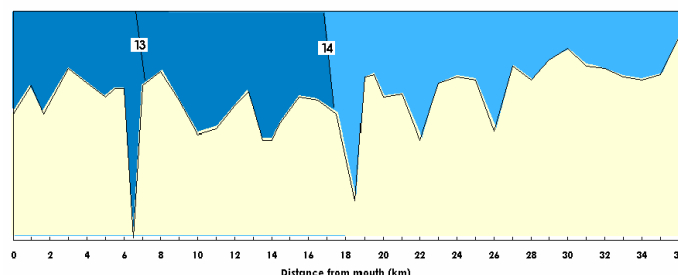


Under State 3 saline intrusion occurs in the lower 10 km of the estuary during high tides. During low tides, the salinity intrusion is restricted to the lower 6.5 km of the estuary. This salinity intrusion is also representative of what occur during flood conditions.

Total volume per salinity range.

SALINITY ZONE	HIGH TIDES		LOW TIDES	
	Distance form mouth (km)	Volume (m ³)	Distance form mouth (km)	Volume (m ³)
30 ppt	4	2 083 800	-	-
20 ppt	5.25	349 400	-	-
10 ppt	6	215 300	1.0	631 100
5 ppt	6.8	195 400	3.0	1 154 300
0.5 ppt	9.0	523 500	5.0	576 300

Temperatures. As State 3 will predominantly occur during the wetter, colder months of the year the temperature distribution along the estuary is estimated as follows:



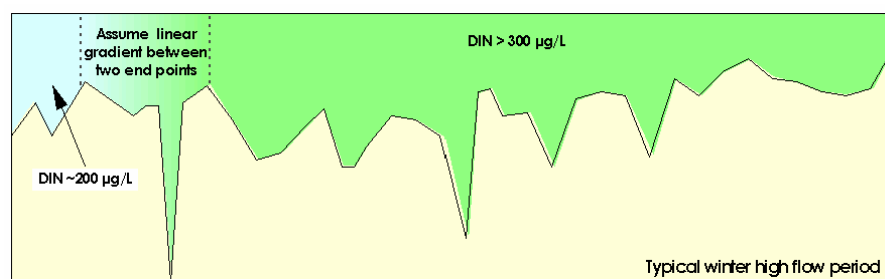
pH. Levels is likely to ranged between 7.3 and 8.5 throughout the system

Dissolved oxygen. Under State 3 (moving into higher flow periods), freshwater flushing together with tidal exchange is expected to maintain well oxygenated conditions throughout the estuary (above 6 mg/l).

Turbidity/Suspended solids. Under State 3 (moving into higher river flow periods) the estuary starts to become more turbid, particularly when inflow originates from the Doring and other tributaries draining the soft leachable shales (Karoo formations). As tidal intrusion still introduce clearer seawater into the lower reaches, a strong horizontal gradient can be expected, ranging from between 25-50 NTU (Secchi disc depth typically less than 1 m) in the upper reaches to <15 NTU (Secchi disc depth typically greater than 1 m) near the mouth.

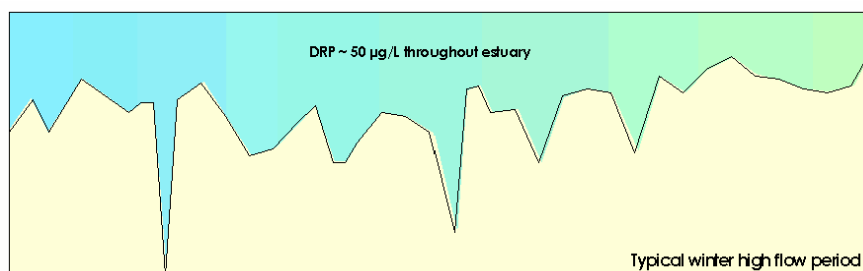
Where future scenarios include damming of the Doring River, it may result in a decrease in the turbidity of water that enters the estuary in the upper reaches during State 3.

Dissolved inorganic nitrogen (DIN). The distribution of DIN concentrations in the estuary during State 3 is estimated as follows:



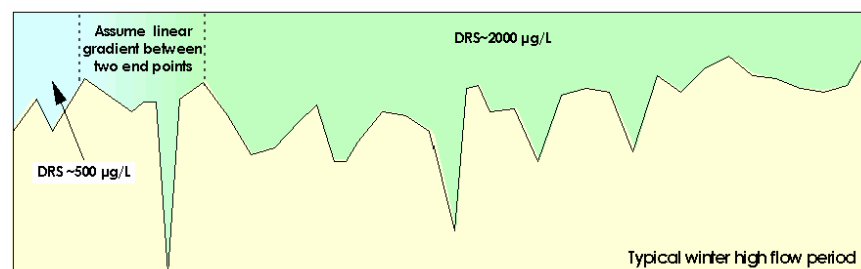
Where State 3 occurred under the Reference Condition, the DIN concentrations in the upper reaches were probably markedly lower (<100 µg/l), based on the predicted Reference Condition for DIN in river inflow.

Dissolved reactive phosphate (DRP). The distribution of DRP concentrations in the estuary during State 3 is estimated as follows:



Where State 3 occurred under the Reference Condition, the DRP concentrations in the upper reaches were probably markedly lower (<20 µg/l), based on the predicted Reference Condition for DRP in river inflow. As a result DRP concentrations in the estuary showed a linear gradient between that present in the upper reaches (<20 µg/l) and that typically measured in lower reaches – characteristics of seawater (~50 µg/l).

Dissolved reactive silicate (DRS). The distribution of DRS concentrations in the estuary during State 3 is estimated as follows:



7.3 State 4: Freshwater dominated

Typical flow patterns. Flows are usually $> 20 \text{ m}^3/\text{s}$. This range is typical of winter high flow conditions (June to September).

State of the mouth. The mouth is permanently open

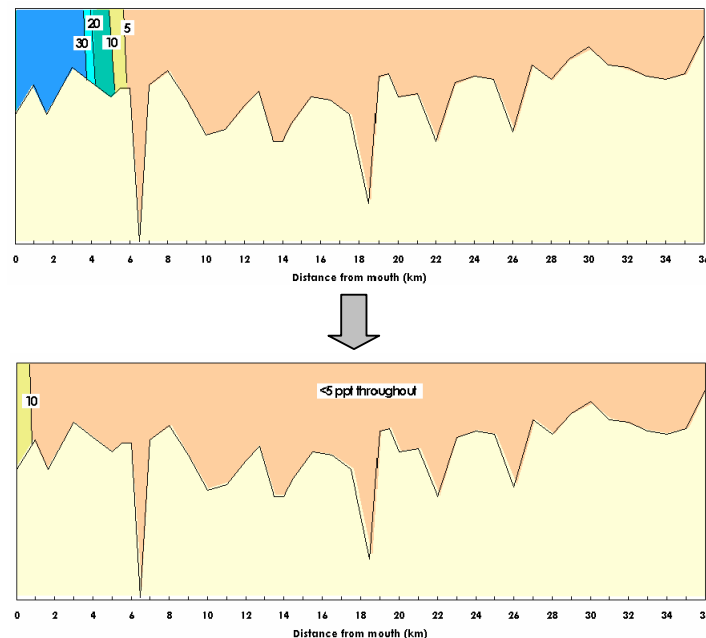
Flood plain inundation patterns. At these flows inundation of the flood plain will be limited, probably on spring high tides. However, during much higher flows at river floods inundation of the flood plain will occur. Such flooding may be essential for the ecological processes on the flood plains.

Amplitude of tidal variation. During neap tides the vertical water level variations are approximately 0.3 m at the mouth and during springtides they are approximately 1.30 m at the mouth. This variation is, contrary to States 1 to 3, reduced further upstream and there is probably no tidal variation at the top at the Lutzville bridge.

Retention times of water masses. At flow of more than $20 \text{ m}^3/\text{s}$ the residence time is estimated to be less than a day in the lower, middle and upper reaches respectively. Due to some stratification in the bottom water in areas deeper than 2.0 m MSL, residence time is expected to be slightly more about 1 – 3 days in these areas. For the entire estuary, water residence time is expected to vary between < 1 day to 4 days at flows of $> 20 \text{ m}^3/\text{s}$.

Estimated (maximum) tidal velocities along the estuary: Approximately 1 m/s at springtide near the mouth and these are strongly reduced further upstream because of the strong river flow.

Salinity distributions in the estuary. The average salinity distribution under State 4 is illustrated below:

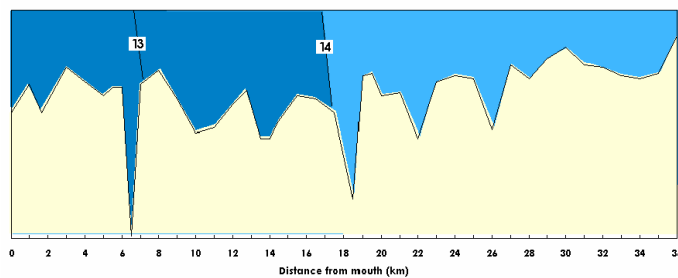


During the lower flow ranges ($20 - 50 \text{ m}^3/\text{s}$) under State 4, some saline intrusion occurs in the lower 7.0 km of the estuary during high tides. During lower tides, the salinity distribution is restricted to the lower 2.2 km of the estuary. This salinity intrusion is also reprehensive of what occur during flood conditions.

Total volume per salinity range.

SALINITY ZONE	HIGH TIDES		LOW TIDES	
	Distance from mouth (km)	Volume (m ³)	Distance from mouth (km)	Volume (m ³)
30 ppt	3.5	1 995 000	-	-
20 ppt	4.5	284 300	-	-
10 ppt	5.4	283 600	-	-
5 ppt	6	144 300	0.25	268 300
0.5 ppt	7.3	337 600	2.2	1 119 000

Temperatures. As State 4 will predominantly occur during the wet winter months when the temperature distribution along the estuary is estimated as follows:

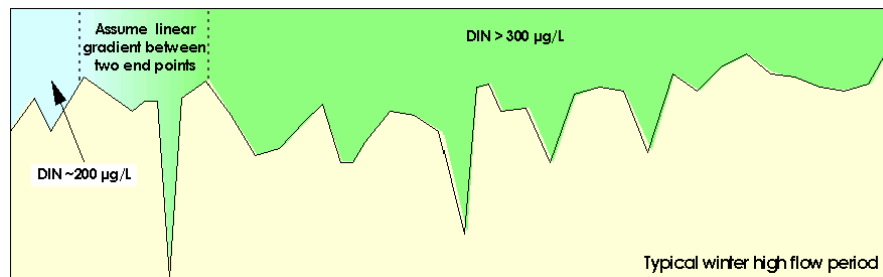


pH. Levels is likely to ranged between 7.3 and 8.5 throughout the system

Dissolved oxygen. Under State 4 (high flow period), freshwater flushing together with tidal exchange is expected to maintain well oxygenated conditions throughout the estuary (above 6 mg/l).

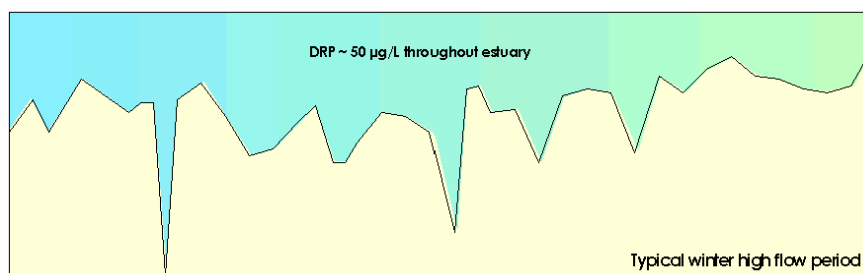
Turbidity/Suspended solids. Under State 4 (high river inflows) the estuary starts to become more turbid, particularly when inflow originates from the Doring and other tributaries draining the soft leachable shales (Karoo formations). As tidal intrusion still introduce clearer seawater into the lower reaches, a strong horizontal gradient can be expected, ranging from between 25-50 NTU (Secchi disc depth typically less than 1 m) in the upper reaches to <15 NTU (Secchi disc depth typically greater than 1 m) near the mouth.

Dissolved inorganic nitrogen (DIN). The distribution of DIN concentrations in the estuary during State 4 is estimated as follows:



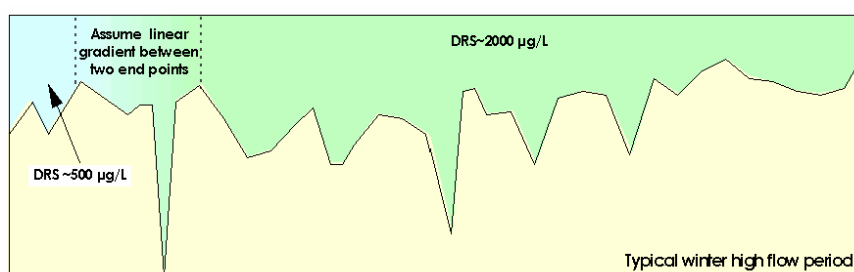
Where State 4 occurred under the Reference Condition, the DIN concentrations in the upper reaches were probably markedly lower (<100 µg/l), based on the predicted Reference Condition for DIN in river inflow.

Dissolved reactive phosphate (DRP). The distribution of DRP concentrations in the estuary during State 4 is estimated as follows:



Where State 4 occurred under the Reference Condition, the DRP concentrations in the upper reaches were probably markedly lower ($<20 \mu\text{g/l}$), based on the predicted Reference Condition for DRP in river inflow. As a result DRP concentrations in the estuary showed a linear gradient between that present in the upper reaches ($<20 \mu\text{g/l}$) and that typically measured in lower reaches – characteristics of seawater ($\sim 50 \mu\text{g/l}$).

Dissolved reactive silicate (DRS). The distribution of DRS concentrations in the estuary during State 4 is estimated as follows:



8. SEDIMENT DYNAMICS

8.1 Introduction

The Olifants Estuary is situated on the west coast of South Africa. The catchment area at the head of the estuary is about 48000 km² and the estuary is about 36 km long. There are two major tributaries to the Olifants River, namely the Doring coming from the southeast and the Sout River coming from the northeast. The catchment of the Doring is by far the largest with about 24000 km². The Olifants catchment up to the confluence of the Doring and Olifants is much smaller with only about 2900 km². However, the two rivers have approximately the same mean annual runoff under natural conditions. The Sout on the other hand produces very little runoff (approximately 2% of the total MAR of the Olifants), and for this reason, together with the fact that there is very little gauging data, it was decided to exclude this area from the modelling and analysis. It was thought that it would have little effect on the functioning of the estuary. The total effective catchment area (also used for sediment yield calculations) would then reduce to about 30 000 km².

Two of South Africa's oldest dams have been constructed on the Olifants River: the Clanwilliam Dam (1935, see Figure 8.1) in the upper catchment and downstream of it the Bulshoek Dam (1922, see Figure 8.2) near the confluence of the Olifants and Doring rivers. Both dams have relatively small storage capacities in relation to the mean annual runoff (MAR) as can be seen in TABLE 8.1:. Clanwilliam Dam has a capacity/MAR ratio of 0.35, while the same ratio at the Bulshoek Dam is only 0.01. This means that the flows from the Olifants River have been impacted for a long time, but since the dams are relatively small, their effect on floods has not been very pronounced.

TABLE 8.1: Dam characteristics

DAM	FSL¹ (m MSL)	FSC² (Mm³)	FSC/MAR
<i>Bulshoek</i>	64	6.5	0.01
<i>Clanwilliam</i>	104.4	124	0.35
<i>Clanwilliam raised by 15m³</i>	119.4	345	1
<i>Melkbosrug⁴</i>	175	470	1

¹: FSL – Full supply level

²: FSC – Full supply capacity

³: Possible future scenario

⁴: Proposed dam on Doring River



Figure 8.1: Clanwilliam Dam (Photo: DWAF website)



Figure 8.2: Bulshoek Dam (Photo: DWAF website)

The estuary is confined to a single main channel, and its bed slope is rather flat. The sediment yield for the catchment is relatively low. From the reservoir surveys the sediment yield at Clanwilliam Dam was calculated at $135 \text{ ton/km}^2 \cdot \text{a}$ and at Bulshoek Dam at $17 \text{ ton/km}^2 \cdot \text{a}$ (Rooseboom, 1992).

8.2 Fluvial Morphological Simulation Scenarios

In order to assess the changes in the sediment dynamics of the Olifants Estuary between the various scenarios, mathematical modelling of the hydraulics and morphology of the Olifants Estuary was carried out. Although a fair number of scenarios were proposed for this study, in terms of the sediment transport dynamics, it is only those scenarios which will affect the floods to a significant degree which will show significant changes. Therefore the following scenarios were selected:

- **Present** day
- **Reference** condition (natural)
- **Scenario 5:** Raising of Clanwilliam Dam by 15 m
- **Scenario 10:** Construction of a dam on the Doring River near the confluence with the Olifants (Melkbosrug) together with the raising of Clanwilliam Dam by 15 m.

The other scenarios specified in this EFR are basically the same as some of the above-mentioned scenarios in terms of floods and therefore will not yield different results in terms of sediment dynamics, but were scored as follows:

- **Scenario 2:** similar to Present State in terms of floods
- **Scenario 7:** similar to Scenario 3 in terms of floods
- **Scenario 17:** similar to Scenario 3 in terms of floods, although sediment loads from the Doring River are changed slightly.

A major problem encountered in this study was the lack of suitable flow data for the whole catchment. Although some gauging stations have got very long records, several problems were encountered:

- No rating table available, i.e. only water levels and no flows
- Very low accuracy of gauging station flow records
- Rating table valid only for lower flows.

Therefore flow series had to be generated from those stations with existing data by using reservoir and river routing to obtain flows at the head of the estuary. Details of the flow series used for the different scenarios are given in Table 8.1. The lack of accuracy and available data poses a serious problem, since this affects the confidence in the conclusions drawn from the simulations.

TABLE 8.1: Details on flow series used for the different scenarios

SCENARIO	FLOW SERIES FOR OLIFANTS	FLOW SERIES FOR DORING	FLOW SERIES FOR INCREMENTAL CATCHMENT	MAR AT HEAD OF ESTUARY
Present	<i>Outflows from Clanwilliam Dam routed through Bulshoek Dam</i>	<i>E2H003</i>	<i>Scaled from E2H003 based on catchment areas</i>	<i>700 Mm³/a</i>
Reference	<i>Outflows from Clanwilliam adjusted to remove the effect of Clanwilliam and scaled according to catchment areas</i>	<i>Same as above</i>	<i>Same as above</i>	<i>1000 Mm³/a</i>
Scenario 5	<i>Outflows from Clanwilliam adjusted for the larger storage capacity and routed through Bulshoek</i>	<i>Same as above</i>	<i>Same as above</i>	<i>600 Mm³/a</i>
Scenario 10	<i>Same as for Scenario 5</i>	<i>E2H003 routed through Melkbosrug Dam</i>	<i>Same as above</i>	<i>450 Mm³/a</i>

i. Present Day

For the Present day condition, outflows from Clanwilliam Dam were first scaled up to account for the incremental catchment between Clanwilliam and Bulshoek. This flow series was then routed through Bulshoek Dam through a dam balance, based on the reservoir characteristics as well as monthly rainfall and evaporation rates and the demand on the dam from the system analysis. This way a times series with hourly time steps was obtained. A 10-year period from 1982 to 1992 was chosen. This flow series was then routed to the head of the estuary together with a flow series for the Doring River obtained from the E2H003 gauging station (see Figure 8.1). The incremental catchment downstream of the confluence of the Olifants and Doring was accounted for by scaling the 10-year flow series from E2H003 down according to a factor based on a ratio of the catchment areas of the incremental catchment to the Doring. The flow series thus obtained is pictured in Figure 8.2.

ii. Reference Condition

For the Reference condition, the same data series was used for the Doring as for the Present condition, because the Doring system is still very close to its natural state, as no big developments have taken place in the catchment as yet. For the incremental catchment the same holds true. For the Olifants on the other hand, no flow data is available for natural conditions, because flow gauging only started when or after the dams were built. In order to obtain a flow series representing natural flows, a series of different floods were routed through Clanwilliam Dam, to determine the effect of the dam on floods. It was found that the incoming flood peaks were reduced by about 10%. This seems realistic as the dam at present only has a storage capacity to MAR ratio of 0.35, which is rather low. It was therefore decided to use the 10-year outflow series from Clanwilliam Dam used for the Present conditions and increase the flood peaks by 10%. This time series was then again adjusted for the incremental catchment between Clanwilliam and Bulshoek. This time series was then routed, together with flows from the Doring and extra incremental catchment, much like for the Present conditions. The flow series thus obtained is shown in Figure 8.3.

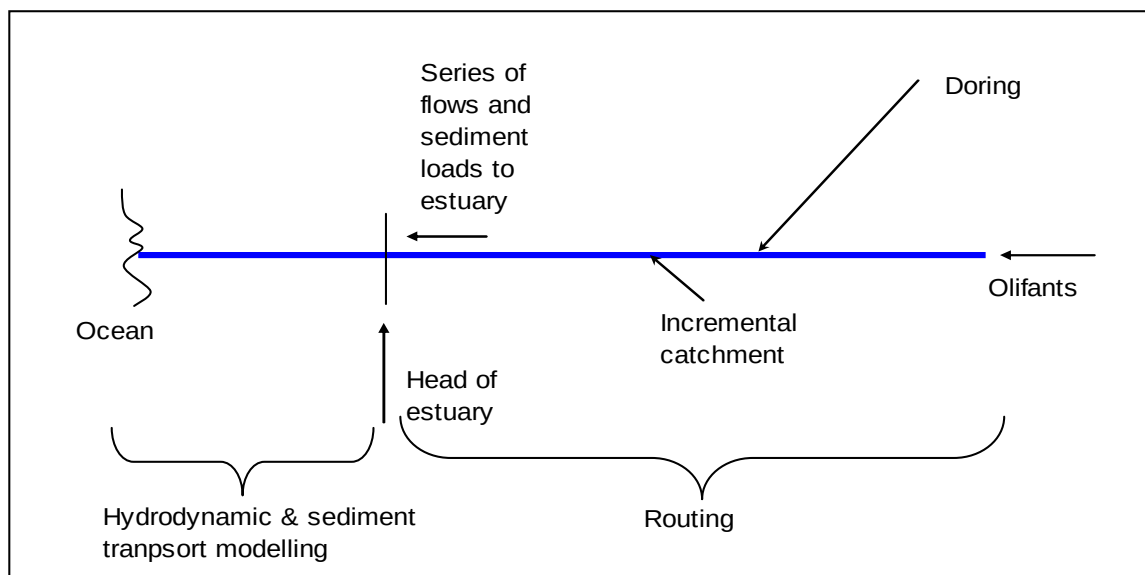


Figure 8.1: System schematic

iii. Scenario 5: Raising of Clanwilliam Dam by 15 m

To obtain a flow series for this scenario, the time series used for the Doring and incremental catchment will be the same as for the Present and Reference conditions. It will only be the flows from the Olifants that will change again. As for the Reference condition a times series of different floods was routed through Clanwilliam Dam, this time with a higher dam wall, and thus a larger storage capacity. The spillway characteristics were assumed to stay the same. The effect on the time series was much more significant than with the smaller storage capacity, which was expected since the raising of the dam wall means that the storage capacity to MAR ratio increases from 0.35 to 1. The flows decreased by about 50%. The inflows to Bulshoek Dam were therefore reduced by 50% to account for the effect of the raising of Clanwilliam Dam. Flows to Bulshoek will still have the releases made for agriculture, only the floods will be reduced significantly. The same procedure was then followed to route the flows to the estuary. The flow series thus obtained is pictured in Figure 8.4.

iv. Scenario 10: Construction of Melkbosrug Dam on the Doring River

For this scenario the same flow series used for Scenario 5 for the Olifants and for Present for the incremental catchment were used, as these are expected to remain un-effected by the construction of Melkbosrug Dam. The reservoir characteristics were obtained from Ninham Shand Consulting Engineers, but the spillway characteristics were still unknown. A typical spillway equation, based on a 150 m spillway length, was assumed. A dam balance for this dam was then set up and the flow series from gauging station E2H003 was used as inflows to the dam. Monthly rainfall, evaporation and demand values were obtained from the system analysis. The storage capacity to MAR ratio of this dam is 1, and as such the actual spillage from the dam is not very high. The same routing procedure as for the other scenarios was then used to obtain a flow series at the estuary (see Figure 8.5).

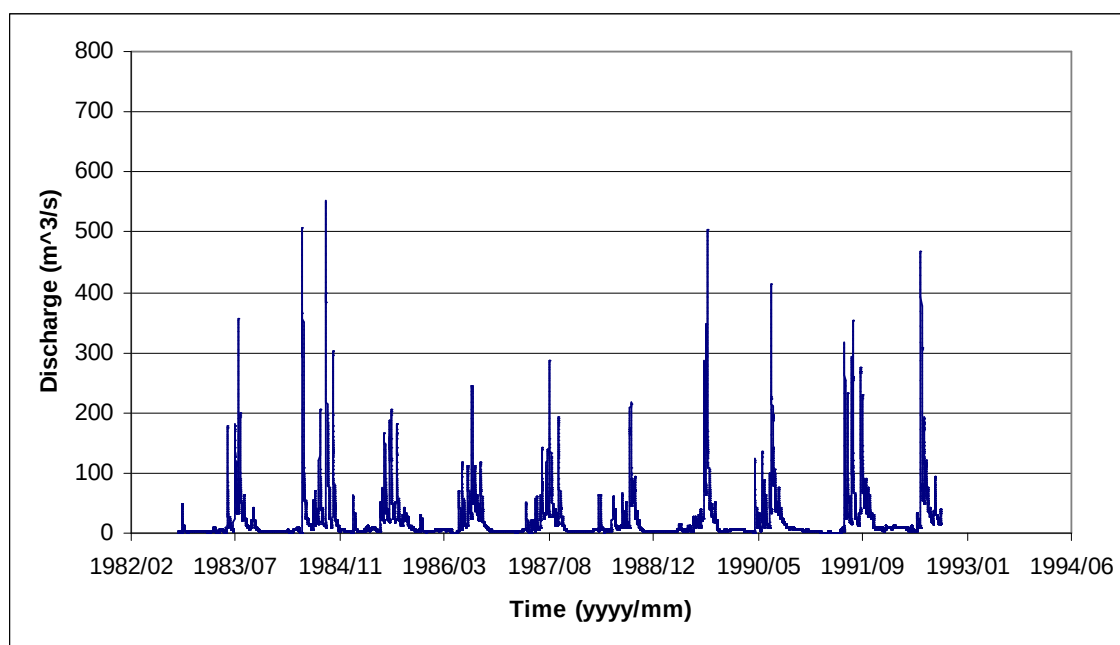


Figure 8.2: Present State - flow series at the head of the estuary

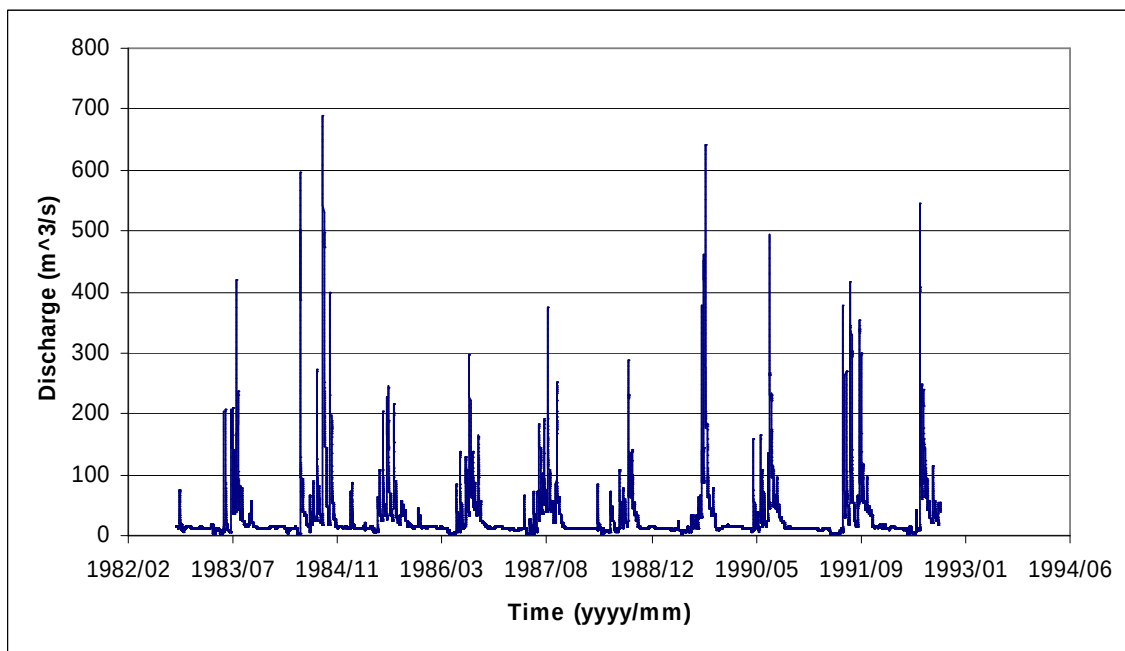


Figure 8.3: Reference Condition - flow series at the head of the estuary

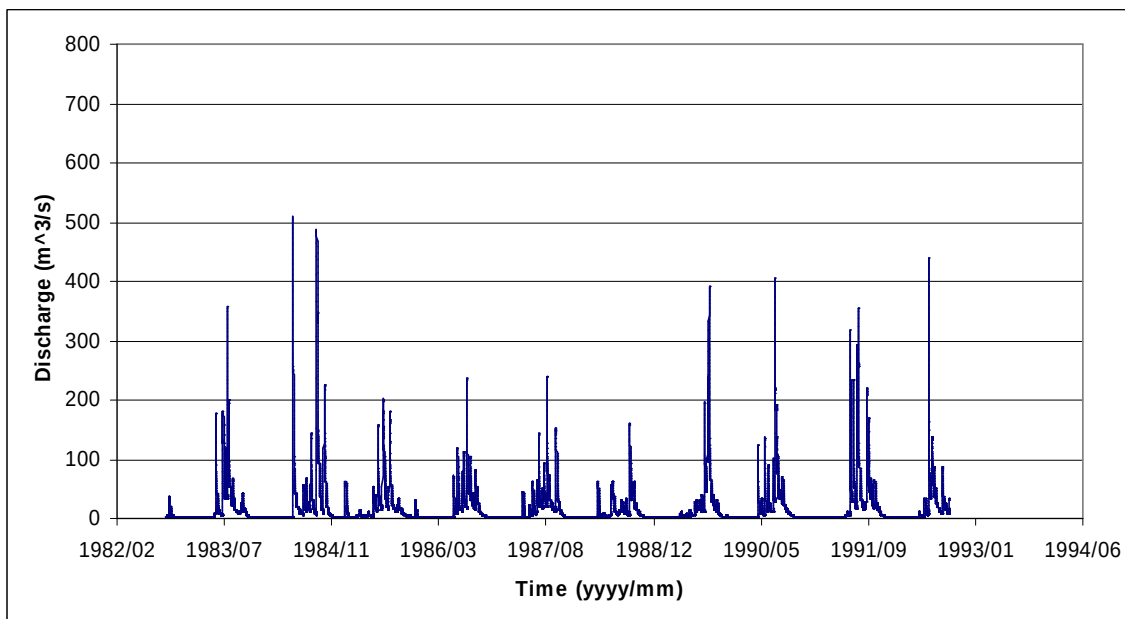


Figure 8.4: Scenario 5 - flow series at the head of the estuary

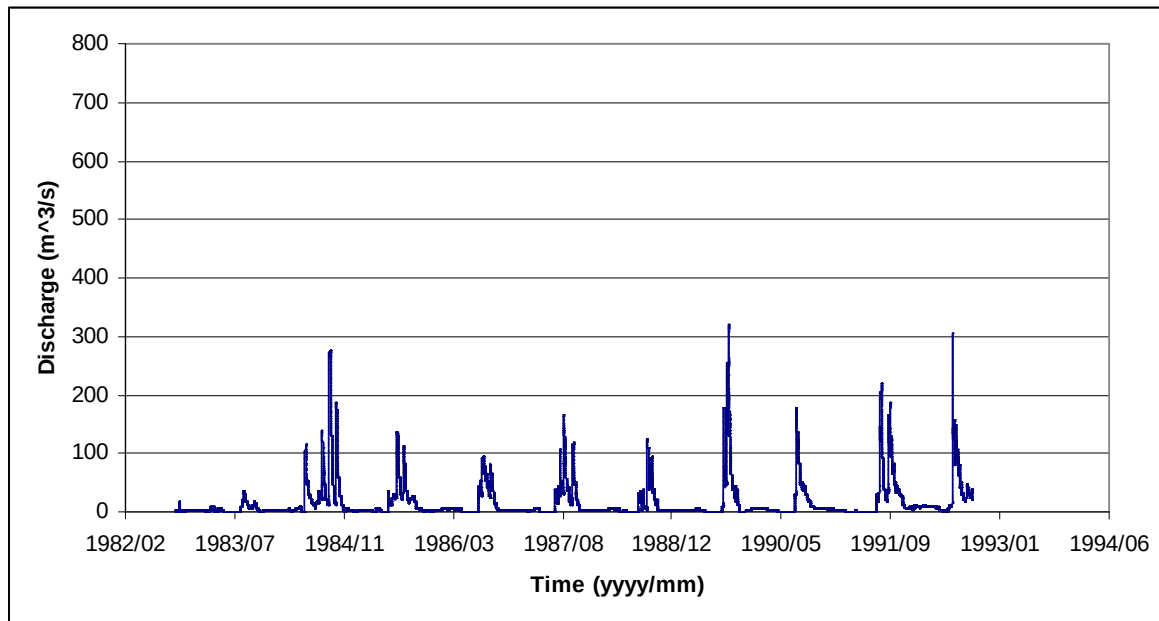


Figure 8.5: Scenario 10 - flow series at the head of the estuary

8.3 Olifants Estuary Model Set-up

8.3.1 Mathematical Model Background

For the computational modelling, the one-dimensional model MIKE 11, developed by the *DHI Water and Environment* (DHI, 2001), was used. MIKE 11 was developed for the simulation of flows, sediment transport and water quality in rivers, estuaries and similar water bodies.

i. *Hydrodynamic Module*

The MIKE 11 hydrodynamic (HD) module is an implicit, finite difference model for the computation of unsteady flows in rivers and reservoirs, based on the St Venant equations representing conservation of mass and momentum. The model can describe both subcritical as well as supercritical flow conditions, and modules are incorporated to describe flow past hydraulic structures. The model can be applied to looped networks and quasi two-dimensional flow simulation on flood plains. The HD module was set up to use the dynamic wave approach, which uses the full momentum equation.

ii. *Non-Cohesive Sediment Transport Module*

The non-cohesive sediment transport (NST) module can be run in two modes: explicit and morphological. In the explicit mode output is required from the HD module, but no feedback occurs from the NTS module to the HD module. In the morphological mode sediment transport is calculated together with the HD module and feedback is given from the NTS module to the HD module. The results are in the form of bed level changes, sediment transport rates and bed resistance. The morphological model updates either the whole cross-section or only a part of it (generally the part representing the river channel or the part below the water surface).

Traditional sediment transport equations are incorporated in the MIKE 11 model for non-cohesive sediment transport. All of these can be run with a single representative particle size or a particle distribution.

8.3.2 Model Setup

The model bathymetry was based on surveyed cross-sections from 1994, spaced about 1000 m apart and stretching 36 km upstream from the mouth.

At the upstream boundary an inflow time series was specified for the various scenarios together with incoming sediment loads. A water level time series with one-hourly time steps, representing the tidal variation in the sea, was specified at the downstream boundary. The tidal variation was simulated, based on tidal constituents for Saldanha Bay (Figure 8.6).

The Manning n-value was taken as 0.03 for the whole area. The hydrodynamic time steps were 45 s and 90 s for sediment transport calculations.

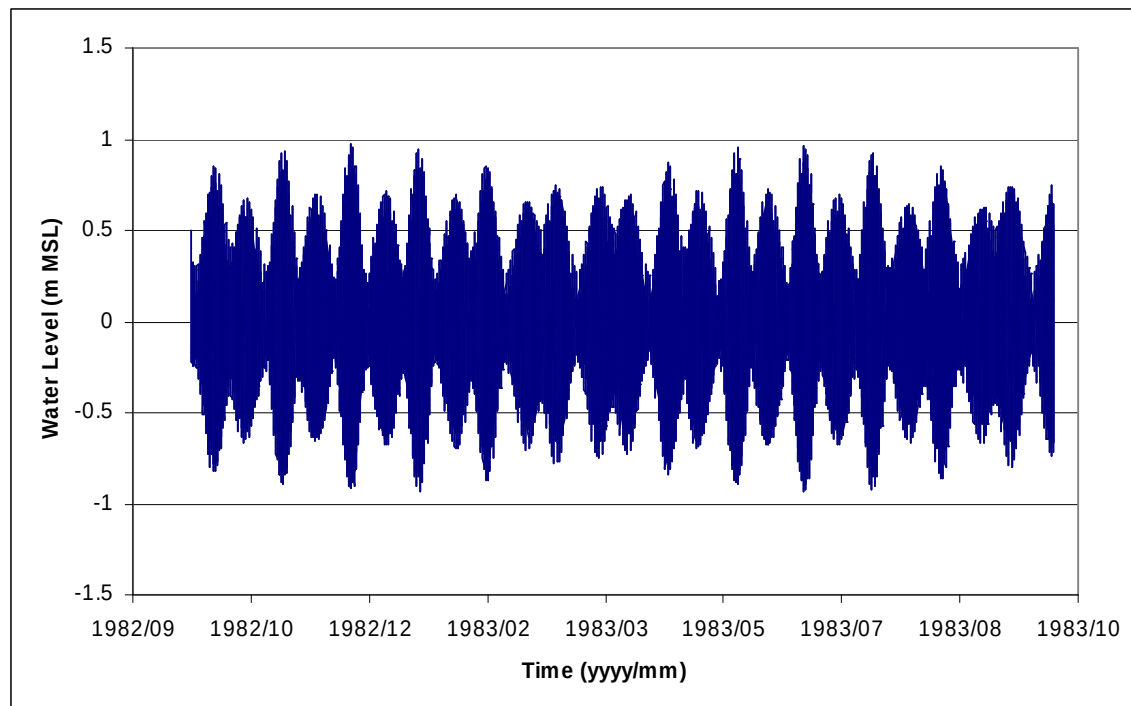


Figure 8.6: Predicted tidal variation based on Saldanha tidal constituents (1982/83)

A uniform sediment size of 0.3 mm was specified throughout the whole model, which was based on bed sediment grab samples taken in the field during April 2004.

Figure 8.7 shows that towards the top of the estuary the sediment becomes increasingly finer, and then coarser again. Figure 8.8 shows the distribution of silt, clay and sand in each of the samples.

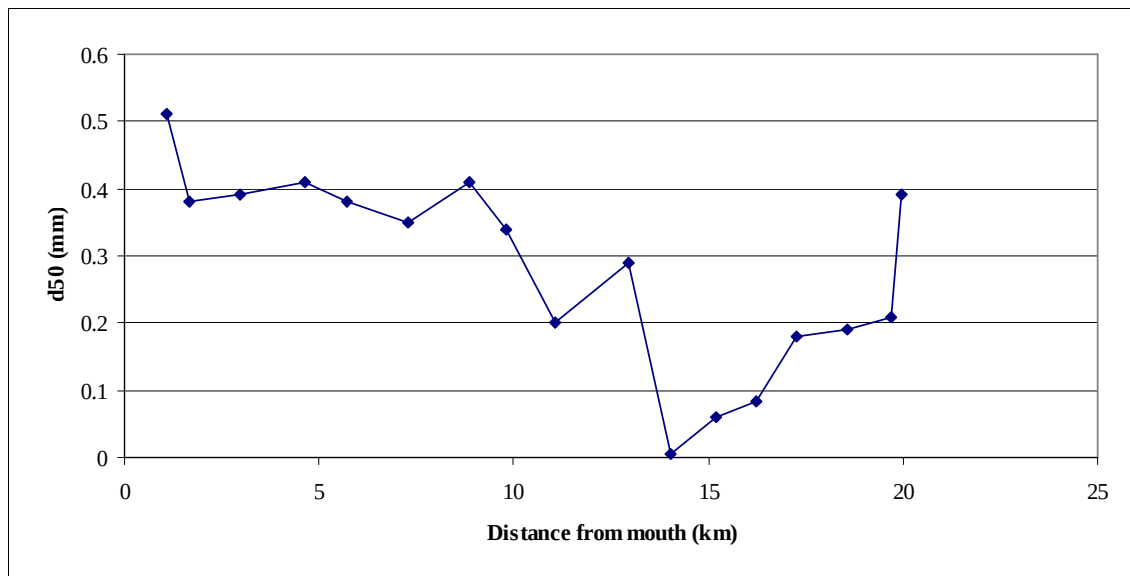


Figure 8.7: Median diameter of sediment samples taken in April 2004 at the Olifants Estuary

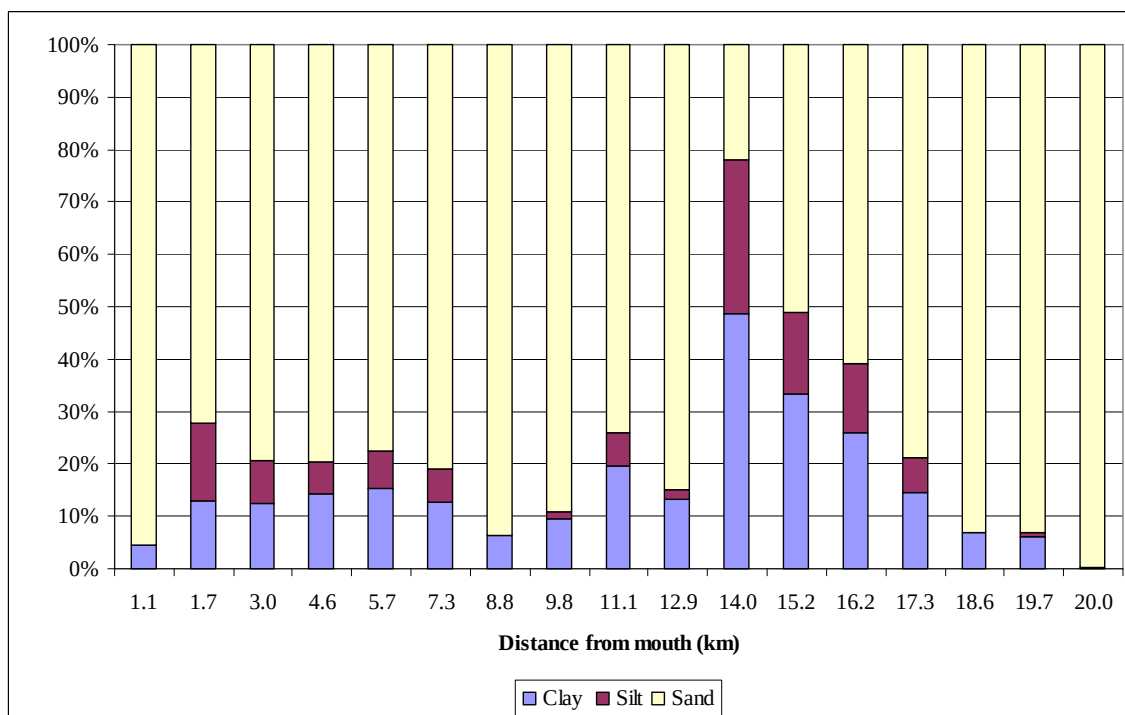


Figure 8.8: Distribution of silt, clay and sand in the sediment samples taken along the estuary during April 2004

The incoming sediment loads were calculated with the aid of the Yang sediment transport formula, based on the local hydraulic conditions. The sediment loads thus obtained are calculated for a representative sediment size of 0.3 mm and represent the total carrying capacity of the inflow. This value usually has to be scaled to account for the fact that although the river can transport a certain amount of sediment, sediment is not always available. It was assumed that the dams will trap most of the incoming sediment, and for that reason the sediment yield calculations were based only on the areas downstream of the different dams. For the Reference Condition this of course meant that the sediment yield for the whole catchment area was calculated.

The only information on sediment yields for the catchment comes from the reservoir surveys on the Olifants River (Rooseboom, 1992). From this the sediment yield at Clanwilliam Dam was calculated at 135 ton/km².a and at Bulshoek Dam at 17 ton/km².a. It is, however, unclear how much sediment is coming from the Doring River. Initially the incoming sediment loads to the estuary were calculated to obtain a sediment yield of 75 ton/km².a. However, this value proved to be too high, as the sediment concentrations would go as high as 100 000 mg/l, which is completely unrealistically, especially since the highest flood peak in the 10-year series is less than 1000 m³/s, based on the Present day flow series. The sediment loads were therefore scaled down to obtain more realistic maximum sediment concentrations of 8 000 mg/l. The sediment loads for the other scenarios were then scaled to obtain the same sediment yield (ton/km².a) as obtained for the Present State scenario.

No sediment input was specified at the downstream boundary since it was assumed that most of the sediment from the ocean would be scoured around the mouth of the estuary, which is included in the model, and that the sediment availability from the ocean is not limited.

8.4 Simulation Results

8.5.1 Return Period Floods

The floods with return periods of 2, 5, and 10 years have been calculated for all the simulated scenarios with the aid of statistical methods (Table 8.2). These methods are based on the maximum annual flood peaks during the 10-year period. Software developed by Alexander (1991) was used to calculate the return period floods. The probability distribution providing the best fit for all the data was Log Pearson Type 3 (LP3). Any return period floods based on a longer period of time could of course be different to the ones listed in Table 8.2. However, the relative differences between the two scenarios are of importance. For comparison, simulated spring tide peak discharges in the estuary are listed in Table 8.3

From Table 8.2 it can be seen that the flood peaks at present are reduced by about 18% from what they would have been under natural conditions, as a result of both Clanwilliam and Bulshoek Dam. With Clanwilliam Dam raised by 15 m the spillage from that dam is reduced considerably, however, the flows from the Doring River are unchanged and as such the effect on the floods at the head of the estuary is relatively small, leading to only a 7% decrease in flood peaks.

With a dam on the Doring River, the effect is much more pronounced (see Figure 8.5), and the flood peaks are reduced by about 50% from the Reference condition. This will have a considerable effect on the sediment transport through the estuary.

TABLE 8.2: Return period flood peaks (m³/s) for all scenarios at the head of the estuary

RETURN PERIOD (YRS)	REFERENCE	PRESENT	SCENARIO 5	SCENARIO 10
2	435	355 (-18%)*	325 (-25%)	190 (-56%)
5	565	465 (-18%)	425 (-25%)	270 (-52%)
10	640	525 (-18%)	490 (-23%)	325 (-49%)

*: Values in parentheses indicate the reduction in flood peaks compared to the Reference condition

Table 8.3: Simulated spring tide peak discharges (m³/s)

	AT THE MOUTH	18 km UPSTREAM
Flood tide	150	40
Ebb tide	120	30

As a result of the reduction in flood peaks the estuary could become narrower. Based on regime equations, relating the 10-yr return period flood peak to channel width, developed during a Water Research Commission study (Beck and Basson, 2003) the estuary could narrow by about 25% (from present state) due to the construction of a dam on the Doring River. At present the estuary would be about 10% narrower compared to Reference. With the raising of Clanwilliam Dam by 15 m, that figure would be about 15%. These changes would probably be confined to the upper reaches of the estuary, since this area is much more affected by the changes in major floods than the lower estuary.

The occurrences of the larger floods are affected just as much as the magnitude of these floods. Figure 8.9 shows the percentage of time that flows within certain ranges occurred during the 10-yr simulated period for the four simulated scenarios. The biggest changes occur within the 10 to 30 m³/s flow range. The effect of the dams is that they trap most of the smaller floods, and attenuate the larger floods, so that whereas under Reference conditions the greatest occurrence of flows was in the range of between 10 to 30 m³/s, this has shifted to a range of 5 to 10 m³/s under Present day conditions. Figure 8.10 highlights the changes in each of the flow categories from Reference condition. It can be seen that flows between 5 and 10 m³/s have increased for all scenarios, but most dramatically for the Present State. In contrast, the flows in the range of 10 to 30 m³/s as well as 200 to 600 m³/s, i.e. the large floods, have decreased the most. Especially with the dam development on the Doring River, the large floods have been almost completely removed.

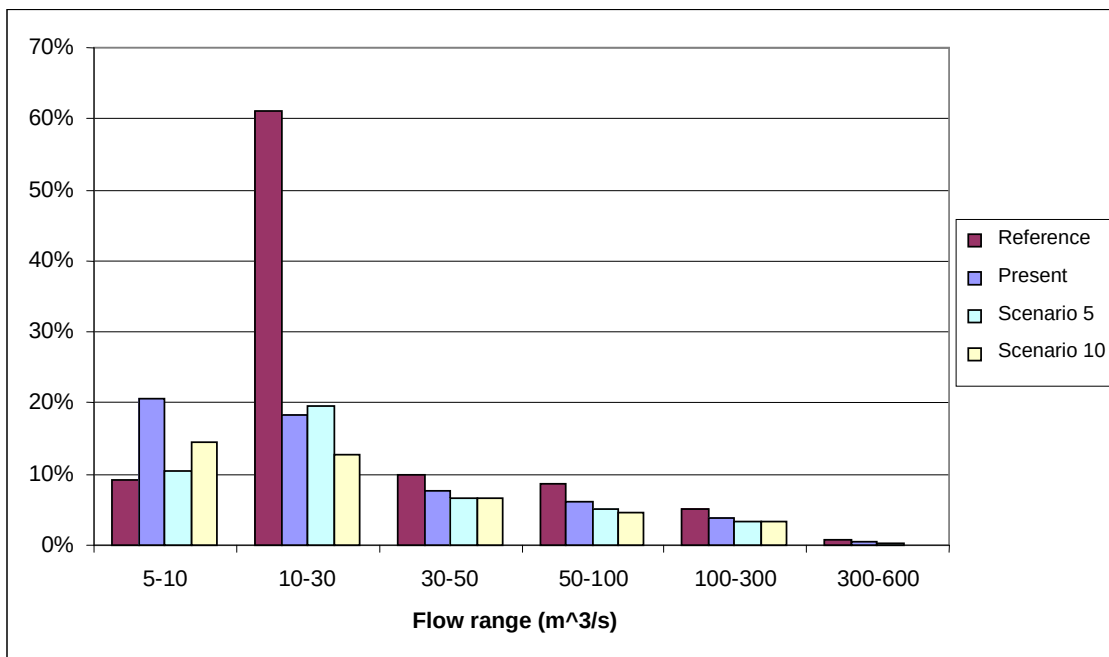


Figure 8.9: Percentage occurrence of different flow ranges for the four simulated scenarios

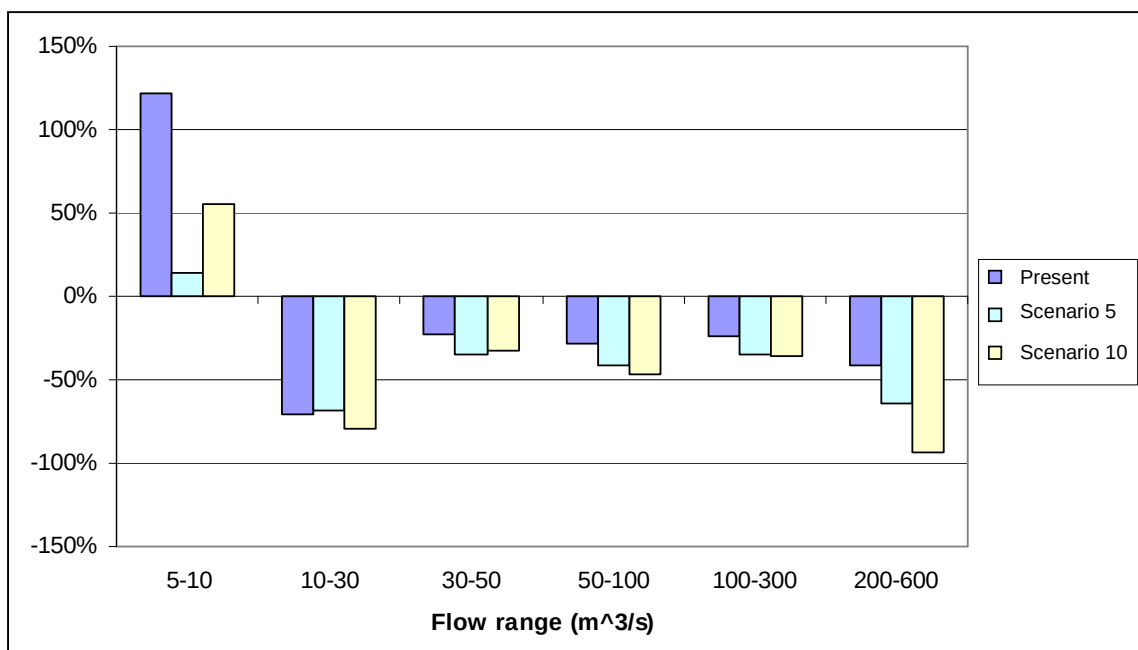


Figure 8.10: Percentage change in the flow ranges from Reference

8.4.2 Sediment Dynamics

From Figure 8.11 it can be seen that the sediment loads at points within the estuary are much reduced from the incoming sediment loads. This means that much of the incoming sediment load is deposited in the upper reaches of the estuary. This phenomena can be observed in all four scenarios and the reason for this is possibly that the estuary is so flat, which means that the sediment transport capacities are very low. However, since the incoming sediment loads are relatively small, it does not seem like the estuary is silting up at a considerable rate, under any scenario. It is important to note that due to the limited data available, the absolute values given in terms of sediment dynamics are not very reliable. However, the relative differences between the various scenarios should give an accurate indication of the impacts associated with different catchment developments.

From Figure 8.11 it can also be seen that with increasing developments in the catchment the sediment loads coming into the estuary are increasingly reduced, especially with a dam on the Doring River. The reason for this is the combination of the reduced duration and magnitude of floods due to reduced spillage and flood attenuation by the dams, as well as the trap efficiency of the dams. A dam with a storage capacity to MAR ratio of 1, such as the proposed dam on the Doring River, will trap up to 100% of the incoming sediment load (Churchill, 1948). Combined with the dams on the Olifants this means that sediment is available from only about 4000 km² of the total 30 000 km² (excluding the Sout River). The effect of the reduced sediment load can clearly be observed from Figure 8.12. Considerable scouring will take place in the upper 15 km of the estuary and the bed level will drop by between 1 to 2 m. The lower part of the estuary up to about 20 km from the mouth remains relatively unaffected by any developments.

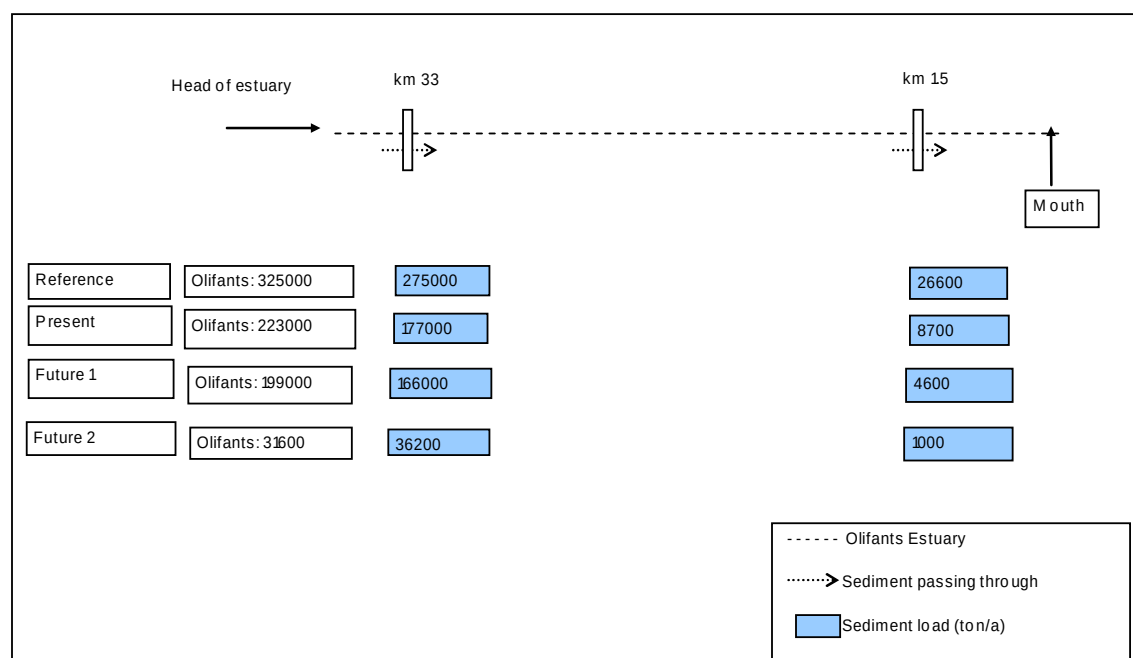


Figure 8.11: Simulated long-term annual loads for all scenarios (ton/a)

From Figure 8.12 it can be seen that the estuary has changed slightly at present compared to the Reference condition. The estuary is now about 0.5 m deeper in the upper reaches than what it was under Reference conditions. This means the tidal effect would also now be noticeable further upstream than under Reference conditions.

In comparison with the construction of a dam on the Doring River, the raising of Clanwilliam Dam shows very little impact on the sediment transport dynamics in the estuary. More sediment than at present seems to be deposited in the upper reaches of the estuary, with the bed level approaching that of the Reference condition. The reason for this could be the reduced sediment transport capacities due to the minor reduction in floods at the estuary due to the larger storage capacity of Clanwilliam Dam. The point at which the tidal effect can still be observed will therefore move downstream.

There would also be a significantly reduced supply of sediment to the marine environment. At present the simulated sediment loads leaving the system are around 9000 ton/a, whereas with the dam on the Doring River, this reduces by almost 90% to about 1000 ton/a.

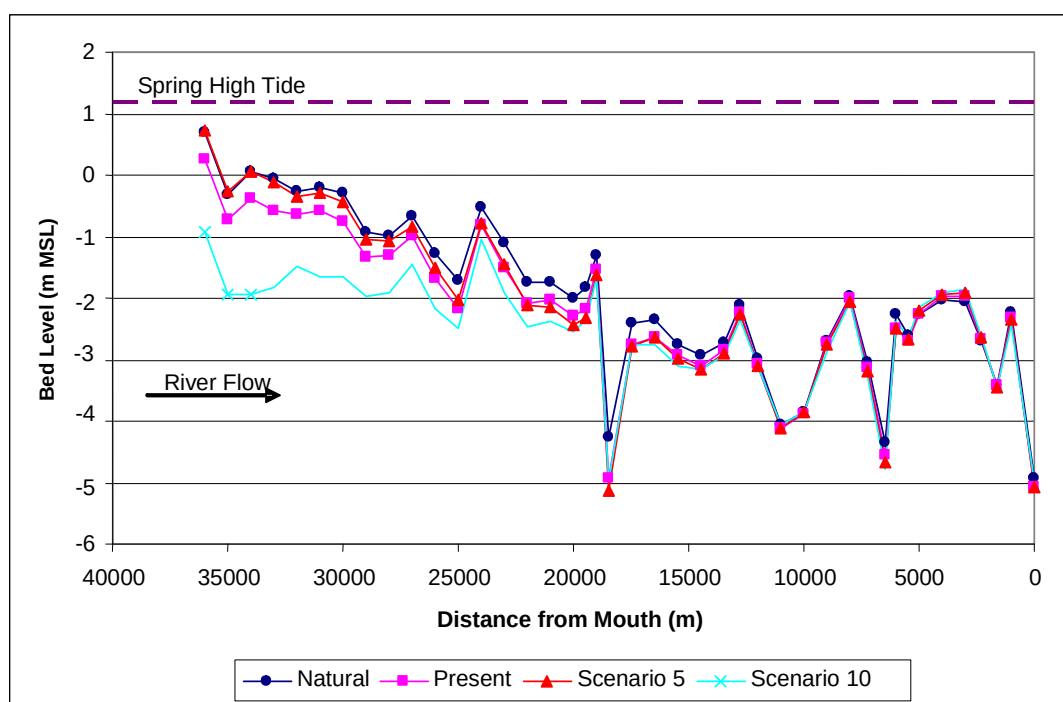


Figure 8.12: Final bed levels after 10-year simulation period (all scenarios)

These changes are generally confined to the upper reaches of the estuary, up to about 15 km from the mouth. In the lower estuary, although not explicitly modelled, it seems from historical aerial photographs that the blind arm of the river at the mouth seems to be silting up. This process will probably increase with increased dam developments in the catchment, but a part of this process seems to be natural.

With respect to the sediment characteristics in the estuary, any dam developments are generally associated with a flushing of fine sediment out of the estuary, leaving the coarser material behind. It is thought that since the raising of Clanwilliam Dam seems to have a limited impact on the larger floods, the removal of fine sediment, especially from the upper reaches of the estuary, will also be limited. However, with the dam development on the Doring River, most of the catchment sediment is cut off, and severe erosion is likely to occur in the upper reaches. This would mean that there would be a significant decrease in the fine sediment in the upper reaches.

Although not simulated the Brandewyn weir on the Doring River (Scenario 17) will to a minor degree affect the sediment loads from the Doring River. The storage capacity of the weir is very small compared to the MAR, and is thus not expected to affect the larger floods. However, some of the sediment from the Doring River will be trapped and since most of the finer sediment originates from the Doring River catchment, this means that the bed sediment in the upper reaches of the estuary will become even coarser than under Scenario 5.

8.5. Key Findings

The key findings are:

- Flood peaks have been reduced by about 18% from Reference to Present due to Clanwilliam and Bulshoek Dams on the Olifants River. A further reduction of 7% in flood peaks would occur if Clanwilliam Dam was raised by 15 m. If a dam is constructed on the Doring River the flood peaks would reduce by about 50% from Reference.
- The lower part of the estuary up to about 20 km from the mouth remains relatively unaffected by any developments in terms of depth.
- In the upper 15 km of the estuary sediment seems to deposit and little sediment is transported out of the estuary.
- Under Reference conditions the estuary would have been about 0.5 m shallower in the upper reaches than at Present. With the raising of Clanwilliam Dam the estuary again approaches the bed level under Reference conditions. The construction of a dam on the Doring River would result in a 1 to 2 m deeper estuary in the upper reaches. The tidal effect would therefore be noticeable further upstream.
- At present the estuary would be about 10% narrower in the upper reaches compared to Reference. With the raising of Clanwilliam Dam by 15 m, that figure would be about 15%.
- With the dam development on the Doring River the estuary could become narrower by about 25% compared to present.
- Sediment in the upper reaches of the estuary would become progressively coarser with more dam developments in the catchment, especially with developments on the Doring River.

9. OCCURRENCE AND DURATION OF ABIOTIC STATES FOR FUTURE SCENARIOS

9.1 Description of Scenarios

The future runoff scenarios that will be used in this preliminary determination of the ecological flow requirements of the Olifants Estuary are listed in Table 9.1, together with details on the Reference Condition and Present State.

TABLE 9.1: A summary of the various simulated monthly runoff scenarios used in this Ecological Reserve Study

SCENARIO	DESCRIPTION	Mean Annual Runoff (MAR) (million m ³ /year)	Percentage
Reference	Representative of flows before agricultural developments and impoundments in the catchment	1070.1	100%
Present	Reflects the present agricultural developments and dam developments in the Olifants main stream (Clanwilliam and Bulshoek Dam) - simulated data reflect inflow without Bulshoek leakage	715.0	66.8%
Scenario 2	Present inflow plus the Ecological Water Requirement releases of the River	800.3	74.8%
Scenario 7	Raising Clanwilliam wall (15 m) plus the Ecological Water Requirement releases of the River	741.5	69.3%
Scenario 5	Raising Clanwilliam wall (15 m) with no River EWR releases	605.7	56.6%
Scenario 17	Brandewyn weir/dam development on the Brandewyn river (a tributary to the Doring River) with a capacity of 5 x 10 ⁶ m ³ , including an abstraction of 5 m ³ /s plus raising the Clanwilliam wall (15 m) with no River EWR releases	529.3	49.5%
Scenario 10	Maximum development represents the Melkbosrug Dam in the Doring catchment. This development would regulate almost all of the inflows from the Doring River and maximise the yield from the Olifants / Doring River system. This scenario ignores the Ecological Water Requirement of the Doring river (includes 15 m raising of Clanwilliam wall) with no River EWR releases	423.5	39.6%

Note: The overall confidence in the hydrology is very low as limited accurate baseflow data was available to base the hydrological assessment on.

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, including:

- Colour coding was used for the full tables of simulated monthly river flow reaching the estuary for the each scenario to highlight the occurrences of the different Abiotic States related to the different flow ranges.
- Summary tables of the occurrences of different flows at increments of 10%ile are listed separately to provide a quick comprehensive overview
- To provide a conceptual overview of the annual distribution of Abiotic States under the different scenarios, median (50%ile) monthly flows were used. The occurrence of different Abiotic States is indicated on the median concentrations. In this instance, the 75%ile and the 25%ile flows are also indicated to illustrate variability in monthly flows (shaded area). Dam developments often reduce the variability in monthly inflow patterns which are usually most profound in the higher flow periods. Maintaining such variability is often important as it represents the stresses under which a particular ecosystem evolved, e.g. regulated inflows has shown to result in a loss of diversity.
- Drought flows are represented by the 10%ile occurrence of simulated monthly flows.

9.2 Present State

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Olifants Estuary, under the Present State is provided in Table 9.2. The mean annual runoff (MAR) is 715 Million m³ for the Present State. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	45.03	31.25	20.88	36.75	26.64	6.99	98.47	186.79	567.98	471.28	231.59	157.39
90%ile	27.01	7.60	6.52	2.88	3.34	3.41	9.19	74.42	160.84	158.30	126.90	76.10
80%ile	14.47	4.36	1.56	0.94	1.09	1.47	4.05	17.74	96.43	105.84	100.55	56.23
70%ile	11.17	1.50	0.93	0.76	0.76	1.06	1.77	8.69	48.30	81.22	69.26	42.07
60%ile	8.29	0.99	0.74	0.75	0.72	0.64	1.05	4.69	30.91	56.77	56.64	32.23
50%ile	6.49	0.76	0.74	0.75	0.70	0.57	0.51	2.19	21.22	40.66	43.61	24.82
40%ile	4.18	0.68	0.74	0.75	0.68	0.57	0.26	1.52	10.31	23.13	32.19	19.97
30%ile	2.72	0.68	0.74	0.75	0.66	0.57	0.19	0.77	5.06	13.84	23.71	15.68
20%ile	1.34	0.68	0.74	0.73	0.66	0.49	0.07	0.40	2.15	6.32	18.26	12.32
10%ile	1.06	0.68	0.74	0.73	0.66	0.28	0.00	0.21	0.74	2.72	5.31	8.01
1%ile	0.59	0.68	0.72	0.73	0.46	0.00	0.00	0.00	0.19	0.30	0.60	1.46

ii. Occurrence and duration of different abiotic states

Estimated occurrence and duration of the different Abiotic States in the Olifants Estuary under the Present State, based on simulated monthly river inflow are indicated Table 9.2.

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under the Reference Condition, median (50%ile) monthly flows are displayed below. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

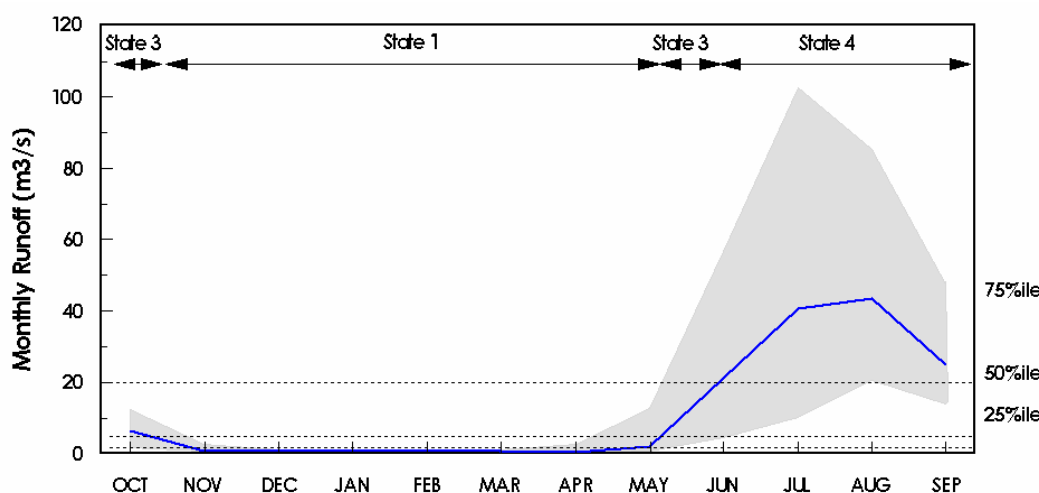


TABLE 9.2: Monthly simulated runoff data in m³/s (70-year period) into the Olifants Estuary for the Present State

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	7.45	0.68	1.06	1.12	9.53	10.83	2.55	0.02	566.13	496.14	105.01	24.52
1921	2.77	0.68	8.59	3.98	0.68	0.29	0.00	0.40	24.88	32.54	107.91	64.37
1922	1.06	0.68	0.74	0.73	0.66	0.00	1.33	2.58	160.84	109.48	31.71	16.00
1923	1.64	0.70	0.74	0.73	0.68	0.36	0.00	0.00	7.61	11.26	56.64	28.30
1924	6.76	1.06	0.74	0.75	1.17	0.57	0.07	1.10	572.29	460.62	46.49	8.10
1925	13.59	2.74	0.74	0.75	0.71	0.57	0.08	4.91	4.47	21.36	24.76	5.46
1926	24.41	5.81	0.74	0.75	0.72	0.57	1.77	2.07	0.66	0.56	8.26	14.62
1927	0.64	0.78	0.74	0.73	0.68	0.62	0.00	0.00	14.03	19.77	15.10	9.67
1928	1.34	0.68	0.74	0.73	0.66	0.00	0.58	0.85	15.01	62.28	41.79	29.11
1929	11.27	0.68	0.74	0.73	5.39	2.03	0.00	0.62	0.74	0.33	4.51	45.07
1930	32.00	0.68	0.74	0.79	0.72	0.51	4.03	4.01	2.31	6.16	80.31	62.09
1931	10.25	0.68	0.74	0.75	5.94	3.56	0.26	2.86	43.86	41.18	19.67	16.50
1932	2.90	0.94	0.93	0.73	0.66	0.23	0.00	1.87	37.56	121.30	57.40	12.07
1933	1.64	0.99	0.83	0.73	0.66	4.04	2.46	0.73	1.27	2.73	2.47	7.09
1934	14.47	29.81	12.71	0.75	0.76	0.64	1.88	4.26	8.40	9.93	66.26	46.65
1935	6.21	0.68	0.74	0.75	0.68	0.61	0.00	1.48	1.02	5.05	20.52	62.49
1936	12.60	7.60	6.28	0.82	0.66	0.68	0.13	0.97	44.48	102.75	41.24	10.66
1937	1.20	0.68	6.67	11.42	0.66	0.28	1.05	5.83	5.83	3.40	13.47	34.85
1938	9.07	0.68	0.74	0.73	1.92	1.14	0.00	17.74	19.92	2.72	90.31	83.95
1939	1.59	0.68	0.72	0.73	5.58	1.77	1.61	1.52	4.07	5.44	5.31	8.01
1940	1.17	0.86	0.78	0.80	0.66	0.05	6.01	55.80	191.19	102.43	103.26	144.25
1941	28.26	2.02	0.74	0.75	0.66	0.57	0.35	2.19	197.04	109.73	34.35	15.09
1942	12.40	9.18	5.18	4.98	0.66	0.68	0.00	0.29	4.65	27.55	114.08	33.77
1943	8.76	9.79	6.52	0.75	0.78	1.47	1.18	8.69	55.35	81.22	65.09	39.76
1944	14.40	1.50	0.74	0.75	0.72	0.61	0.19	15.73	124.12	158.30	125.22	20.83
1945	8.24	1.01	0.74	0.75	0.66	0.51	0.59	0.64	0.21	0.34	0.51	94.08
1946	42.75	0.68	0.74	0.75	0.66	1.42	0.29	6.86	7.87	47.95	44.47	16.07
1947	3.49	0.68	0.74	0.75	0.76	5.34	7.93	4.69	5.06	35.36	27.86	47.23
1948	14.89	0.73	0.74	0.75	0.66	0.49	0.02	0.37	0.51	1.00	20.41	24.82
1949	6.01	27.62	6.49	0.75	0.76	0.57	9.82	9.21	2.15	70.42	40.59	27.02
1950	21.24	5.11	1.79	0.75	0.68	0.57	0.26	0.43	46.16	104.39	43.61	32.23
1951	8.29	4.36	0.74	0.75	1.72	0.87	0.26	7.72	9.20	48.08	141.54	61.53
1952	12.55	26.72	19.00	0.75	1.09	0.98	25.24	48.08	24.51	83.33	99.43	22.94
1953	0.91	1.40	1.56	1.31	0.66	1.27	1.66	92.11	96.43	192.62	143.84	56.23
1954	11.05	0.68	0.74	0.75	2.12	1.18	1.41	0.99	30.91	107.54	197.96	88.27
1955	27.01	7.52	1.30	0.79	0.78	1.02	0.78	0.77	22.88	75.05	69.26	22.44
1956	1.36	0.68	0.74	0.73	3.34	2.53	0.26	19.35	122.79	158.33	126.90	48.09
1957	36.38	3.36	1.16	1.16	0.70	0.57	0.24	14.31	21.22	5.11	7.97	15.85
1958	1.16	0.68	0.74	0.73	0.66	0.45	0.90	248.80	238.46	15.35	44.93	17.22
1959	5.08	1.09	0.74	0.75	0.73	0.57	0.26	1.60	12.00	10.54	4.98	1.68
1960	0.59	0.68	1.18	1.24	0.70	2.34	98.72	86.26	57.98	67.76	34.74	48.45
1961	7.54	0.68	0.74	0.73	0.66	0.34	0.08	0.29	309.18	260.77	156.20	76.10
1962	42.12	5.63	0.78	0.76	0.78	0.57	0.30	0.21	4.44	11.88	168.74	53.42
1963	2.70	0.76	0.74	0.75	0.72	0.57	0.23	0.21	55.81	56.77	23.08	20.63
1964	2.72	2.82	1.30	0.75	0.66	1.06	7.63	7.03	1.66	1.68	3.34	5.80
1965	0.59	0.68	0.74	0.73	0.66	0.36	0.14	0.20	2.01	13.84	19.26	11.08
1966	0.99	0.68	0.73	0.73	0.66	0.54	7.85	12.36	152.67	95.78	32.19	19.97
1967	4.18	0.72	0.74	0.75	0.68	0.57	0.26	26.49	25.64	44.60	46.52	15.68
1968	32.26	4.68	0.74	0.75	0.66	0.51	0.45	0.76	0.24	0.33	0.64	0.96
1969	3.01	1.25	0.72	0.73	0.00	0.00	0.00	2.76	19.34	40.66	59.64	28.78
1970	4.58	0.68	0.74	0.73	0.66	0.43	0.00	0.21	1.70	36.76	62.25	12.32
1971	0.77	0.68	0.74	1.33	0.89	0.21	0.18	1.11	2.08	6.32	3.68	7.87
1972	1.19	0.68	0.74	0.73	0.66	4.23	2.85	0.21	0.16	23.60	29.12	23.62
1973	3.32	0.68	0.91	0.89	1.94	1.68	0.00	1.83	48.30	61.85	310.06	188.05
1974	7.47	1.54	0.74	0.94	1.09	0.64	0.58	74.42	78.95	23.13	32.87	15.35
1975	6.49	0.99	1.71	5.97	7.44	1.34	4.60	3.82	132.97	151.96	43.82	15.71
1976	1.13	34.61	25.26	0.88	0.76	0.64	4.37	160.22	217.75	167.53	135.09	41.10
1977	11.17	0.68	2.28	2.88	0.76	0.60	0.51	0.32	0.23	0.23	12.05	12.84
1978	2.05	0.68	0.74	0.75	0.66	0.57	0.00	0.64	23.00	25.79	22.61	13.43
1979	14.54	0.68	0.74	0.75	0.68	0.57	0.07	1.69	12.01	10.27	18.26	13.66
1980	1.15	27.76	12.64	81.25	43.09	2.41	2.28	0.21	0.21	20.93	111.13	85.39
1981	10.50	0.71	0.74	0.75	0.71	0.57	9.19	9.93	4.80	7.89	10.01	1.89
1982	8.08	3.10	0.74	0.75	0.66	0.54	0.00	77.51	130.60	104.61	31.77	30.52
1983	10.16	0.68	0.74	0.75	0.68	3.49	1.36	79.12	61.62	48.13	23.71	69.90
1984	50.35	5.11	0.86	17.68	19.58	4.39	4.05	5.67	48.80	77.36	76.38	27.33
1985	5.12	0.92	17.18	10.83	0.66	0.57	0.26	0.34	106.79	105.84	93.92	40.76
1986	3.61	0.68	0.74	0.75	0.66	0.57	25.19	31.80	21.28	47.59	48.96	42.07
1987	14.48	0.68	0.74	0.75	0.68	3.41	17.68	13.22	10.31	14.50	24.48	39.05
1988	5.69	0.68	0.75	0.75	0.70	1.08	26.54	22.05	9.88	19.14	76.79	85.51
1989	17.07	1.30	0.74	0.75	0.72	0.64	98.37	104.53	41.60	154.72	59.89	9.87
1990	0.91	0.95	0.99	1.14	1.17	0.11	0.61	2.01	38.21	192.06	100.55	71.57
Median	6.49	0.76	0.74	0.75	0.70	0.57	0.51	2.19	21.22	40.66	43.61	24.82
Average	9.93	3.75	2.52	2.67	2.11	1.22	5.49	18.59	61.53	68.22	58.69	35.88

<2.0

02.0-5.0

5.0-20.0

>20.0

9.2 Reference Condition

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Olifants Estuary, under the Reference Condition is provided in Table 9.3. The mean annual runoff (MAR) is 1070.1 Million m³ for the Reference Condition. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	59.99	56.18	35.98	50.57	37.62	22.26	119.78	247.81	654.34	472.73	238.15	164.98
90%ile	38.04	21.79	16.20	10.93	11.71	10.30	31.94	122.39	199.34	162.39	130.56	91.05
80%ile	26.35	16.89	9.18	4.36	4.09	6.12	16.66	48.16	106.52	114.31	108.26	69.91
70%ile	22.92	12.23	6.34	3.62	3.01	4.03	10.22	34.65	99.38	98.30	80.86	50.88
60%ile	20.42	10.10	5.33	2.76	2.75	3.54	6.71	25.20	67.59	81.73	63.77	42.32
50%ile	17.21	9.06	4.36	2.27	2.41	2.76	5.51	19.34	57.95	63.32	50.62	34.87
40%ile	15.75	7.94	3.77	1.71	1.80	2.24	4.67	14.86	34.80	46.07	45.50	28.74
30%ile	13.36	7.13	3.21	1.53	1.40	1.49	3.20	8.70	24.19	31.02	36.01	24.03
20%ile	10.23	5.59	2.42	1.08	1.14	1.04	2.00	6.72	18.90	19.45	30.61	21.41
10%ile	8.25	4.43	1.90	0.78	0.82	0.78	1.46	3.84	11.96	16.43	23.86	17.78
1%ile	6.83	3.06	1.19	0.29	0.28	0.36	0.36	1.10	4.92	7.60	11.25	9.56

ii. Occurrence and duration of different abiotic states

Estimated occurrence and duration of the different Abiotic States in the Olifants Estuary under the Reference Condition, based on simulated monthly river inflow are indicated Table 9.3.

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under the Reference Condition, median (50%ile) monthly flows are displayed below. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

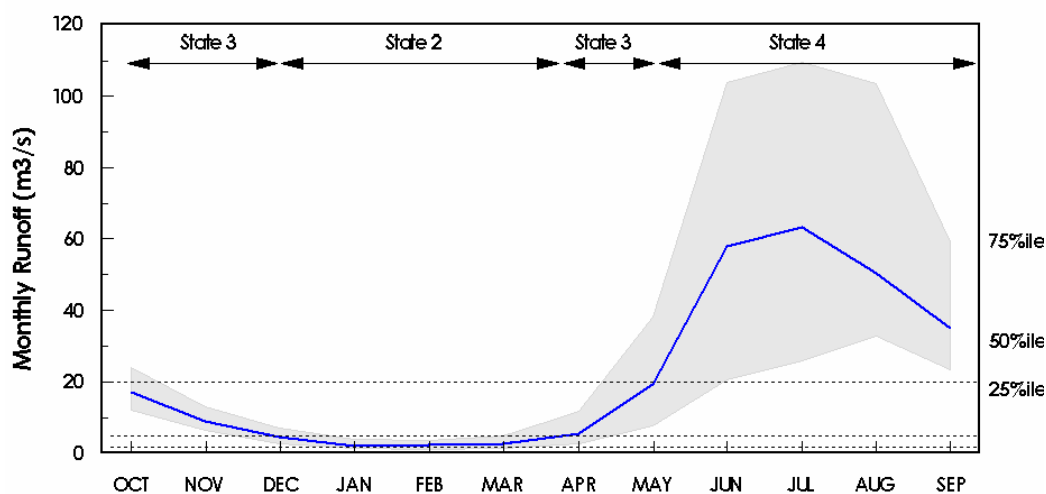


TABLE 9.3: Monthly simulated runoff data in m³/s (70-year period) into the Olifants Estuary under the Reference Condition

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	16.16	8.21	6.34	3.99	25.97	21.35	7.91	1.98	649.88	497.14	108.26	32.29
1921	12.24	4.97	15.15	12.61	3.80	0.85	3.78	6.76	87.34	41.52	115.16	73.29
1922	8.17	4.55	1.26	1.79	0.86	0.37	10.22	48.16	195.88	113.48	35.28	24.03
1923	11.87	7.36	2.39	0.70	0.29	0.52	1.46	1.38	60.18	31.02	65.78	36.34
1924	17.17	12.30	3.36	0.82	3.15	1.34	0.31	6.42	664.72	462.27	50.62	16.35
1925	23.89	15.66	3.69	0.70	1.35	0.56	0.38	39.65	21.68	41.37	32.93	13.35
1926	38.04	21.79	2.39	0.67	1.72	0.59	6.29	10.56	12.31	9.63	47.97	28.74
1927	6.87	9.18	3.95	1.34	0.50	2.72	1.08	0.45	73.15	37.26	20.68	17.24
1928	8.66	4.55	1.60	0.29	0.24	0.59	14.50	30.43	43.25	84.38	55.03	38.46
1929	23.74	4.43	2.87	1.53	11.71	6.08	1.23	6.20	5.82	11.24	19.71	91.05
1930	47.97	7.94	2.68	0.93	0.82	0.33	15.70	29.61	14.20	19.45	111.89	71.49
1931	21.31	7.52	1.90	1.38	32.16	12.47	0.84	37.52	67.59	46.07	23.86	23.61
1932	13.36	6.01	2.35	0.67	0.90	1.98	0.92	17.14	99.38	129.77	63.77	20.37
1933	12.35	5.90	5.37	2.31	1.80	10.64	6.71	14.11	20.37	17.62	15.90	25.58
1934	29.57	55.51	25.12	0.78	0.53	1.42	10.53	27.89	32.79	29.94	73.10	55.35
1935	18.37	8.52	2.42	2.39	1.40	1.26	1.69	11.61	11.96	25.57	58.28	73.72
1936	23.63	17.67	16.20	4.36	1.14	4.03	6.25	19.94	95.41	109.58	45.50	18.40
1937	9.67	5.01	19.56	19.90	1.06	1.38	10.92	37.71	18.52	16.43	29.87	43.32
1938	20.42	5.59	1.60	0.89	5.48	3.39	2.16	47.30	33.68	10.19	119.44	96.56
1939	8.32	3.08	1.00	0.29	9.42	5.33	11.88	15.72	34.80	21.54	16.91	17.20
1940	7.61	6.94	3.65	4.59	2.86	1.00	22.91	122.39	199.34	105.06	107.03	151.50
1941	39.16	12.03	4.36	2.95	2.41	2.98	1.58	18.59	262.86	114.31	38.15	23.07
1942	29.16	18.63	8.28	9.63	2.45	3.73	3.62	3.84	21.68	81.91	121.45	42.32
1943	20.16	27.35	13.55	0.93	0.72	3.95	5.32	35.13	101.81	87.55	69.22	47.76
1944	26.35	12.84	6.72	1.64	1.26	0.93	4.01	62.13	156.09	164.81	129.10	29.47
1945	19.86	9.22	1.79	1.64	2.90	1.04	6.90	8.70	10.07	12.09	26.39	128.62
1946	58.95	7.13	2.42	1.08	0.98	6.16	4.47	23.67	20.45	97.82	53.80	23.49
1947	14.00	8.14	2.53	0.63	1.14	17.10	17.82	22.44	30.21	62.65	33.30	54.24
1948	26.35	8.48	2.31	0.78	0.94	0.85	4.67	8.33	14.81	18.70	50.85	36.49
1949	17.47	55.63	17.69	1.60	0.69	0.78	31.94	16.61	8.49	113.96	46.67	34.06
1950	33.97	17.24	11.46	2.76	1.96	5.33	1.23	8.51	106.52	116.04	47.27	39.54
1951	19.75	21.72	6.08	1.38	2.54	1.49	2.00	34.65	24.73	75.83	160.33	69.91
1952	24.30	40.66	26.88	1.30	2.45	2.39	79.40	73.10	27.70	88.86	103.46	31.67
1953	9.37	11.45	7.58	4.25	1.18	2.39	11.34	167.20	100.94	195.94	146.33	64.59
1954	22.14	9.80	9.18	3.09	15.85	7.46	8.18	6.72	64.81	140.20	203.51	96.64
1955	37.74	26.54	11.64	4.51	3.01	4.25	3.85	12.06	70.41	91.92	74.52	30.47
1956	11.98	5.55	3.21	1.64	20.36	10.64	4.51	51.78	165.85	162.39	130.56	56.49
1957	46.44	16.89	6.30	3.62	4.05	3.10	3.20	39.09	51.27	17.88	20.98	25.38
1958	10.97	7.36	2.61	1.45	2.86	2.83	9.83	328.42	242.98	18.14	48.68	25.31
1959	16.12	13.00	5.48	2.01	2.67	2.65	5.32	25.20	52.81	16.69	9.89	9.18
1960	6.75	3.01	4.51	3.88	2.78	6.12	116.08	96.81	105.62	75.44	44.74	62.81
1961	21.46	5.47	2.31	1.60	1.67	2.16	5.44	5.15	391.89	264.50	159.81	84.77
1962	52.90	20.87	6.01	3.62	2.62	1.90	2.97	3.17	20.79	43.84	200.29	62.46
1963	13.51	10.14	6.38	2.61	2.27	3.01	6.16	6.16	105.82	78.25	37.04	28.66
1964	14.00	13.00	4.40	2.27	2.74	7.72	22.22	24.86	13.54	12.54	27.03	13.69
1965	10.23	4.32	3.54	2.05	1.51	3.88	5.44	3.25	18.90	63.32	30.69	20.21
1966	7.76	3.55	1.86	2.01	1.96	2.24	17.24	21.65	230.31	105.80	35.65	27.23
1967	15.12	8.83	4.07	3.24	2.75	2.91	6.09	64.33	57.95	56.00	55.09	24.01
1968	42.86	15.12	1.56	0.85	0.82	0.59	5.63	4.89	6.56	9.11	11.83	21.14
1969	22.81	9.06	3.21	2.39	2.21	1.82	1.66	14.86	62.19	69.89	65.52	37.23
1970	15.64	6.71	3.99	3.09	2.13	2.05	2.04	4.37	13.69	98.30	81.13	20.95
1971	8.06	3.97	3.24	4.55	4.58	3.54	5.51	19.34	24.19	18.70	23.93	17.78
1972	8.25	3.66	4.85	1.49	1.02	10.30	7.09	3.73	3.90	81.73	49.92	31.75
1973	8.77	9.10	6.83	1.71	4.83	4.40	1.62	18.70	106.45	74.71	318.99	196.43
1974	15.75	12.23	5.07	15.97	3.35	0.97	5.82	141.61	88.66	26.06	36.70	23.69
1975	16.91	10.45	7.35	12.35	13.83	3.88	33.60	13.37	182.01	154.62	47.99	23.34
1976	10.56	53.74	43.19	10.93	5.73	3.36	17.63	213.26	221.64	168.68	137.37	49.73
1977	22.58	10.10	14.37	9.18	3.15	3.62	5.71	7.17	5.36	4.07	41.59	44.13
1978	16.35	6.71	4.96	3.84	2.99	2.76	1.93	8.03	76.12	50.40	31.10	21.41
1979	26.13	9.49	3.77	3.95	1.31	0.97	3.12	15.08	39.81	25.20	39.01	27.16
1980	9.22	57.48	32.89	90.87	50.35	6.57	5.17	3.02	6.21	62.87	125.63	93.12
1981	22.62	9.06	5.63	5.19	4.09	4.74	30.05	24.30	19.02	30.17	26.13	9.72
1982	20.12	11.26	4.21	3.17	4.26	4.03	1.93	130.86	158.87	109.31	36.01	38.81
1983	22.92	6.52	4.10	1.68	1.40	13.55	9.02	150.87	65.47	52.45	27.48	77.54
1984	62.42	18.24	12.09	33.30	28.47	24.38	16.66	26.17	65.01	81.06	80.86	34.87
1985	17.17	8.41	28.44	16.12	1.63	2.72	4.67	7.50	144.52	137.79	103.92	49.19
1986	14.59	7.75	2.50	1.90	1.76	1.34	41.01	62.91	55.29	58.58	54.21	50.88
1987	28.11	7.64	5.33	2.05	1.69	9.52	38.07	25.69	45.25	32.41	30.61	48.34
1988	17.21	7.75	4.66	2.39	1.92	8.88	48.30	34.35	33.37	45.66	84.60	94.19
1989	28.45	10.68	3.84	2.27	2.21	1.79	128.39	145.16	59.64	162.26	64.21	17.92
1990	7.46	3.51	2.39	3.54	2.99	1.42	2.08	9.05	102.04	212.47	105.34	77.91
Median	17.21	9.06	4.36	2.27	2.41	2.76	5.51	19.34	57.95	63.32	50.62	34.87
Average	20.71	12.96	7.27	5.13	4.84	4.29	13.27	39.28	91.65	84.57	69.66	46.03

<2.0

02.0-5.0

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>20.0

9.3 Scenario 2: Present state plus EWR Releases

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Olifants Estuary, under the Scenario 2 is provided in Table 9.4. The mean annual runoff (MAR) is 800.3 Million m³ for this scenario. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	48.13	32.08	21.50	37.21	24.46	7.77	96.73	194.20	550.92	472.06	230.02	153.70
90%ile	28.90	9.60	7.24	3.64	3.76	3.85	9.62	80.90	151.71	159.08	126.25	65.58
80%ile	16.05	4.30	2.06	1.75	1.68	2.21	4.85	22.01	93.83	104.19	79.44	48.08
70%ile	12.84	2.93	1.68	1.55	1.38	1.81	3.07	11.18	57.99	78.10	66.22	34.22
60%ile	11.49	2.93	1.51	1.51	1.37	1.46	2.88	8.24	42.45	58.26	50.45	25.66
50%ile	10.11	2.93	1.50	1.51	1.34	1.42	2.84	6.19	37.99	51.82	47.54	22.18
40%ile	9.01	2.49	1.50	1.51	1.34	1.42	2.49	3.57	36.22	39.92	44.77	16.34
30%ile	8.32	1.51	1.50	1.51	1.34	1.42	1.76	3.42	24.20	30.79	33.23	14.73
20%ile	6.36	1.43	1.18	1.51	0.91	1.11	1.41	2.05	15.78	21.17	28.07	11.21
10%ile	4.02	0.83	0.58	0.99	0.85	1.00	1.28	1.15	7.44	9.49	17.41	9.66
1%ile	1.01	0.15	0.00	0.99	0.34	0.00	0.04	0.29	0.82	2.07	5.35	4.04

ii. Occurrence and duration of different abiotic states

Estimated occurrence and duration of the different Abiotic States in the Olifants Estuary under the Scenario 2, based on simulated monthly river inflow are indicated Table 9.4.

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under Scenario 2, median (50%ile) monthly flows are displayed below. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

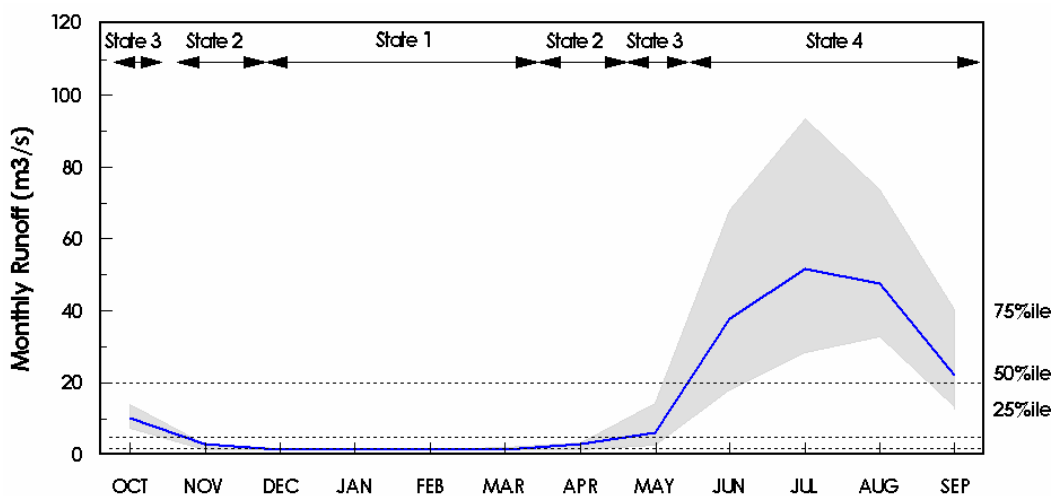


TABLE 9.4: Monthly simulated runoff data in m³/s (70-year period) into the Olifants Estuary under Scenario 2

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	10.53	2.93	1.81	1.88	9.24	11.53	3.38	3.46	555.99	496.93	106.04	25.54
1921	9.01	2.93	9.34	4.76	1.35	1.42	2.84	3.46	39.04	51.82	74.12	62.48
1922	9.01	2.93	1.50	1.51	1.34	1.39	2.62	8.24	151.71	108.96	47.74	15.09
1923	9.01	2.93	1.50	1.51	1.36	1.00	1.87	3.08	37.74	30.79	47.40	16.09
1924	11.53	2.97	1.50	1.51	1.68	1.00	1.76	3.92	548.74	461.40	50.93	12.29
1925	12.84	3.39	1.50	1.51	1.34	1.42	2.86	9.57	37.99	35.45	33.23	10.30
1926	16.05	6.17	1.29	0.99	0.88	1.00	2.57	4.16	15.69	7.20	32.58	14.21
1927	8.65	2.73	1.00	0.99	0.91	1.00	1.68	1.15	40.39	39.92	23.90	10.33
1928	8.61	2.49	0.99	0.99	0.20	0.24	2.77	5.84	37.96	52.38	47.78	25.66
1929	11.19	0.46	0.49	1.51	5.13	2.16	0.00	0.61	2.18	3.60	9.76	38.18
1930	33.86	2.93	1.50	1.55	1.39	1.42	4.93	7.88	31.12	21.31	65.98	45.41
1931	12.97	2.93	1.50	1.51	6.04	4.34	2.88	6.27	50.60	51.82	47.33	14.73
1932	9.01	2.93	1.18	0.99	0.88	1.00	1.72	3.42	41.20	112.53	58.61	16.09
1933	1.71	0.76	0.58	1.51	0.85	3.85	2.70	0.71	3.21	6.02	6.01	11.09
1934	17.50	30.94	13.01	1.51	1.34	1.42	3.03	7.76	37.81	38.35	47.85	28.18
1935	12.18	2.93	1.50	1.51	1.38	1.46	2.38	3.57	12.78	21.17	46.01	33.63
1936	17.60	7.88	6.92	1.60	0.88	1.11	2.49	4.32	42.45	101.85	47.63	10.62
1937	9.01	2.93	7.42	12.20	1.34	1.42	2.66	9.27	30.22	19.76	28.07	15.92
1938	10.12	2.93	1.50	1.19	1.82	1.15	2.20	22.01	36.54	10.86	109.13	82.37
1939	1.51	0.03	0.00	0.99	4.47	1.81	1.51	1.50	7.44	8.61	6.41	5.71
1940	9.05	2.97	1.54	1.59	1.34	1.42	6.75	62.11	178.45	103.19	104.54	140.91
1941	30.14	2.93	1.50	1.51	1.34	1.42	3.32	5.39	193.82	113.25	47.33	11.86
1942	16.65	9.60	5.94	5.73	1.34	1.60	2.11	3.39	15.78	51.86	79.44	34.22
1943	11.49	10.19	7.24	1.51	1.38	2.32	2.88	12.52	59.13	82.18	66.22	39.70
1944	17.03	2.93	1.50	1.51	1.34	1.46	2.88	21.01	122.52	159.08	126.25	22.18
1945	11.04	2.93	1.50	1.51	1.34	1.42	3.03	3.53	17.08	14.59	23.00	52.54
1946	46.37	2.93	1.50	1.51	1.34	2.28	2.90	9.58	24.20	53.88	48.11	10.62
1947	9.01	2.93	1.50	1.51	1.46	6.17	8.51	8.18	31.38	51.90	36.17	17.76
1948	11.93	2.93	1.50	1.51	1.34	1.26	2.49	3.46	17.49	14.32	38.51	14.05
1949	10.11	18.31	6.84	1.51	1.34	1.31	10.11	9.09	13.44	64.74	54.36	24.29
1950	15.17	5.69	2.55	1.51	1.35	1.42	2.86	3.46	57.17	90.30	47.29	30.86
1951	11.18	6.48	1.50	1.51	2.23	1.72	2.88	11.18	36.22	58.78	110.29	61.10
1952	15.55	26.15	19.76	1.51	1.73	1.83	27.84	57.65	37.70	70.56	100.62	24.18
1953	9.01	2.93	2.31	2.07	1.34	2.21	3.40	95.32	93.83	193.40	144.89	55.95
1954	13.81	2.93	1.50	1.51	2.57	1.97	3.17	3.57	43.89	104.19	199.02	86.95
1955	28.90	9.69	2.06	1.55	1.38	1.81	2.95	3.55	39.93	66.39	70.58	23.73
1956	9.01	2.93	1.50	1.51	3.76	3.38	2.88	24.63	117.14	159.12	127.95	48.08
1957	38.27	3.99	1.92	1.92	1.34	1.42	2.88	19.21	39.07	30.91	24.74	10.62
1958	8.85	2.60	1.00	0.99	0.88	1.00	2.61	249.47	230.26	51.38	48.04	15.55
1959	4.16	0.83	0.49	1.43	0.41	0.00	0.24	1.88	11.48	10.98	5.98	4.34
1960	3.79	1.43	2.04	2.06	1.42	3.77	96.67	90.26	66.84	76.22	37.70	27.60
1961	11.70	1.43	1.50	1.51	1.34	1.42	1.41	2.28	303.62	261.53	157.26	75.19
1962	44.00	6.61	1.54	1.63	1.45	1.42	1.41	2.05	20.87	29.41	145.87	53.24
1963	7.51	1.50	1.51	1.51	1.38	1.42	1.37	2.13	67.58	76.01	34.38	17.02
1964	2.65	2.50	1.05	1.51	0.39	0.64	7.03	7.02	3.44	5.01	6.11	4.17
1965	4.02	1.44	1.51	1.51	1.34	1.42	1.37	1.98	18.67	31.30	30.21	9.66
1966	6.17	1.28	0.99	0.99	0.94	1.66	8.50	14.37	147.37	96.36	33.20	20.87
1967	7.65	1.49	1.51	1.51	1.38	1.42	1.37	31.79	38.60	38.05	47.54	16.34
1968	34.15	4.30	0.49	1.51	0.85	0.41	0.63	0.73	0.84	2.13	3.90	3.73
1969	6.66	1.98	1.50	1.51	1.34	1.42	1.28	6.19	34.53	48.84	50.45	18.81
1970	8.32	1.43	1.50	1.51	1.34	1.44	1.38	2.13	13.13	57.57	73.56	13.83
1971	0.79	0.20	0.00	1.59	0.60	0.14	0.27	1.10	5.93	9.49	7.82	5.49
1972	1.10	0.46	0.49	1.51	0.85	4.43	3.07	0.29	0.81	28.66	33.05	21.52
1973	8.41	1.43	1.68	1.69	2.50	2.79	1.50	6.25	57.99	58.26	302.36	183.52
1974	14.26	2.36	1.50	1.75	1.64	1.49	1.39	82.65	87.93	28.82	39.75	13.38
1975	10.24	1.84	2.47	6.72	7.48	2.13	7.33	8.96	121.84	152.73	44.84	16.94
1976	6.36	34.74	25.58	1.75	1.37	1.46	4.85	170.51	211.26	168.30	136.12	41.31
1977	13.04	0.46	2.03	3.64	0.85	0.41	0.37	0.29	0.82	1.93	17.41	23.90
1978	7.63	1.43	1.54	1.55	1.34	1.42	1.37	1.63	48.09	45.96	27.62	8.80
1979	3.14	0.46	0.49	1.51	0.82	0.00	0.06	1.69	15.52	13.42	22.55	15.59
1980	4.59	26.09	13.40	82.01	39.58	3.24	3.12	1.14	17.06	40.61	82.37	84.19
1981	12.37	1.51	1.51	1.52	1.34	1.42	9.62	11.32	21.65	28.42	27.82	4.44
1982	7.55	3.46	1.00	0.99	0.88	1.00	0.96	80.90	138.90	90.57	37.86	26.06
1983	12.02	1.43	1.50	1.51	1.38	4.40	2.92	85.15	69.05	39.96	28.37	65.58
1984	52.25	5.61	1.72	18.02	17.98	5.17	4.53	10.53	56.94	78.10	77.40	28.00
1985	7.00	1.63	17.52	11.28	1.34	1.42	1.44	1.38	117.28	124.25	72.21	40.99
1986	5.86	1.43	1.50	1.51	1.34	1.42	25.60	35.02	36.77	45.53	44.77	38.14
1987	16.34	1.43	1.50	1.51	1.38	4.27	18.07	14.06	26.15	28.13	33.07	23.67
1988	5.81	1.43	1.62	1.63	1.37	2.00	26.62	22.89	26.42	38.18	65.35	60.77
1989	18.94	2.12	1.50	1.51	1.48	1.56	96.88	110.53	48.43	152.03	60.89	11.21
1990	4.39	1.69	1.76	2.03	1.88	1.65	1.82	3.02	70.95	185.33	74.66	70.69
Median	10.11	2.93	1.50	1.51	1.34	1.42	2.84	6.19	37.99	51.82	47.54	22.18
Average	12.78	4.60	3.05	3.36	2.46	1.93	6.76	21.53	70.93	74.74	60.51	31.94

<2.0

02.0-5.0

5.0-20.0

>20.0

9.4 Scenario 7: Raising Clanwilliam (15 m) with EWR Releases

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Olifants Estuary, under the Scenario 7 is provided in Table 9.5. The mean annual runoff (MAR) is 741.5 Million m³ for this scenario. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	38.67	28.63	21.90	37.61	24.80	7.37	96.27	174.77	456.58	471.55	205.43	148.18
90%ile	16.94	8.24	7.64	4.04	4.13	4.07	9.92	69.28	127.88	158.65	111.97	51.47
80%ile	12.56	4.35	2.46	2.15	2.01	2.37	4.92	21.44	88.02	81.43	73.72	35.30
70%ile	10.61	3.29	2.08	1.91	1.77	1.96	3.25	10.60	57.48	67.52	57.21	26.31
60%ile	9.40	3.29	1.90	1.91	1.71	1.77	3.18	7.67	41.29	54.98	48.28	22.32
50%ile	9.33	3.29	1.90	1.91	1.71	1.77	2.86	5.48	38.23	51.94	47.57	16.21
40%ile	9.33	2.72	1.90	1.91	1.71	1.77	2.53	3.65	37.67	47.54	44.17	14.00
30%ile	7.22	1.87	1.90	1.88	1.30	1.26	1.76	3.41	26.23	29.53	34.55	12.50
20%ile	5.69	1.79	1.43	1.88	1.15	1.00	1.68	1.62	15.69	21.31	28.53	10.87
10%ile	4.34	1.13	0.98	0.99	0.88	1.00	1.00	1.21	6.44	7.88	15.28	8.11
1%ile	1.29	0.03	0.00	0.99	0.44	0.15	0.17	0.40	0.90	1.54	4.80	4.26

ii. Occurrence and duration of different abiotic states

Estimated occurrence and duration of the different Abiotic States in the Olifants Estuary under the Scenario 7, based on simulated monthly river inflow are indicated Table 9.5.

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under Scenario 7, median (50%ile) monthly flows are displayed below. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

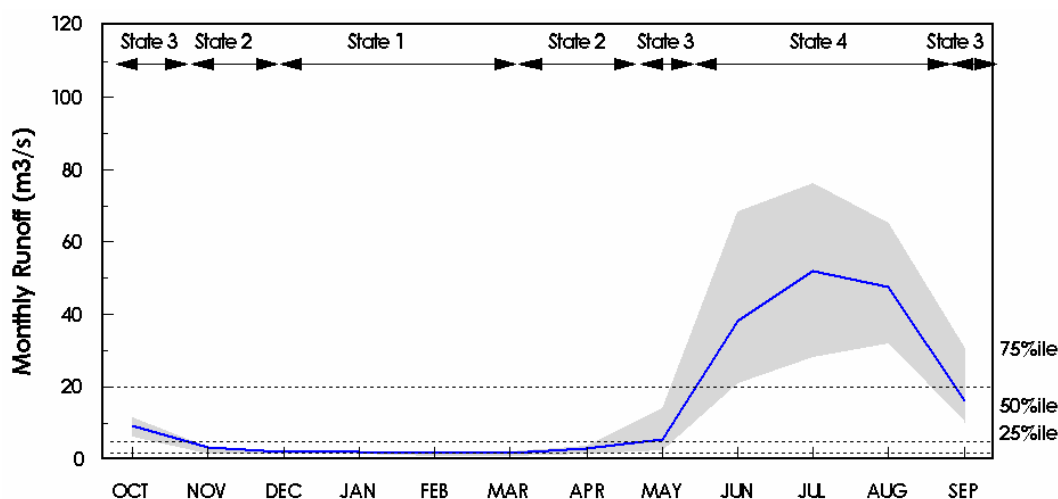


TABLE 9.5: Monthly simulated runoff data in m3/s (70-year period) into the Olifants Estuary under Scenario 7

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	9.33	3.29	2.21	2.25	9.53	11.66	3.00	3.32	455.47	496.51	105.14	23.80
1921	9.33	3.29	9.74	5.16	1.73	1.77	3.18	3.57	39.12	51.94	74.28	50.87
1922	9.33	3.29	1.90	1.91	1.71	1.77	3.18	7.67	98.28	108.28	47.90	13.54
1923	9.33	3.29	1.90	1.91	1.77	1.77	3.18	3.57	38.86	51.90	47.57	14.54
1924	9.71	3.33	1.90	1.88	2.09	1.15	1.97	3.92	459.17	460.86	51.09	10.91
1925	10.98	3.75	1.90	1.91	1.71	1.77	3.18	8.99	38.08	53.47	48.09	10.87
1926	14.82	6.53	1.88	1.67	0.88	1.00	2.57	4.13	15.69	7.20	32.58	12.66
1927	8.65	2.73	1.00	0.99	0.91	1.00	1.68	1.15	40.47	39.33	23.90	10.33
1928	8.61	2.49	0.99	0.99	0.20	0.24	2.77	5.26	38.04	52.50	47.94	24.11
1929	11.50	0.83	0.87	1.41	4.67	1.74	0.00	0.73	1.42	2.57	8.76	34.90
1930	27.94	3.29	1.90	1.95	1.68	1.59	4.92	7.31	21.38	21.31	66.15	35.30
1931	10.27	3.29	1.90	1.91	6.43	4.69	2.86	5.69	38.23	51.94	47.49	13.18
1932	9.33	2.83	1.18	0.99	0.88	1.00	1.72	3.34	41.29	68.36	54.57	12.69
1933	1.84	1.13	0.98	1.91	1.23	4.21	3.00	0.83	2.14	5.30	5.66	9.91
1934	14.81	22.18	13.41	1.91	1.71	1.77	3.33	7.18	37.89	47.54	48.01	26.16
1935	10.36	3.29	1.88	1.88	1.15	1.03	1.76	3.43	12.05	21.17	46.01	32.08
1936	15.65	8.24	7.30	1.11	0.88	1.11	2.33	3.74	42.53	67.52	47.79	10.87
1937	9.33	3.29	7.82	12.60	1.71	1.77	3.09	8.70	33.15	19.76	28.07	14.38
1938	9.36	3.29	1.43	0.99	1.39	1.15	2.04	21.44	36.54	10.71	109.13	80.82
1939	1.55	0.03	0.00	0.99	4.47	1.81	1.51	1.62	6.44	7.88	5.76	5.96
1940	9.36	3.33	1.91	1.81	0.88	1.00	6.81	60.53	127.88	79.44	86.30	139.37
1941	27.87	3.29	1.90	1.91	1.71	1.77	3.63	4.82	168.60	113.37	47.49	10.91
1942	14.67	9.96	6.34	6.13	1.71	1.96	3.18	3.65	38.19	51.98	60.13	30.09
1943	9.33	10.44	7.64	1.91	1.77	2.67	3.18	11.94	59.05	51.79	52.88	25.76
1944	10.02	3.29	1.90	1.91	1.71	1.81	3.18	20.43	93.20	158.65	125.35	20.33
1945	9.33	3.29	1.90	1.91	1.71	1.77	3.33	3.65	37.67	50.31	23.72	50.99
1946	44.55	3.29	1.90	1.88	1.62	1.96	2.53	8.87	22.73	54.00	48.28	10.87
1947	9.33	3.29	1.88	1.45	0.98	5.48	8.51	7.61	31.26	52.02	36.17	16.21
1948	10.11	3.29	1.88	1.88	0.88	1.00	2.49	3.49	16.30	14.18	38.51	12.50
1949	9.40	18.49	7.21	1.88	0.88	1.00	10.08	8.54	12.35	64.80	54.52	22.75
1950	13.34	6.05	2.92	1.88	1.32	1.00	2.35	3.41	57.25	68.21	47.45	13.65
1951	9.36	3.32	1.90	1.91	2.61	2.07	3.18	10.60	37.78	62.11	99.54	35.53
1952	9.33	26.51	20.15	1.91	2.10	2.18	25.99	46.43	37.78	56.91	57.27	22.32
1953	9.33	3.29	2.71	2.47	1.71	2.56	3.70	78.59	81.92	193.31	144.11	54.18
1954	11.46	3.29	1.90	1.91	2.94	2.32	3.48	3.69	43.98	77.41	198.54	85.21
1955	26.69	7.03	2.46	1.95	1.77	2.16	3.25	3.61	40.02	56.30	56.78	21.91
1956	9.33	3.29	1.90	1.91	4.13	3.73	3.18	24.05	88.83	158.65	127.07	46.31
1957	36.16	4.35	2.31	2.32	1.71	1.77	3.18	18.63	39.15	51.49	47.45	10.87
1958	9.33	3.29	1.15	0.99	0.88	1.00	2.61	239.26	210.35	51.49	48.20	14.00
1959	4.48	1.19	0.89	1.88	1.18	0.15	0.24	1.71	10.63	6.41	5.43	4.59
1960	4.11	1.79	2.41	2.43	1.37	3.34	96.50	89.56	66.33	76.34	37.86	19.90
1961	9.88	1.79	1.90	1.88	1.62	1.08	1.17	1.44	295.04	250.91	111.97	62.06
1962	22.28	6.55	1.94	2.03	1.82	1.77	1.71	1.48	20.95	29.53	118.42	51.47
1963	5.69	1.86	1.91	1.91	1.77	1.77	1.68	1.55	67.66	76.12	34.55	15.47
1964	2.96	2.86	1.45	1.91	1.23	1.26	7.34	7.13	2.30	4.27	5.11	4.42
1965	4.34	1.81	1.91	1.91	1.71	1.77	1.68	1.29	18.67	31.42	30.37	8.11
1966	4.80	0.99	0.99	0.99	0.94	1.66	8.50	13.66	124.65	96.43	31.52	10.34
1967	5.83	1.85	1.90	1.91	1.77	1.77	1.68	31.21	38.69	29.16	32.28	10.50
1968	16.94	4.66	0.89	1.91	1.23	0.77	0.93	0.84	0.92	1.54	4.06	3.98
1969	6.38	2.34	1.90	1.91	1.71	1.71	1.27	5.48	34.61	48.96	50.62	17.26
1970	6.74	1.79	1.88	1.88	1.30	1.02	1.00	1.26	11.71	57.69	73.72	11.55
1971	0.98	0.03	0.00	1.59	0.60	0.14	0.27	1.21	4.62	8.77	6.87	5.74
1972	1.42	0.83	0.87	1.88	0.54	4.07	2.69	0.40	0.89	27.06	32.05	12.87
1973	6.56	1.79	2.08	2.07	2.78	2.37	1.13	5.54	57.48	58.38	221.49	168.74
1974	12.44	2.72	1.90	2.15	2.01	1.84	1.69	79.16	88.02	28.94	39.91	11.84
1975	8.45	2.20	2.87	7.12	7.87	2.55	5.48	8.38	90.40	135.15	43.72	15.13
1976	4.90	33.59	25.98	2.15	1.75	1.81	5.15	147.14	211.24	167.93	135.43	39.54
1977	10.61	0.83	2.43	4.04	1.23	0.77	0.68	0.40	0.91	1.54	15.28	15.48
1978	5.26	1.79	1.94	1.95	1.71	1.77	1.68	1.75	46.89	46.08	27.96	9.05
1979	3.46	0.83	0.89	1.91	1.27	0.77	0.68	1.81	14.25	12.70	21.55	15.84
1980	4.90	26.45	13.80	82.41	39.86	3.53	2.75	1.14	9.73	40.73	70.09	67.36
1981	10.68	1.87	1.90	1.91	1.71	1.77	9.92	10.88	21.74	28.54	27.43	4.38
1982	7.87	3.22	1.00	0.99	0.88	1.00	0.96	80.33	138.39	81.43	38.02	18.09
1983	12.27	1.79	1.90	1.91	1.77	4.68	2.73	69.28	69.13	27.38	28.53	30.17
1984	27.85	5.98	2.12	18.42	18.35	5.53	4.83	8.21	46.43	54.98	72.81	26.31
1985	7.22	2.00	17.92	11.68	1.71	1.77	1.74	1.49	117.37	123.53	57.21	25.26
1986	6.10	1.79	1.90	1.91	1.71	1.77	25.90	34.44	36.85	45.65	44.17	27.38
1987	12.56	1.79	1.90	1.91	1.77	4.62	18.37	14.17	26.23	28.25	33.23	22.12
1988	6.13	1.79	2.02	2.03	1.75	2.35	26.92	23.00	26.50	38.30	64.35	46.07
1989	14.88	2.48	1.90	1.91	1.85	1.92	96.17	108.81	48.51	114.57	44.45	7.96
1990	4.71	2.05	2.16	2.42	2.25	2.00	2.43	3.13	75.66	184.61	74.82	30.92
Median	9.33	3.29	1.90	1.91	1.71	1.77	2.86	5.48	38.23	51.94	47.57	16.21
Average	10.76	4.67	3.40	3.68	2.69	2.09	6.83	20.07	64.28	71.49	56.07	26.92

<2.0
 02.0-5.0
 5.0-20.0
 >20.0

9.5 Scenario 5: Raising Clanwilliam (15 m)

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Olifants Estuary, under the Scenario 5 is provided in Table 9.6. The mean annual runoff (MAR) is 605.7 Million m³ for this scenario. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	42.17	28.76	21.52	37.04	24.33	7.43	95.80	153.56	471.91	470.40	210.01	149.81
90%ile	23.61	7.85	7.27	3.66	3.84	4.07	9.43	66.69	112.14	150.96	116.78	65.34
80%ile	11.33	3.96	2.33	1.62	1.80	2.11	4.34	17.92	72.07	78.37	81.56	40.07
70%ile	7.85	2.16	1.64	1.53	1.46	1.73	2.24	8.84	44.03	53.49	52.19	30.07
60%ile	5.44	1.67	1.52	1.53	1.45	1.39	1.79	4.84	21.61	38.99	33.68	20.61
50%ile	4.36	1.42	1.52	1.53	1.41	1.32	1.23	2.33	14.39	22.60	27.35	13.96
40%ile	3.17	1.36	1.52	1.53	1.41	1.32	1.15	1.65	9.02	12.62	17.14	12.10
30%ile	2.00	1.36	1.52	1.53	1.41	1.32	1.15	0.90	5.01	8.22	11.91	8.78
20%ile	1.70	1.36	1.52	1.53	1.41	1.32	1.15	0.52	2.19	5.28	8.21	5.68
10%ile	1.43	1.36	1.52	1.24	0.95	0.70	0.80	0.43	0.84	2.91	3.92	3.28
1%ile	1.20	1.19	0.89	0.88	0.40	0.22	0.00	0.04	0.32	0.49	0.84	1.59

ii. Occurrence and duration of different abiotic states

Estimated occurrence and duration of the different Abiotic States in the Olifants Estuary under the Scenario 5, based on simulated monthly river inflow are indicated Table 9.6.

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under Scenario 5, median (50%ile) monthly flows are displayed below. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

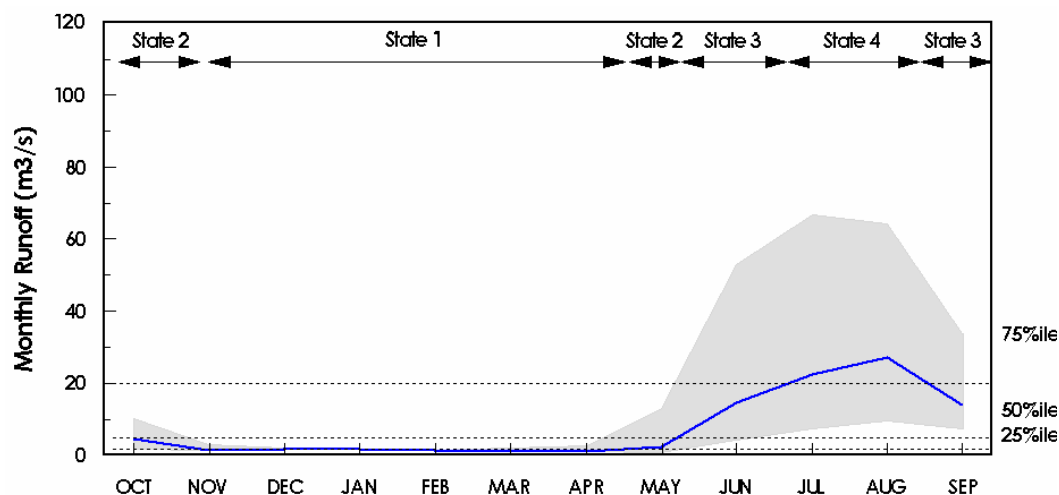


TABLE 9.6: Monthly simulated runoff data in m³/s (70year period) into the Olifants Estuary under Scenario 5

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	2.72	1.36	1.54	1.24	8.64	10.56	2.04	0.06	457.33	495.35	103.55	21.06
1921	3.13	1.36	9.36	4.78	1.43	1.32	1.15	0.52	14.39	11.84	81.56	59.55
1922	1.43	1.36	1.52	1.53	1.41	1.32	2.16	2.72	100.36	108.39	30.15	12.80
1923	2.00	1.38	1.52	1.53	1.46	1.32	1.15	0.43	7.49	7.36	10.51	15.85
1924	5.44	1.73	1.52	1.53	1.88	1.32	1.15	1.24	505.91	459.70	44.76	5.12
1925	10.19	3.35	1.52	1.53	1.41	1.32	1.15	5.07	4.43	12.62	10.29	2.36
1926	13.83	6.14	1.52	1.53	1.41	1.32	2.48	2.20	0.76	0.72	8.53	7.71
1927	1.20	1.46	1.52	1.53	0.85	1.11	0.22	0.00	13.31	10.95	3.38	4.33
1928	1.70	1.36	1.52	0.88	0.73	0.48	0.80	0.98	5.99	28.29	20.17	18.07
1929	11.63	1.36	1.52	1.53	5.68	3.08	1.15	0.76	0.84	0.51	4.77	30.15
1930	23.89	1.36	1.52	1.57	0.99	0.70	4.01	4.13	2.36	6.36	39.86	31.65
1931	4.50	1.36	1.52	1.53	6.12	4.24	1.15	3.00	9.90	15.91	9.24	12.10
1932	3.27	1.62	1.71	1.53	1.41	1.32	1.15	2.00	23.96	76.57	55.77	9.00
1933	1.97	1.66	1.61	1.53	1.41	4.76	3.48	0.86	1.35	2.91	2.71	7.21
1934	12.59	21.79	13.03	1.53	1.41	1.32	2.24	4.41	8.25	7.17	28.28	20.61
1935	5.25	1.36	1.52	1.53	1.46	1.36	1.15	1.62	1.09	5.24	12.27	28.53
1936	12.96	7.85	6.94	1.62	1.41	1.51	0.86	1.10	29.26	53.49	17.14	4.62
1937	1.58	1.36	7.44	12.22	1.41	1.32	1.99	5.97	5.76	3.57	6.98	8.78
1938	3.66	1.36	1.52	1.53	2.55	2.08	1.15	17.92	19.39	2.91	88.14	75.99
1939	1.95	1.36	1.52	0.88	5.18	1.93	1.51	1.65	4.07	5.09	2.81	3.26
1940	1.53	1.33	0.91	0.95	0.41	0.00	5.78	54.77	117.29	78.54	101.77	137.16
1941	24.78	2.66	1.52	1.53	1.41	1.32	1.60	2.33	143.49	108.51	32.94	11.87
1942	12.50	9.57	5.96	5.75	1.41	1.51	1.15	0.51	4.64	19.64	66.94	30.07
1943	5.12	10.04	7.26	1.53	1.46	2.22	1.94	8.84	46.10	43.98	63.78	35.81
1944	10.83	2.16	1.52	1.53	1.41	1.36	1.15	14.79	77.47	157.50	123.77	17.38
1945	4.69	1.68	1.52	1.53	1.41	1.32	1.35	0.77	0.32	0.52	0.74	41.82
1946	40.08	1.36	1.52	1.53	1.41	2.18	1.36	7.02	7.72	27.98	20.83	3.59
1947	1.79	1.36	1.52	1.53	1.54	6.09	8.56	4.84	5.01	16.02	13.03	25.39
1948	11.33	1.42	1.52	1.53	1.41	1.32	1.15	0.51	0.61	1.18	5.19	5.37
1949	2.80	19.56	7.27	1.53	1.41	1.32	9.93	9.34	2.19	51.62	31.14	18.16
1950	9.96	5.66	2.57	1.53	1.43	1.32	1.15	0.57	44.03	50.52	42.07	28.53
1951	4.93	2.92	1.52	1.53	2.31	1.62	1.15	7.87	9.02	46.29	100.55	56.93
1952	8.92	26.57	19.78	1.53	1.80	1.73	24.88	39.50	9.42	65.70	97.97	19.42
1953	1.28	2.06	2.33	2.09	1.41	2.11	2.35	74.15	63.21	192.16	142.52	51.73
1954	7.50	1.36	1.52	1.53	2.65	1.87	1.79	1.11	29.28	68.13	196.96	82.76
1955	23.61	5.73	2.08	1.57	1.46	1.71	1.23	0.90	21.49	41.40	65.18	18.98
1956	1.72	1.36	1.52	1.53	3.84	3.28	1.15	19.46	72.13	156.22	125.49	43.86
1957	33.07	3.96	1.94	1.94	1.41	1.32	1.15	14.48	19.87	5.28	8.21	5.22
1958	1.52	1.36	1.52	1.53	1.41	1.32	1.82	233.60	196.28	2.94	16.12	13.96
1959	5.45	1.76	1.52	1.53	1.46	1.32	1.15	1.74	6.43	4.17	2.47	1.89
1960	1.20	1.36	1.95	2.04	1.45	3.67	96.07	86.39	53.85	58.03	16.28	11.72
1961	5.98	1.36	1.52	1.53	1.41	1.32	1.15	0.43	284.39	234.72	116.78	71.04
1962	38.82	6.16	1.56	1.53	1.43	1.32	1.19	0.43	4.13	10.36	124.96	49.02
1963	1.74	1.44	1.52	1.53	1.46	1.32	1.15	0.43	53.37	55.74	11.91	11.11
1964	3.09	3.44	2.08	1.53	1.41	1.82	7.82	7.17	1.73	1.86	2.11	1.72
1965	1.20	1.36	1.52	0.88	0.73	0.44	0.25	0.24	2.07	11.91	7.26	3.28
1966	1.35	1.36	1.49	0.88	0.73	0.69	7.56	12.51	112.14	78.37	8.52	5.68
1967	2.47	1.40	1.52	1.53	1.46	1.32	1.15	25.45	24.14	11.40	26.21	12.38
1968	28.92	5.24	1.52	1.53	1.41	1.32	1.41	0.87	0.34	0.51	0.88	1.28
1969	3.39	1.92	1.52	1.53	0.73	0.57	0.00	2.91	17.83	30.92	27.84	12.94
1970	3.63	1.36	1.52	1.53	1.41	1.32	0.99	0.43	1.76	36.97	51.49	8.34
1971	1.20	1.36	1.02	1.47	0.95	0.31	0.27	1.24	2.14	5.29	3.92	3.04
1972	1.55	0.87	0.87	0.88	0.38	4.07	2.69	0.26	0.31	22.60	27.35	10.17
1973	3.70	1.36	1.50	1.03	1.89	1.42	0.00	1.96	45.00	38.99	240.48	179.34
1974	7.85	2.19	1.52	1.71	1.72	1.32	1.15	73.39	72.07	8.22	16.80	8.49
1975	5.59	1.67	2.49	6.74	7.56	2.10	4.89	3.95	80.33	150.96	42.14	12.47
1976	1.50	33.87	25.60	1.66	1.41	1.32	4.66	119.26	210.43	166.78	133.85	37.09
1977	7.53	1.36	3.06	3.66	1.41	1.32	1.15	0.43	0.33	0.46	12.32	12.78
1978	1.87	1.36	1.52	1.53	1.41	1.32	0.44	0.78	21.61	25.36	4.84	6.47
1979	3.58	1.36	1.52	1.53	1.46	0.70	0.36	1.84	11.32	10.09	17.64	13.14
1980	1.51	26.52	13.42	81.37	38.97	2.25	1.48	0.26	0.32	20.09	52.19	40.07
1981	7.82	1.39	1.52	1.53	1.41	1.32	9.43	10.06	4.77	7.82	4.87	1.80
1982	5.01	3.60	1.52	1.53	1.41	1.32	1.02	76.49	99.91	42.54	30.06	26.96
1983	9.41	1.36	1.52	1.53	1.46	4.24	2.38	66.69	52.31	16.62	22.04	65.34
1984	47.07	5.58	1.64	18.04	18.06	5.08	4.34	5.82	16.77	68.38	74.92	23.86
1985	4.36	1.60	17.54	11.30	1.41	1.32	1.15	0.46	102.71	103.40	47.30	36.78
1986	2.79	1.36	1.52	1.53	1.41	1.32	25.41	31.93	20.43	27.33	23.08	32.24
1987	10.78	1.36	1.52	1.53	1.46	4.17	17.88	13.35	9.41	7.77	10.11	11.06
1988	3.17	1.36	1.53	1.53	1.45	1.83	26.43	22.18	9.69	17.64	33.68	77.01
1989	13.52	1.96	1.52	1.53	1.47	1.39	95.68	103.47	36.33	118.70	58.18	6.75
1990	1.28	1.62	1.78	1.94	1.88	1.47	1.86	2.14	36.34	133.73	98.91	66.94
Median	4.36	1.42	1.52	1.53	1.41	1.32	1.23	2.33	14.39	22.60	27.35	13.96
Average	8.04	4.02	3.24	3.35	2.58	1.90	5.99	17.28	49.02	56.01	44.89	26.61

<2.0

02.0-5.0

5.0-20.0

>20.0

9.6 Scenario 17: Brandewyn

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Olifants Estuary, under the Scenario 17 is provided in Table 9.7. The mean annual runoff (MAR) is 529.3 Million m³ for this scenario. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	36.85	26.10	21.25	36.41	23.93	6.63	86.04	137.02	446.75	459.95	199.56	140.54
90%ile	17.01	7.10	6.79	3.50	2.31	3.38	4.85	56.18	101.70	142.02	117.27	60.52
80%ile	7.08	3.83	2.08	1.57	1.53	1.84	1.89	9.24	62.60	65.22	69.92	34.26
70%ile	5.06	2.80	1.64	1.53	1.46	1.47	1.31	3.18	34.62	44.46	43.60	23.69
60%ile	2.95	2.09	1.52	1.53	1.44	1.32	1.19	1.51	19.07	32.72	30.17	15.48
50%ile	1.75	1.87	1.52	1.53	1.41	1.32	1.15	0.78	12.54	20.11	21.10	10.19
40%ile	1.24	1.68	1.52	1.53	1.41	1.32	1.15	0.56	5.51	10.57	14.26	7.92
30%ile	1.20	1.48	1.52	1.53	1.41	1.32	1.15	0.47	1.35	5.32	7.84	5.85
20%ile	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.43	0.38	2.23	4.51	2.96
10%ile	1.20	1.36	1.52	1.27	1.11	0.70	0.36	0.43	0.31	0.50	0.71	1.00
1%ile	1.20	1.22	0.89	0.88	0.46	0.22	0.05	0.07	0.31	0.46	0.63	0.97

ii. Occurrence and duration of different abiotic states

Estimated occurrence and duration of the different Abiotic States in the Olifants Estuary under the Scenario 17, based on simulated monthly river inflow are indicated Table 9.7.

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under Scenario 17, median (50%ile) monthly flows are displayed below. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

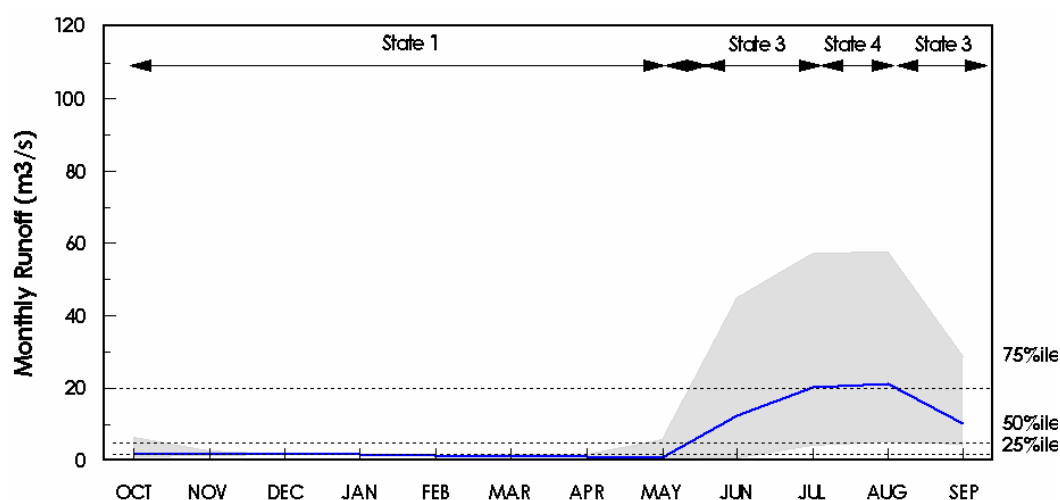


TABLE 9.7: Monthly simulated runoff data in m³/s (70-year period) into the Olifants Estuary under Scenario 17

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	1.20	1.83	1.49	0.88	7.49	10.47	0.07	0.10	432.87	494.75	102.22	18.92
1921	2.95	1.72	7.50	4.63	1.41	1.32	1.15	0.43	12.54	8.56	67.76	50.75
1922	1.20	1.57	1.52	1.53	1.41	1.32	1.15	0.93	89.54	95.75	27.30	9.36
1923	1.20	1.91	1.52	1.53	1.46	1.32	1.15	0.43	5.29	5.34	7.84	14.69
1924	1.78	2.45	1.52	1.53	1.41	1.32	1.15	1.05	479.12	445.03	43.60	5.60
1925	7.98	2.80	1.52	1.53	1.41	1.32	1.15	1.72	0.90	9.84	7.23	0.97
1926	6.75	4.35	1.52	1.53	1.41	1.32	1.30	0.60	0.31	0.46	4.51	4.44
1927	1.20	2.09	1.52	1.53	1.31	0.70	0.22	0.00	11.84	8.95	0.67	1.00
1928	1.20	1.68	1.52	1.01	0.73	0.58	0.80	0.52	1.80	26.18	17.14	10.19
1929	5.78	1.36	1.52	1.53	5.14	2.97	1.15	0.52	0.38	0.46	2.71	21.03
1930	17.01	2.80	1.52	1.53	1.11	0.70	2.56	1.19	0.31	2.23	35.58	21.85
1931	2.60	1.87	1.52	1.53	4.20	4.13	1.15	0.43	7.20	11.26	4.68	9.10
1932	1.20	2.09	1.52	1.53	1.41	1.32	1.15	0.43	23.60	62.69	49.84	6.94
1933	1.20	1.66	1.60	1.53	1.41	3.38	1.89	0.43	0.35	0.64	0.67	1.16
1934	6.41	19.62	12.35	1.53	1.41	1.32	1.30	1.09	5.52	4.85	22.94	10.11
1935	3.12	1.76	1.52	1.53	1.46	1.36	1.15	0.54	0.35	1.77	11.21	15.48
1936	7.08	7.10	6.79	1.53	1.41	1.44	1.15	0.43	25.91	41.25	14.26	2.96
1937	1.20	1.64	5.58	12.06	1.41	1.32	1.15	2.99	2.81	0.46	3.70	4.68
1938	1.24	1.80	1.52	1.53	1.93	1.47	1.15	9.24	15.24	0.74	75.75	65.90
1939	1.20	1.36	1.52	1.01	4.13	1.72	0.73	0.60	0.53	0.59	0.63	1.00
1940	1.24	1.99	0.90	0.95	0.49	0.00	1.31	44.57	105.80	69.52	97.81	129.67
1941	20.10	2.80	1.52	1.53	1.41	1.32	1.60	0.66	130.93	95.95	30.17	7.92
1942	7.16	7.70	5.82	5.59	1.41	1.32	1.15	0.51	1.02	20.11	54.67	24.41
1943	3.27	8.17	7.11	1.53	1.46	1.84	1.15	4.48	36.40	41.36	58.73	28.72
1944	8.75	2.55	1.52	1.53	1.41	1.32	1.15	7.44	71.54	150.12	117.27	14.14
1945	2.56	2.21	1.52	1.53	1.41	1.32	1.30	0.52	0.31	0.46	0.63	31.83
1946	32.03	2.80	1.52	1.53	1.41	1.55	1.19	1.80	2.58	26.38	18.09	4.58
1947	1.20	1.68	1.52	1.53	1.54	4.30	3.80	2.55	1.47	14.96	8.25	23.69
1948	7.47	1.98	1.52	1.53	1.41	1.32	1.15	0.43	0.31	0.50	1.90	2.56
1949	1.28	16.23	6.70	1.53	1.41	1.32	4.85	3.13	0.31	41.88	26.04	11.25
1950	6.85	3.87	2.42	1.53	1.41	1.32	1.15	0.45	34.62	47.61	39.24	24.46
1951	1.20	2.84	1.52	1.53	2.31	1.62	1.15	3.18	7.45	33.50	93.36	50.79
1952	7.27	24.25	19.62	1.53	1.53	1.62	18.80	32.49	6.41	61.19	90.70	16.29
1953	1.20	2.60	1.93	1.64	1.41	2.11	1.71	64.39	59.29	184.66	134.10	46.14
1954	5.64	1.91	1.52	1.53	1.60	1.40	1.45	0.56	24.58	56.52	188.04	74.64
1955	18.88	5.62	1.92	1.57	1.46	1.47	1.23	0.47	21.06	35.35	60.62	14.97
1956	1.20	1.57	1.52	1.53	1.99	3.17	1.15	11.81	65.65	148.85	117.41	38.34
1957	28.39	3.83	1.79	1.78	1.41	1.32	1.15	6.54	19.07	2.80	3.69	1.23
1958	1.20	1.65	1.52	1.53	1.41	1.32	1.19	211.24	176.08	3.90	20.75	12.25
1959	1.20	1.36	1.52	1.53	1.46	1.32	1.15	0.52	0.38	0.52	0.63	0.97
1960	1.20	1.36	1.95	2.01	1.45	3.47	86.07	73.82	46.64	45.89	13.96	9.39
1961	4.34	1.36	1.52	1.53	1.41	1.32	1.15	0.43	261.64	226.96	118.67	68.69
1962	35.83	6.03	1.56	1.54	1.44	1.32	1.19	0.43	1.35	5.89	121.92	36.36
1963	1.20	1.44	1.52	1.53	1.46	1.32	1.15	0.43	45.50	44.46	10.18	6.84
1964	1.35	3.12	2.08	1.53	1.41	1.62	2.95	1.16	0.31	0.46	0.67	0.97
1965	1.20	1.36	1.52	1.27	0.73	0.63	0.27	0.26	0.38	10.57	4.85	1.00
1966	1.20	1.36	1.52	0.88	0.73	0.85	3.65	6.63	101.70	65.22	5.73	1.57
1967	1.20	1.40	1.52	1.53	1.46	1.32	1.15	19.35	18.73	8.94	27.88	8.38
1968	17.90	4.79	1.52	1.53	1.41	1.32	1.38	0.56	0.31	0.46	0.63	0.97
1969	1.20	1.88	1.52	1.53	0.73	0.70	0.13	1.42	12.95	25.08	20.47	9.33
1970	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.43	0.31	32.72	39.84	5.85
1971	1.20	1.36	1.33	1.47	0.95	0.31	0.27	0.47	0.57	0.67	0.71	0.97
1972	1.20	0.87	0.87	0.88	0.38	2.70	0.96	0.26	0.31	14.53	21.10	5.44
1973	1.79	1.36	1.67	1.02	1.18	1.06	0.00	0.66	36.66	28.77	226.45	165.92
1974	5.00	2.23	1.52	1.70	1.65	1.32	1.15	61.92	62.60	5.32	11.54	4.59
1975	1.88	1.71	2.30	5.04	7.44	1.99	1.93	0.78	74.67	142.02	36.73	10.23
1976	1.20	30.42	25.05	1.65	1.41	1.32	1.67	105.22	197.27	162.67	132.56	34.78
1977	4.63	1.36	2.61	3.50	1.41	1.32	1.15	0.43	0.31	0.46	4.83	7.45
1978	1.20	1.36	1.52	1.53	1.41	1.32	0.45	0.47	17.97	20.29	1.76	2.74
1979	1.20	1.36	1.52	1.53	1.46	0.70	0.36	0.56	3.79	4.48	11.62	7.45
1980	1.20	22.99	13.26	81.22	38.84	2.24	0.15	0.26	0.31	14.99	42.61	34.26
1981	5.06	1.38	1.52	1.53	1.41	1.32	5.01	5.15	1.09	4.02	0.88	0.97
1982	1.75	3.51	1.52	1.53	1.41	1.32	1.04	63.05	87.62	36.52	26.91	20.92
1983	4.98	1.36	1.52	1.53	1.46	4.22	1.19	56.18	44.79	13.87	17.42	60.52
1984	39.23	5.52	1.64	17.21	17.54	4.98	2.95	1.51	12.54	58.21	69.92	19.77
1985	1.59	1.48	16.02	10.90	1.41	1.32	1.15	0.43	89.72	87.56	39.96	31.48
1986	2.31	1.36	1.52	1.53	1.41	1.32	20.12	24.40	14.50	21.39	17.30	28.59
1987	6.56	1.36	1.52	1.53	1.46	3.55	14.59	5.49	5.51	5.15	6.37	6.73
1988	1.24	1.36	1.53	1.54	1.45	1.82	19.87	17.14	7.20	12.07	24.60	72.19
1989	8.86	2.00	1.52	1.53	1.46	1.39	86.02	93.46	30.32	113.31	56.59	6.69
1990	1.28	1.62	1.78	1.93	1.87	1.47	1.86	2.02	33.60	116.29	90.96	61.49
Median	1.75	1.87	1.52	1.53	1.41	1.32	1.15	0.78	12.54	20.11	21.10	10.19
Average	5.53	3.84	3.11	3.29	2.44	1.77	4.70	13.61	43.56	50.52	40.39	22.08

<2.0

02.0-5.0

5.0-20.0

>20.0

9.7 Scenario 10: Maximum development

i. Seasonal variability in river inflow

Monthly simulated runoff data (73-year period) for the Olifants Estuary, under the Scenario 10 is provided in Table 9.8. The mean annual runoff (MAR) is 423.5 Million m³ for this scenario. A summary of the flow distributions (mean monthly flows in m³/s), derived from the simulated data set, is provided below:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	35.07	15.97	13.61	9.22	13.15	2.96	33.40	121.63	322.41	468.45	189.47	144.94
90%ile	7.03	1.77	1.93	1.61	1.60	1.55	2.56	22.28	70.34	148.86	100.53	60.62
80%ile	3.99	1.47	1.56	1.53	1.46	1.44	1.71	2.33	47.25	66.16	62.08	32.18
70%ile	1.77	1.40	1.52	1.53	1.45	1.32	1.30	1.42	14.01	38.42	41.71	19.06
60%ile	1.33	1.36	1.52	1.53	1.41	1.32	1.19	1.05	6.42	10.74	26.17	8.62
50%ile	1.24	1.36	1.52	1.53	1.41	1.32	1.15	0.67	2.20	4.53	13.11	6.36
40%ile	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.56	1.31	2.25	3.12	2.58
30%ile	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.47	0.64	1.15	1.55	1.38
20%ile	1.20	1.36	1.52	1.53	1.41	1.32	1.02	0.43	0.38	0.64	0.84	1.00
10%ile	1.20	1.36	1.52	1.02	0.85	0.70	0.36	0.43	0.31	0.46	0.67	0.97
1%ile	1.20	1.09	0.89	0.88	0.40	0.09	0.00	0.04	0.31	0.46	0.63	0.97

ii. Occurrence and duration of different abiotic states

Estimated occurrence and duration of the different Abiotic States in the Olifants Estuary under the Scenario 10, based on simulated monthly river inflow are indicated Table 9.8.

To provide a conceptual overview of the annual distribution of Abiotic States for the Olifants Estuary under Scenario 10, median (50%ile) monthly flows are displayed below. The occurrence of different Abiotic States is indicated for the median monthly flow conditions and the 75%ile and the 25%ile flows are also indicated to illustrate variability in the monthly flows (shaded area).

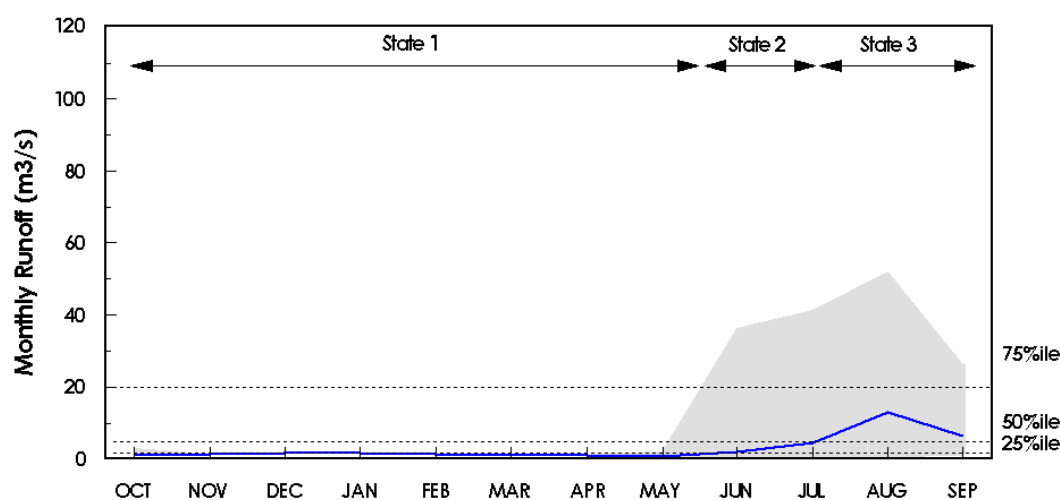


TABLE 9.8: Monthly simulated runoff data in m³/s (70-year period) into the Olifants Estuary under Scenario 10

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	1.20	1.36	1.23	0.88	1.39	0.80	0.00	0.06	280.29	493.51	100.53	16.03
1921	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.43	4.07	1.15	54.22	54.52
1922	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.93	47.25	106.08	27.07	7.80
1923	1.20	1.36	1.52	1.53	1.46	1.32	1.15	0.43	1.54	0.89	0.80	8.45
1924	1.20	1.40	1.52	1.53	1.41	1.32	1.15	1.05	420.70	457.71	41.71	1.74
1925	3.37	1.36	1.52	1.53	1.41	1.32	1.15	1.72	0.90	2.65	1.51	0.97
1926	1.49	1.53	1.52	1.53	1.41	1.32	1.30	0.60	0.31	0.46	1.67	1.38
1927	1.20	1.36	1.52	1.53	0.85	0.70	0.22	0.00	3.30	1.60	0.67	1.00
1928	1.20	1.36	1.52	0.88	0.73	0.48	0.80	0.52	1.80	6.51	3.12	2.14
1929	1.77	1.36	1.52	1.53	1.41	1.32	1.15	0.52	0.38	0.46	2.71	5.31
1930	2.93	1.36	1.52	1.53	0.93	0.70	2.56	1.19	0.31	0.75	9.03	3.55
1931	1.28	1.36	1.52	1.53	1.65	1.40	1.15	0.43	2.20	2.99	0.76	4.28
1932	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.43	7.58	26.07	26.17	2.67
1933	1.20	1.66	1.60	1.53	1.41	3.38	1.89	0.43	0.35	0.64	0.67	1.00
1934	1.20	7.86	3.99	1.53	1.41	1.32	1.30	1.09	0.64	0.56	7.33	1.90
1935	1.40	1.36	1.52	1.53	1.46	1.36	1.15	0.54	0.35	0.82	0.95	2.58
1936	1.81	4.72	2.72	1.53	1.41	1.44	0.85	0.43	5.38	9.02	1.30	0.97
1937	1.20	1.36	1.52	1.53	1.41	1.32	1.15	0.67	0.45	0.46	0.63	1.08
1938	1.24	1.36	1.52	1.53	1.93	1.47	1.15	1.91	1.31	0.74	17.55	63.34
1939	1.20	1.36	1.52	0.88	4.13	1.19	0.73	0.60	0.53	0.52	0.63	1.00
1940	1.24	1.19	0.90	0.95	0.41	0.00	1.16	10.58	64.06	76.43	98.81	132.33
1941	18.42	1.36	1.52	1.53	1.41	1.32	1.60	0.66	96.54	106.13	29.81	7.64
1942	5.61	1.77	1.56	1.53	1.41	1.32	1.15	0.51	1.02	1.23	50.20	25.14
1943	1.32	3.07	2.12	1.53	1.46	1.32	1.15	2.17	14.02	41.68	60.75	30.95
1944	6.60	1.36	1.52	1.53	1.41	1.32	1.15	2.06	39.17	155.49	120.72	12.36
1945	2.56	1.36	1.52	1.53	1.41	1.32	1.30	0.52	0.31	0.46	0.63	7.18
1946	5.10	1.36	1.52	1.53	1.41	1.55	1.19	1.42	0.79	7.03	2.41	0.97
1947	1.20	1.36	1.52	1.53	1.54	1.33	1.30	1.31	0.64	1.16	0.91	12.29
1948	5.16	1.36	1.52	1.53	1.41	1.32	1.15	0.43	0.31	0.50	0.92	1.08
1949	1.28	1.44	1.52	1.53	1.41	1.32	2.20	0.82	0.31	10.74	2.37	6.36
1950	3.56	1.40	1.52	1.53	1.41	1.32	1.15	0.45	9.57	38.42	38.96	23.59
1951	1.20	1.36	1.52	1.53	2.31	1.62	1.15	0.86	0.49	8.77	97.66	52.09
1952	7.03	14.53	10.98	1.53	1.41	1.32	4.11	28.98	7.65	63.66	94.95	14.40
1953	1.20	1.36	1.93	1.64	1.41	2.11	1.71	22.43	61.51	190.23	139.59	46.76
1954	3.99	1.36	1.52	1.53	1.60	1.40	1.45	0.56	5.46	39.86	194.19	77.76
1955	17.37	1.96	1.71	1.57	1.46	1.47	1.23	0.47	3.14	12.58	62.08	13.98
1956	1.20	1.36	1.52	1.53	1.56	1.36	1.15	2.84	37.63	154.27	122.55	38.94
1957	26.81	1.36	1.52	1.53	1.41	1.32	1.15	3.89	1.80	0.46	0.67	0.97
1958	1.20	1.36	1.52	1.53	1.41	1.32	1.19	169.22	194.51	0.60	13.11	9.01
1959	1.20	1.36	1.52	1.53	1.46	1.32	1.15	0.52	0.38	0.46	0.63	0.97
1960	1.20	1.36	1.78	1.76	1.45	2.78	26.03	57.44	52.58	55.96	13.14	6.95
1961	1.33	1.36	1.52	1.53	1.41	1.32	1.15	0.43	232.83	232.64	113.98	66.09
1962	32.57	1.51	1.56	1.53	1.41	1.32	1.19	0.43	1.35	4.05	83.55	44.06
1963	1.20	1.44	1.52	1.53	1.46	1.32	1.15	0.43	10.13	40.96	8.80	6.22
1964	1.35	3.12	2.08	1.53	1.41	1.62	2.95	1.16	0.31	0.46	0.67	0.97
1965	1.20	1.36	1.52	0.88	0.73	0.44	0.25	0.24	0.38	2.14	0.84	1.00
1966	1.20	1.36	1.49	0.88	0.73	0.68	3.59	3.55	45.33	14.51	3.86	0.97
1967	1.20	1.40	1.52	1.53	1.46	1.32	1.15	11.50	6.91	3.71	18.08	7.49
1968	13.39	1.47	1.52	1.53	1.41	1.32	1.38	0.56	0.31	0.46	0.63	0.97
1969	1.20	1.36	1.52	1.53	0.73	0.57	0.00	1.42	1.67	4.53	1.55	0.97
1970	1.20	1.36	1.52	1.53	1.41	1.32	0.99	0.43	0.31	2.92	2.52	1.19
1971	1.20	1.36	1.02	1.47	0.95	0.31	0.27	0.47	0.57	0.59	0.63	0.97
1972	1.20	0.87	0.87	0.88	0.38	2.70	0.96	0.26	0.31	2.25	2.22	1.08
1973	1.20	1.36	1.48	1.02	0.83	0.13	0.00	0.66	14.01	4.55	187.44	174.38
1974	1.55	1.36	1.52	1.53	1.41	1.32	1.15	26.84	70.34	5.93	13.66	3.50
1975	1.24	1.36	1.52	1.83	2.08	1.51	1.86	0.78	47.51	148.86	38.94	8.62
1976	1.20	19.32	16.96	1.61	1.41	1.32	1.30	90.95	208.94	164.72	130.88	32.18
1977	4.63	1.36	1.52	1.53	1.41	1.32	1.15	0.43	0.31	0.46	3.68	2.16
1978	1.20	1.36	1.52	1.53	1.41	1.32	0.44	0.47	1.90	1.15	0.65	0.97
1979	1.20	1.36	1.52	1.53	1.46	0.70	0.36	0.56	3.26	1.60	4.47	2.50
1980	1.20	1.47	1.56	18.65	30.90	0.81	0.14	0.26	0.31	3.31	49.26	35.26
1981	1.52	1.36	1.52	1.53	1.41	1.32	2.16	0.89	0.68	1.01	0.84	0.97
1982	1.75	1.57	1.52	1.53	1.41	1.32	1.02	12.97	86.01	40.37	26.84	22.30
1983	2.97	1.36	1.52	1.53	1.46	1.51	1.19	22.28	50.49	14.36	18.83	60.62
1984	40.92	1.53	1.63	1.91	5.54	1.55	1.27	1.31	10.69	66.16	71.79	19.06
1985	1.20	1.40	12.17	5.19	1.41	1.32	1.15	0.43	61.62	101.24	44.34	31.85
1986	1.20	1.36	1.52	1.53	1.41	1.32	1.72	2.33	18.85	25.26	20.01	27.54
1987	4.32	1.36	1.52	1.53	1.46	1.58	5.71	2.20	0.94	0.94	0.77	1.34
1988	1.24	1.36	1.52	1.53	1.45	1.36	2.69	0.93	0.95	15.38	30.66	72.16
1989	7.14	1.36	1.52	1.53	1.41	1.32	50.61	101.23	34.80	116.62	54.91	2.52
1990	1.28	1.62	1.78	1.61	1.52	1.47	1.86	2.02	6.42	105.91	95.68	62.26
Median	1.24	1.36	1.52	1.53	1.41	1.32	1.15	0.67	2.20	4.53	13.11	6.36
Average	3.94	2.02	2.08	1.77	1.88	1.30	2.37	8.60	32.25	45.17	34.86	19.66

<2.0

02.0-5.0

5.0-20.0

>20.0

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ANNEXURE 1

FIELD DATA COLLECTED DURING 2004

AS PART OF THIS STUDY

Data collected from DWAF water quality station at Lutzville causeway (E2H016)

Date	Time	EC mS/m	pH	NOx-N µg/L	NH4-N µg/L	PO4-P (µg/L)	SiO4-Si (µg/L)
11/12/2002	12:25:00 PM	393	8.4	45	55	31	7506
16/01/2003	2:30:00 PM	376	8.3	47	42	72	5489
05/02/2003	10:21:00 AM	361	8.2	46	49	96	6688
05/03/2003	11:16:00 AM	368	8.3	66	<40	47	6548
02/04/2003	10:14:00 AM	309	8.1	182	<40	65	7468
30/04/2003	9:35:00 AM	333	8.1	357	54	59	6751
16/05/2003	9:00:00 AM	376	7.9	434	55	69	6666
12/06/2003	11:10:00 AM	356	8.2	497	50	55	5810
14/08/2003	9:30:00 AM	431	8.1	316	220	62	4003
17/07/2003	10:40:00 AM	409	8.2	274	43	40	4533
10/09/2003	11:00:00 AM	33	7.7	264	<40	53	2564
17/09/2003	11:30:00 AM	46	7.6	1071	<40	59	4310
30/10/2003	4:46:00 PM	24.5	8.1	562	58	26	6593
12/11/2003	10:00:00 AM	219	8.0	<110	<30	29	2983
11/12/2003	1:55:00 PM	487	8.2	<110	<30	<23	4589
07/01/2004	10:15:00 AM	477	8.4	<110	46	157	5548
04/02/2004	10:30:00 AM	491	8.3	<110	49	129	6549
20/01/2004	2:05:00 PM	474	8.2	<110	<30	191	7468
03/03/2004	11:15:00 AM	496	8.0	<110	<30	110	6655
30/03/2004	11:00:00 AM	489	8.4	<110	<30	105	7903
18/05/2004	2:35:00 PM	457	8.3	127	<30	74	4923
25/05/2004	2:40:00 PM	443	8.3	329	<30	215	4510
22/06/2004	2:33:00 PM	74.7	7.8	275	<30	78	2909
20/07/2004	3:00:00 PM	155	7.6	193	63	48	3597
17/08/2004	2:26:00 PM	21	7.1	<110	65	34	2428
04/08/2004	11:30:00 AM	24.3	7.1	<110	34	37	2152
14/09/2004	1:52:00 PM	182	8.2	<80	47	114	2349
12/10/2004	2:15:00 PM	297	8.4	<110	<30	41	3181
09/11/2004	2:06:00 PM	260	8.3	<110	<30	61	3599
07/12/2004	1:55:00 PM	569	8.4	<110	40	64	1793
02/12/2004	1:30:00 PM	560	8.5	<110	42	91	4235
04/01/2005	2:45:00 PM	593	8.5	<110	41	289	1119
13/01/2005	12:30:00 PM	581	8.5	<80	46		931

Data collected from the Olifants Estuary during March 2004

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	SS (mg/l)	DO (mg/l)	NO2-N (µg/l)	NO3-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
3	3	2004	9	59	0.5	2.00	16.62	32.64										Low
3	3	2004	9	59	0.5	1.00	16.68	32.84										Low
3	3	2004	9	59	0.5	0.00	16.74	32.74										Low
3	3	2004	10	5	1.5	3.70	15.23	33.91										Low
3	3	2004	10	5	1.5	3.00	15.22	33.96										Low
3	3	2004	10	5	1.5	3.20	15.93	33.59										Low
3	3	2004	10	5	1.5	1.00	17.31	32.12										Low
3	3	2004	10	5	1.5	0.00	18.51	30.33										Low
3	3	2004	10	15	3.0	1.88	14.53	34.39										Low
3	3	2004	10	15	3.0	1.00	16.72	33.39										Low
3	3	2004	10	15	3.0	0.50	18.98	29.17										Low
3	3	2004	10	15	3.0	0.00	18.95	29.17										Low
3	3	2004	10	20	4.0	1.80	18.04	32.84										Low
3	3	2004	10	20	4.0	1.00	19.97	27.66										Low
3	3	2004	10	20	4.0	0.50	19.25	26.07										Low
3	3	2004	10	20	4.0	0.00	19.27	26.02										Low
3	3	2004	10	23	5.0	2.80	19.17	31.41										Low
3	3	2004	10	23	5.0	2.00	19.47	29.41										Low
3	3	2004	10	23	5.0	1.00	19.55	28.40										Low
3	3	2004	10	23	5.0	0.50	19.76	23.43										Low
3	3	2004	10	23	5.0	0.00	19.78	23.37										Low
3	3	2004	10	30	6.5	6.60	19.92	28.77										Low
3	3	2004	10	30	6.5	6.00	19.91	28.67										Low
3	3	2004	10	30	6.5	5.00	19.89	28.37										Low
3	3	2004	10	30	6.5	4.00	19.86	28.01										Low
3	3	2004	10	30	6.5	3.00	19.87	27.84										Low
3	3	2004	10	30	6.5	3.50	19.89	27.47										Low
3	3	2004	10	30	6.5	2.50	19.89	27.03										Low
3	3	2004	10	30	6.5	2.00	19.84	26.17										Low
3	3	2004	10	30	6.5	1.50	19.84	25.19										Low
3	3	2004	10	30	6.5	1.00	19.86	24.57										Low
3	3	2004	10	30	6.5	0.50	20.54	20.39										Low
3	3	2004	10	30	6.5	0.00	20.67	19.48										Low

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	SS (mg/l)	DO (mg/l)	NO2-N (µg/l)	NO3-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
3	3	2004	10	38	8.0	2.06	20.43	23.65										Low
3	3	2004	10	38	8.0	1.00	20.73	21.11										Low
3	3	2004	10	38	8.0	0.75	20.61	16.81										Low
3	3	2004	10	38	8.0	0.50	20.75	16.46										Low
3	3	2004	10	38	8.0	0.00	20.76	16.34										Low
3	3	2004	10	47	10.0	4.00	20.43	23.74										Low
3	3	2004	10	47	10.0	3.00	20.56	22.67										Low
3	3	2004	10	47	10.0	2.00	20.90	20.58										Low
3	3	2004	10	47	10.0	1.50	21.00	20.48										Low
3	3	2004	10	47	10.0	1.00	21.11	15.76										Low
3	3	2004	10	47	10.0	0.75	20.97	14.43										Low
3	3	2004	10	47	10.0	0.50	21.16	13.89										Low
3	3	2004	10	47	10.0	0.00	21.18	13.85										Low
3	3	2004	10	52	12.0	3.09	21.19	20.18										Low
3	3	2004	10	52	12.0	2.00	21.40	19.92										Low
3	3	2004	10	52	12.0	1.50	21.77	19.44										Low
3	3	2004	10	52	12.0	1.00	22.13	17.56										Low
3	3	2004	10	52	12.0	0.75	21.13	12.50										Low
3	3	2004	10	52	12.0	0.50	21.56	11.56										Low
3	3	2004	10	52	12.0	0.00	21.67	11.45										Low
3	3	2004	11	2	14.0	4.02	23.22	18.01										Low
3	3	2004	11	2	14.0	3.00	22.80	17.10										Low
3	3	2004	11	2	14.0	2.00	22.80	16.44										Low
3	3	2004	11	2	14.0	1.50	22.84	15.28										Low
3	3	2004	11	2	14.0	1.25	22.62	13.62										Low
3	3	2004	11	2	14.0	1.00	22.29	11.33										Low
3	3	2004	11	2	14.0	0.75	21.45	7.89										Low
3	3	2004	11	2	14.0	0.50	21.91	7.79										Low
3	3	2004	11	2	14.0	0.00	21.91	7.77										Low

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	SS (mg/l)	DO (mg/l)	NO2-N (µg/l)	NO3-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
3	3	2004	11	11	16.0	2.91	23.38	16.11										Low
3	3	2004	11	11	16.0	2.00	23.42	14.41										Low
3	3	2004	11	11	16.0	1.50	22.75	11.89										Low
3	3	2004	11	11	16.0	1.00	21.50	6.93										Low
3	3	2004	11	11	16.0	0.75	21.63	6.96										Low
3	3	2004	11	11	16.0	0.50	22.09	6.87										Low
3	3	2004	11	11	16.0	0.00	22.10	6.85										Low
3	3	2004	11	16	18.0	3.19	23.88	15.27										Low
3	3	2004	11	16	18.0	2.00	23.42	13.25										Low
3	3	2004	11	16	18.0	1.50	22.10	7.00										Low
3	3	2004	11	16	18.0	1.25	22.09	6.93										Low
3	3	2004	11	16	18.0	1.00	22.09	6.82										Low
3	3	2004	11	16	18.0	0.50	22.47	6.47										Low
3	3	2004	11	16	18.0	0.00	22.90	6.13										Low
3	3	2004	11	20	20.0	1.56	22.46	4.08										Low
3	3	2004	11	20	20.0	1.00	22.47	3.72										Low
3	3	2004	11	20	20.0	0.50	22.53	3.66										Low
3	3	2004	11	20	20.0	0.00	22.73	3.58										Low
3	3	2004	11	36	21.0	2.30	22.69	3.18										Low
3	3	2004	11	36	21.0	2.00	22.83	3.18										Low
3	3	2004	11	36	21.0	1.00	22.90	3.18										Low
3	3	2004	11	36	21.0	0.00	23.00	3.18										Low
3	3	2004	11	57	22.0	3.87	22.45	3.19										Low
3	3	2004	11	57	22.0	3.00	22.36	3.19										Low
3	3	2004	11	57	22.0	2.00	22.37	3.19										Low
3	3	2004	11	57	22.0	1.00	22.40	3.19										Low
3	3	2004	11	57	22.0	0.00	22.70	3.17										Low
3	3	2004			36.0	0.00	23.18	2.68										Low

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	SS (mg/l)	DO (mg/l)	NO2-N (µg/l)	NO3-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
2	3	2004	10	37	0.5	2.80	12.24	34.80				8.17						High
2	3	2004	10	37	0.5	2.00	12.42	34.81				8.17						High
2	3	2004	10	37	0.5	1.00	12.25	34.83				8.18						High
2	3	2004	10	37	0.5	0.00	12.26	34.71	7.5	0.3	6.0	8.14	18	377	11	48	198	High
2	3	2004	11	3	1.5	3.69	13.47	34.53				7.30						High
2	3	2004	11	3	1.5	3.00	13.64	34.66				7.28						High
2	3	2004	11	3	1.5	2.00	13.36	34.67				7.26						High
2	3	2004	11	3	1.5	1.00	13.28	34.68				7.30						High
2	3	2004	11	3	1.5	0.00	14.51	34.85	7.6	0.2	4.0	7.14	22	328	24	50	340	High
2	3	2004	11	13	3.0	2.01	17.07	33.61				5.30						High
2	3	2004	11	13	3.0	1.00	17.15	33.62				5.26						High
2	3	2004	11	13	3.0	0.50	18.32	32.73				6.36						High
2	3	2004	11	13	3.0	0.00	18.48	32.62	7.7	0.1	6.0	6.84	16	80	33	67	741	High
2	3	2004	11	29	4.0	2.66	19.64	31.08				5.31						High
2	3	2004	11	29	4.0	2.00	19.63	31.09				5.32						High
2	3	2004	11	29	4.0	1.00	19.96	30.53				5.57						High
2	3	2004	11	29	4.0	0.00	20.02	30.43	7.8	0.1	5.0	5.64	11	35	14	72	1104	High
2	3	2004	11	48	5.0	2.96	20.34	29.78				5.02						High
2	3	2004	11	48	5.0	2.50	20.34	29.79				5.18						High
2	3	2004	11	48	5.0	2.00	20.48	29.67				5.15						High
2	3	2004	11	48	5.0	1.00	20.69	29.36				5.35						High
2	3	2004	11	48	5.0	0.50	20.92	29.14				5.53						High
2	3	2004	11	48	5.0	0.00	20.97	29.03	7.8	0.2	19.0	5.76	<10	31	<10	79	1313	High
2	3	2004	12	10	6.5	5.97	21.32	28.19	7.9	0.3	22.0	4.68	13	34	11	88	1782	High
2	3	2004	12	10	6.5	5.00	21.33	28.21				4.62						High
2	3	2004	12	10	6.5	4.00	21.30	28.02				4.60						High
2	3	2004	12	10	6.5	3.00	21.29	27.95				4.72						High
2	3	2004	12	10	6.5	2.00	21.19	27.31				4.71						High
2	3	2004	12	10	6.5	1.50	21.11	27.13				5.04						High
2	3	2004	12	10	6.5	0.00	21.00	25.14				5.61						High
2	3	2004	12	10	6.5	0.50	21.01	25.10				5.87						High
2	3	2004	12	10	6.5	0.00	21.08	24.76	7.9	0.2	24.0	5.99	<10	31	<10	114	1955	High

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	SS (mg/l)	DO (mg/l)	NO2-N (µg/l)	NO3-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
2	3	2004	12	51	8.0	2.40	21.71	23.10				5.91						High
2	3	2004	12	51	8.0	2.00	21.71	23.11				5.89						High
2	3	2004	12	51	8.0	0.00	21.73	23.11				5.98						High
2	3	2004	12	51	8.0	0.50	21.74	23.10				6.00						High
2	3	2004	12	51	8.0	0.00	21.79	23.07	7.9	0.5	4.0	6.03	<10	15	<10	124	2230	High
2	3	2004	13	8	10.0	3.95	22.11	22.94	7.9	0.2	2.0	4.08	10	9	<10	121	2400	High
2	3	2004	13	8	10.0	3.00	22.09	23.24				4.16						High
2	3	2004	13	8	10.0	2.00	21.67	20.11										High
2	3	2004	13	8	10.0	2.50	21.67	20.40				5.98						High
2	3	2004	13	8	10.0	1.50	21.66	20.24				6.33						High
2	3	2004	13	8	10.0	1.00	21.78	19.95				6.40						High
2	3	2004	13	8	10.0	0.50	21.77	19.89				6.49						High
2	3	2004	13	8	10.0	0.00	21.71	19.85	8.1	0.1	3.0	6.55	<10	<10	<10	118	2680	High
2	3	2004	13	35	12.0	3.25	22.66	20.64	7.9	0.2	4.0	2.51	<10	<10	<10	126	2988	High
2	3	2004	13	35	12.0	2.50	22.65	20.55				2.97						High
2	3	2004	13	35	12.0	2.00	22.50	20.25				3.41						High
2	3	2004	13	35	12.0	1.50	22.22	19.64				5.50						High
2	3	2004	13	35	12.0	1.00	22.33	15.49				7.25						High
2	3	2004	13	35	12.0	0.50	22.41	15.32				7.35						High
2	3	2004	13	35	12.0	0.00	22.43	15.27	7.9	0.1	14.0	7.44	<10	<10	<10	122	2683	High
2	3	2004	14	15	14.0	4.42	23.40	18.80	8.0	3.0	4.0	2.19	<10	<10	<10	129	2622	High
2	3	2004	14	15	14.0	4.00	23.39	18.32				3.54						High
2	3	2004	14	15	14.0	3.50	23.32	17.95				3.74						High
2	3	2004	14	15	14.0	3.00	23.28	17.62				4.13						High
2	3	2004	14	15	14.0	2.50	23.44	17.20				4.31						High
2	3	2004	14	15	14.0	2.00	23.45	16.38				4.88						High
2	3	2004	14	15	14.0	1.50	23.36	14.23				6.46						High
2	3	2004	14	15	14.0	1.00	23.10	10.73				6.98						High
2	3	2004	14	15	14.0	0.50	23.10	10.08				7.12						High
2	3	2004	14	15	14.0	0.00	23.10	9.99	8.3	1.3	3.0	7.23	<10	<10	<10	152	3902	High

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	SS (mg/l)	DO (mg/l)	NO2-N (µg/l)	NO3-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
2	3	2004	14	57	16.0	2.98	23.74	17.21	8.1	0.1	5.0	3.86	<10	<10	<10	142	3293	High
2	3	2004	14	57	16.0	2.50	23.63	13.73				6.17						High
2	3	2004	14	57	16.0	2.00	23.35	9.55				6.94						High
2	3	2004	14	57	16.0	1.50	23.32	9.41				7.12						High
2	3	2004	14	57	16.0	1.00	23.38	8.86				7.21						High
2	3	2004	14	57	16.0	0.50	23.40	8.58				7.40						High
2	3	2004	14	57	16.0	0.00	23.41	8.45	8.3	0.7	2.0	7.47	<10	<10	<10	149		High
2	3	2004	15	18	18.0	3.60	24.18	15.86	8.1	0.2	5.0	2.30	<10	<10	<10	157	3475	High
2	3	2004	15	18	18.0	3.00	24.11	15.30				3.37						High
2	3	2004	15	18	18.0	2.50	24.11	15.00				4.60						High
2	3	2004	15	18	18.0	2.00	24.09	12.32				6.77						High
2	3	2004	15	18	18.0	1.50	23.56	6.52				7.83						High
2	3	2004	15	18	18.0	1.00	23.51	6.29				8.10						High
2	3	2004	15	18	18.0	0.50	23.46	6.21				8.35						High
2	3	2004	15	18	18.0	0.00	23.46	6.17	8.4	1.1	3.0	8.35	<10	<10	<10	122	2321	High
2	3	2004	15	45	20.0	1.99	23.81	8.55				6.03						High
2	3	2004	15	45	20.0	1.50	23.77	7.98				7.35						High
2	3	2004	15	45	20.0	1.00	23.74	6.52				7.90						High
2	3	2004	15	45	20.0	0.50	23.79	6.35				8.13						High
2	3	2004	15	45	20.0	0.00	23.79	6.30	8.4	6.3	3.0	8.48	<10	<10	<10	122	1860	High
2	3	2004	16	7	21.0	2.83	23.93	3.57				9.23						High
2	3	2004	16	7	21.0	2.00	23.96	3.56				9.27						High
2	3	2004	16	7	21.0	1.00	23.95	3.55				9.24						High
2	3	2004	16	7	21.0	0.50	23.96	3.55				9.30						High
2	3	2004	16	7	21.0	0.00	23.95	3.50	8.4	5.7	3.0	9.39	<10	<10	<10	102	1654	High

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	SS (mg/l)	DO (mg/l)	NO2-N (µg/l)	NO3-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
2	3	2004	16	32	22.0	4.45	23.27	3.19	8.3	10.8	9.0	6.82	10	<10	<10	60	3083	High
2	3	2004	16	32	22.0	4.00	23.57	3.18				7.17						High
2	3	2004	16	32	22.0	3.00	23.81	3.19				8.36						High
2	3	2004	16	32	22.0	2.00	23.87	3.18				8.72						High
2	3	2004	16	32	22.0	1.00	23.90	3.18				8.88						High
2	3	2004	16	32	22.0	0.50	23.92	3.18				9.12						High
2	3	2004	16	32	22.0	0.00	23.89	3.18	8.4	2.5	3.0	9.12	10	<10	<10	58	2791	High
3	3	2004	16	35	31.0	0.00	23.44	2.89	8.4	23.7	5.0	8.27	12	11	13	55	7857	High
3	3	2004	16	15	33.0	0.00	23.73	2.78	8.4	9.4	4.0	7.76	23	131	12	71	7678	High
3	3	2004	16	0	36.0	0.00	23.22	2.68	8.1	25.8	7.0	6.72	32	15	25	46	7500	High

Data collected from the Olifants Estuary during August 2004

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	DO (mg/l)	NO3-N (µg/l)	NO2-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
10	8	2004	18	15		0.00	12.70	34.65				121	<10	40	34	339	High
10	8	2004	9	48	0.5	1.70	12.60	34.07	8.0	23.6							High
10	8	2004	9	48	0.5	1.00	12.64	33.49	8.0	14.9							High
10	8	2004	9	48	0.5	0.50	12.62	34.17	8.0	13.9							High
10	8	2004	9	48	0.5	0.00	12.58	34.05	8.0	13.4	8.05	121	<10	<10	13	491	High
10	8	2004	10	0	1.5	3.40	12.76	34.72	8.0	9.6	6.89	120	<10	63	42	545	High
10	8	2004	10	0	1.5	3.00	12.86	34.72	8.0	9.1							High
10	8	2004	10	0	1.5	2.50	12.78	34.54	8.0	9.1							High
10	8	2004	10	0	1.5	2.00	12.85	34.08	8.0	10.0							High
10	8	2004	10	0	1.5	1.50	12.97	32.65	8.0	11.7							High
10	8	2004	10	0	1.5	1.00	13.54	29.77	7.9	12.8							High
10	8	2004	10	0	1.5	0.50	13.27	11.67	8.0	17.8							High
10	8	2004	10	0	1.5	0.00	13.16	7.72	8.0	17.7	7.81	73	<10	<10	33	2182	High
10	8	2004	10	40	3.0	1.60	12.92	33.81	7.9	14.2	7.07	114	<10	<10	40	1464	High
10	8	2004	10	40	3.0	1.00	13.53	19.34	8.0	14.6							High
10	8	2004	10	40	3.0	0.50	13.67	8.92	8.1	16.4							High
10	8	2004	10	40	3.0	0.00	13.29	5.47	7.9	18.7	8.12	77	<10	11	37	2000	High
10	8	2004	11	0	4.0	2.00	13.05	32.56	7.9	19.0	6.41	153	<10	40	44	670	High
10	8	2004	11	0	4.0	1.50	13.16	29.73	7.9	19.4							High
10	8	2004	11	0	4.0	1.25	13.40	24.27	7.7	15.7							High
10	8	2004	11	0	4.0	1.00	13.40	14.51	8.0	16.1							High
10	8	2004	11	0	4.0	0.75	13.35	4.60	7.9	19.6							High
10	8	2004	11	0	4.0	0.50	13.37	4.51	8.1	19.3							High
10	8	2004	11	0	4.0	0.00	13.37	4.51	7.8	19.8	8.13	<10	<10	<10	35	2227	High
10	8	2004	11	49	5.0	3.30	13.06	32.30	7.9	46.7	6.24	164	<10	18	42	841	High
10	8	2004	11	49	5.0	2.50	13.09	31.94	7.9	17.4							High
10	8	2004	11	49	5.0	2.00	13.12	31.36	7.9	16.6							High
10	8	2004	11	49	5.0	1.50	13.31	23.20	7.9	13.8							High
10	8	2004	11	49	5.0	1.25	13.51	5.32	8.1	18.2							High
10	8	2004	11	49	5.0	1.00	13.45	5.30	8.3	17.9							High
10	8	2004	11	49	5.0	0.50	13.60	4.64	8.0	19.5							High
10	8	2004	11	49	5.0	0.00	13.77	4.40	7.9	19.1	8.67	81	<10	13	25	2545	High

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	DO (mg/l)	NO3-N (µg/l)	NO2-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
10	8	2004	12	21	6.5	9.50	13.07	31.91	7.9	14.7	6.43	175	<10	36	44	761	High
10	8	2004	12	21	6.5	8.00	13.07	31.86	7.9	14.2							High
10	8	2004	12	21	6.5	7.00	13.07	31.84	7.9	14.3							High
10	8	2004	12	21	6.5	6.00	13.08	31.81	7.9	14.2							High
10	8	2004	12	21	6.5	5.00	13.07	31.82	7.9	13.7							High
10	8	2004	12	21	6.5	4.00	13.08	31.75	7.9	13.5	6.13	171	<10	<10	46	795	High
10	8	2004	12	21	6.5	3.00	13.09	31.71	7.9	13.5							High
10	8	2004	12	21	6.5	2.50	13.11	31.48	7.9	13.3							High
10	8	2004	12	21	6.5	2.00	13.16	30.90	7.9	12.5							High
10	8	2004	12	21	6.5	1.50	13.18	30.00	7.9	13.3							High
10	8	2004	12	21	6.5	1.25	13.53	15.47	7.9	14.7							High
10	8	2004	12	21	6.5	1.00	13.65	9.98	7.7	17.1							High
10	8	2004	12	21	6.5	0.50	13.68	2.87	8.0	19.8							High
10	8	2004	12	21	6.5	0.00	14.04	2.68	7.8	20.8	8.26	80	<10	19	27	2682	High
10	8	2004	12	53	8.0	2.20	13.40	27.88	7.6	20.0	5.35	158	<10	21	49	1163	High
10	8	2004	12	53	8.0	2.00	13.42	26.76	7.8	22.8							High
10	8	2004	12	53	8.0	1.75	13.54	15.15	7.9	22.8							High
10	8	2004	12	53	8.0	1.50	13.58	11.37	7.7	20.0							High
10	8	2004	12	53	8.0	1.25	13.72	2.31	8.2	33.8							High
10	8	2004	12	53	8.0	1.00	14.05	2.06	8.0	38.4							High
10	8	2004	12	53	8.0	0.50	14.04	2.05	7.9	38.1							High
10	8	2004	12	53	8.0	0.00	14.10	2.05	7.8	37.6	8.63	59	<10	<10	35	2182	High
10	8	2004	13	15	10.0	3.80	13.40	28.24	7.5	22.7	5.38	163	<10	44	53	1120	High
10	8	2004	13	15	10.0	3.50	13.35	28.19	7.7	16.1							High
10	8	2004	13	15	10.0	3.00	13.36	27.78	7.8	13.6							High
10	8	2004	13	15	10.0	2.50	13.42	26.18	7.8	13.7							High
10	8	2004	13	15	10.0	2.25	13.56	21.58	7.8	14.4							High
10	8	2004	13	15	10.0	2.00	13.56	20.12	7.8	14.6							High
10	8	2004	13	15	10.0	1.75	13.92	7.45	8.0	18.7							High
10	8	2004	13	15	10.0	1.50	14.33	1.21	8.1	22.2							High
10	8	2004	13	15	10.0	1.00	14.56	1.17	8.0	22.8							High
10	8	2004	13	15	10.0	0.50	14.57	1.16	7.9	22.8							High
10	8	2004	13	15	10.0	0.00	14.59	1.16	7.8	22.8	8.09	67	<10	<10	35	2455	High

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	DO (mg/l)	NO3-N (µg/l)	NO2-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
10	8	2004	13	40	12.0	3.80	13.43	24.77	7.5	16.4	4.46	148	<10	102	58	1273	High
10	8	2004	13	40	12.0	3.00	13.42	24.13	7.7	13.9							High
10	8	2004	13	40	12.0	2.50	13.45	23.01	7.7	12.3							High
10	8	2004	13	40	12.0	2.25	13.84	16.12	7.7	12.8							High
10	8	2004	13	40	12.0	2.00	14.58	0.97	8.3	20.8							High
10	8	2004	13	40	12.0	1.50	14.57	0.70	8.1	21.2							High
10	8	2004	13	40	12.0	1.00	14.62	0.66	8.0	22.5							High
10	8	2004	13	40	12.0	0.50	14.73	0.65	7.8	22.4							High
10	8	2004	13	40	12.0	0.00	14.76	0.65	7.8	22.8	???	67	<10	<10	36	2409	High
10	8	2004	14	10	14.0	4.10	13.67	15.20	7.3	17.0	3.77	115	<10	110	48	1929	High
10	8	2004	14	10	14.0	3.50	13.73	14.40	7.4	15.0							High
10	8	2004	14	10	14.0	3.00	13.73	13.09	7.4	15.5							High
10	8	2004	14	10	14.0	2.50	13.73	9.22	7.6	17.4							High
10	8	2004	14	10	14.0	2.25	13.62	0.34	7.8	22.8							High
10	8	2004	14	10	14.0	2.00	13.59	0.81	8.4	22.5							High
10	8	2004	14	10	14.0	1.50	13.82	0.21	8.0	23.4							High
10	8	2004	14	10	14.0	1.00	13.87	0.21	7.8	23.6							High
10	8	2004	14	10	14.0	0.50	14.24	0.21	7.7	23.9							High
10	8	2004	14	10	14.0	0.00	14.93	0.21	7.7	23.8	7.84	66	<10	16	34	2545	High
10	8	2004	14	30	16.0	2.90	13.84	0.20	7.6	27.2							High
10	8	2004	14	30	16.0	2.00	13.91	0.20	7.6	24.9							High
10	8	2004	14	30	16.0	1.00	14.22	0.20	7.5	24.2							High
10	8	2004	14	30	16.0	0.00	14.27	0.20	7.4	25.7	8.22	68	<10	19	32	2455	High
10	8	2004	14	55	18.0	3.10	14.21	0.20	7.7	26.4							High
10	8	2004	14	55	18.0	2.00	14.01	0.20	7.5	25.7							High
10	8	2004	14	55	18.0	1.00	14.10	0.20	7.5	25.7							High
10	8	2004	14	55	18.0	0.50	14.21	0.20	7.5	25.6	7.75	73	<10	23	31	2545	High
11	8	2004	13	0	36.0	0.00	14.16	0.13	8.0	33.7	8.18	<10	<10	<10	24	2136	High

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	DO (mg/l)	NO3-N (µg/l)	NO2-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
11	8	2004	7	43	0.5	1.80	12.67	11.82	7.9	21.9							Low
11	8	2004	7	43	0.5	1.00	12.60	11.71	7.9	21.3							Low
11	8	2004	7	43	0.5	0.00	12.63	11.25	7.9	20.9							Low
11	8	2004	8	0	1.5	3.10	12.60	34.85	8.0	31.2							Low
11	8	2004	8	0	1.5	2.00	12.63	34.62	8.0	30.9							Low
11	8	2004	8	0	1.5	1.50	12.71	33.90	8.0	31.7							Low
11	8	2004	8	0	1.5	1.25	12.95	28.33	7.9	35.4							Low
11	8	2004	8	0	1.5	1.00	12.97	26.37	7.9	36.7							Low
11	8	2004	8	0	1.5	0.75	12.77	17.86	7.9	40.6							Low
11	8	2004	8	0	1.5	0.50	12.75	10.60	8.0	40.9							Low
11	8	2004	8	0	1.5	0.00	12.72	10.50	7.9	20.6							Low
11	8	2004	8	5	3.0	1.40	13.12	31.00	7.8	25.0							Low
11	8	2004	8	5	3.0	1.25	13.26	26.88	7.9	21.0							Low
11	8	2004	8	5	3.0	1.00	13.27	15.19	8.0	18.5							Low
11	8	2004	8	5	3.0	0.50	13.13	12.13	8.0	22.3							Low
11	8	2004	8	5	3.0	0.00	13.13	12.10	7.9	23.2							Low
11	8	2004	8	15	4.0	1.22	13.34	30.28	7.8	18.5							Low
11	8	2004	8	15	4.0	1.00	13.37	13.35	8.0	18.8							Low
11	8	2004	8	15	4.0	0.50	13.26	9.25	7.9	20.7							Low
11	8	2004	8	15	4.0	0.00	12.86	9.12	7.8	22.1							Low
11	8	2004	8	30	5.0	1.80	13.29	30.40	7.7	23.9							Low
11	8	2004	8	30	5.0	1.50	13.33	29.95	7.8	23.9							Low
11	8	2004	8	30	5.0	1.10	13.42	20.57	7.9	26.7							Low
11	8	2004	8	30	5.0	0.75	13.35	10.84	8.0	30.0							Low
11	8	2004	8	30	5.0	0.50	13.23	4.32	8.1	32.1							Low
11	8	2004	8	30	5.0	0.00	13.17	2.82	8.0	33.0							Low

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	DO (mg/l)	NO3-N (µg/l)	NO2-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
11	8	2004	8	40	6.5	6.80	13.11	31.75	7.7	19.6							Low
11	8	2004	8	40	6.5	6.00	13.11	31.73	7.7	36.2							Low
11	8	2004	8	40	6.5	5.00	13.11	31.66	7.8	36.8							Low
11	8	2004	8	40	6.5	4.00	13.12	31.50	7.8	18.2							Low
11	8	2004	8	40	6.5	3.00	13.18	31.21	7.8	14.1							Low
11	8	2004	8	40	6.5	2.50	13.25	30.16	7.8	14.6							Low
11	8	2004	8	40	6.5	2.00	13.25	19.41	8.0	18.2							Low
11	8	2004	8	40	6.5	1.75	13.16	7.42	7.4	23.8							Low
11	8	2004	8	40	6.5	1.50	13.15	2.34	8.0	23.3							Low
11	8	2004	8	40	6.5	1.00	13.24	2.38	7.6	24.3							Low
11	8	2004	8	40	6.5	0.50	13.17	2.30	7.5	26.2							Low
11	8	2004	8	40	6.5	0.00	13.18	2.24	7.5	26.1							Low
11	8	2004	9	5	8.0	1.53	13.65	22.03	7.2	23.1							Low
11	8	2004	9	5	8.0	1.50	13.91	13.69	7.6	17.6							Low
11	8	2004	9	5	8.0	1.25	13.82	7.75	7.7								Low
11	8	2004	9	5	8.0	1.00	13.52	3.38	7.8								Low
11	8	2004	9	5	8.0	0.50	13.51	1.84	7.8								Low
11	8	2004	9	15	8.0	0.00	13.52	1.77	7.8	22.5							Low
11	8	2004	9	15	10.0	3.90	13.44	27.42	7.4	19.3							Low
11	8	2004	9	15	10.0	3.00	13.32	27.03	7.6	16.1							Low
11	8	2004	9	15	10.0	2.50	13.46	26.00	7.6	13.4							Low
11	8	2004	9	15	10.0	2.00	13.58	22.67	7.1	13.3							Low
11	8	2004	9	15	10.0	1.75	13.65	21.01	7.7	13.4							Low
11	8	2004	9	15	10.0	1.50	13.64	5.12	8.1	19.6							Low
11	8	2004	9	15	10.0	1.25	13.58	1.68	8.1	22.6							Low
11	8	2004	9	15	10.0	1.00	13.57	1.37	8.0	23.3							Low
11	8	2004	9	15	10.0	0.50	13.57	1.30	7.9	23.6							Low
11	8	2004	9	15	10.0	0.00	13.57	1.22	7.8	23.6							Low

Day	Month	Year	Hour	Min	Distance (km)	Depth (m)	Temp °C	Sal (ppt)	pH	Turbidity (NTU)	DO (mg/l)	NO3-N (µg/l)	NO2-N (µg/l)	NH4-N (µg/l)	PO4-P (µg/l)	SiO4-Si (µg/l)	Tide
11	8	2004	9	30	12.0	3.30	13.47	25.84	7.5	16.6							Low
11	8	2004	9	30	12.0	2.50	13.47	25.76	7.6	16.2							Low
11	8	2004	9	30	12.0	2.00	13.47	24.98	7.6	12.7							Low
11	8	2004	9	30	12.0	1.75	13.59	1.22	8.4	22.0							Low
11	8	2004	9	30	12.0	1.50	13.48	1.04	8.1	23.8							Low
11	8	2004	9	30	12.0	1.00	13.49	1.02	8.0	24.1							Low
11	8	2004	9	30	12.0	0.50	13.50	1.00	7.9	23.9							Low
11	8	2004	9	30	12.0	0.00	13.51	0.99	7.8	23.8							Low
11	8	2004	10	1	14.0	3.60	13.71	16.56	7.1	21.5							Low
11	8	2004	10	1	14.0	3.00	13.73	16.00	7.3	15.2							Low
11	8	2004	10	1	14.0	2.75	13.69	15.30	7.3	14.5							Low
11	8	2004	10	1	14.0	2.50	13.69	1.03	7.9	23.6							Low
11	8	2004	10	1	14.0	2.00	13.38	0.64	7.9	24.1							Low
11	8	2004	10	1	14.0	1.50	13.39	0.33	7.8	23.9							Low
11	8	2004	10	1	14.0	1.00	13.38	0.31	7.7	23.7							Low
11	8	2004	10	1	14.0	0.50	13.39	0.31	7.7	24.8							Low
11	8	2004	10	1	14.0	0.00	13.40	0.31	7.6	24.4							Low
11	8	2004	10	10	16.0	1.90	13.38	0.21	7.9	26.2							Low
11	8	2004	10	10	16.0	1.50	13.38	0.21	7.8	25.0							Low
11	8	2004	10	10	16.0	1.00	13.38	0.21	7.7	25.3							Low
11	8	2004	10	10	16.0	0.50	13.40	0.21	7.7	25.0							Low
11	8	2004	10	19	18.0	2.70	13.32	0.21	7.8	25.7							Low
11	8	2004	10	19	18.0	2.00	13.33	0.21	7.7	25.6							Low
11	8	2004	10	19	18.0	1.00	13.33	0.21	7.7	25.4							Low
11	8	2004	10	19	18.0	0.00	13.34	0.21	7.6	26.3							Low

ANNEXURE 2

NUMERICAL MODELLING OF THE SALINITY DISTRIBUTION IN THE OLIFANTS ESTUARY

LIST OF SYMBOLS

Q	=	discharge (m^3/s)
h	=	stage above datum (m)
C	=	Chezy coefficient
R	=	hydraulic radius (m)
α	=	momentum distribution coefficient
C	=	concentration (arbitrary units)
D	=	dispersion coefficients (m^2/s)
A	=	cross-sectional area (m^2)
x	=	space coordinate (m)
t	=	time coordinate (s)
v	=	the mean velocity in the cross-section (m/s)
MSL	=	mean sea level

1. GENERAL

A major result of development (e.g. impoundments and direct abstraction) in the catchment of a permanently open estuary is that a reduction in low baseflow and increase in the duration of the low flow periods could result in increased salinities upstream in the estuary.

A mathematical model utilizing the Mike 11 modelling system was therefore applied to the estuary to simulate the effects of low flow conditions on the salinities.

The Mike 11 modelling system, which was developed in the 1970's at the Danish Hydraulics Institute and is regularly upgraded, has been applied worldwide in various investigations. It is an advanced and user-friendly one-dimensional dynamic modelling system for rivers and estuaries. The hydrodynamic module is the basic module in Mike 11; additional modules can be used for simulations of transport dispersion, water quality and sediment transport among others.

The hydrodynamic and transport-dispersion modules were used in the investigations described in this report.

2. BACKGROUND

2.1 Hydrodynamic module

The hydrodynamic module is based on the solution of the Saint Venant equations of continuity and momentum for one-dimensional flow by implicit finite difference techniques. These equations are:

The continuity equation:

$$\delta Q / \delta x + \delta A / \delta t = q \quad (1)$$

The momentum equation:

$$\delta((\alpha Q^2)/A) / \delta x + \delta Q / \delta t + gA(\delta h / \delta x) + (gQ |Q|) / C^2 AR = 0 \quad (2)$$

Such a model is usually driven by the tidal variation of water levels at the downstream open boundary at the mouth and by the river flow at the upstream open boundary condition. The calibration of the hydrodynamic model is done by adjusting the bottom roughness until a satisfactory agreement is reached between simulated and measured water level variations.

2.2 Transport dispersion module

The transport dispersion module can be used to simulate, among others, the effects of the intrusion of seawater on salinities in an estuary, based on tidal flows at the mouth and the inflow of freshwater upstream. The transport dispersion formula used in the Mike 11 modelling system is:

$$\delta(AC) / \delta t + \delta(QC) / \delta x - \delta(AD(\delta C / \delta x)) / \delta x = -AKC + C_2q \quad (3)$$

The transport dispersion module is operated separately in Mike 11, using the same topographical information as the hydrodynamic model. The results of the latter are stored in data files and are used as input to the transport dispersion module.

The open boundary conditions on both sides are time series of concentrations associated with the hydrodynamic boundaries, i.e. the concentrations of sea salinity at the mouth and normally zero salinities of the river flow upstream.

The transport dispersion model is usually calibrated by adjusting the dispersion coefficients until a satisfactory agreement is reached between the computed and measured salinity concentrations.

2.3 Computer requirements for Mike 11 applications

The Mike 11 system can be operated on a microcomputer or a mainframe version. The numerical model of the Olifants Estuary was set up on the Unix version of the Mike 11 modelling system at the CSIR in Stellenbosch (CSIR 1997). As accurate inflow data to the estuary could not be provided for this study, the existing calibrated model was used to simulate the result of changes in runoff on the estuary.

3. MODEL SET UP AND CALIBRATION

3.1 Topographical data

Topographical data collected on another project undertaken by the CSIR for the department of Environment Affairs and Tourism was used for the model of the Olifants Estuary. These data consisted of cross-sections surveyed in 1994 and are summarised in Table 1 (CSIR, 2000). Water level recordings and salinity data collected in 1990 and 1994 were used for calibration.

These data show that the estuary is up to 545 metres wide near the mouth and gradually becomes narrower further upstream with a width of 19 metres just below the low water bridge at Lutzville. The depths are mostly between 2 and 3 metres below mean sea level (MSL). A maximum depth of - 6.6 m MSL is observed at 18.5 km from the mouth.

3.2 Tidal variations

Water level recordings were collected at several positions in the estuary by visual observation from temporarily installed gauging poles. The positions where these recordings were undertaken are shown on Figure 4.1 (refer to Appendix C). These recordings were undertaken during a neap tidal cycle on 22 January 1994 (Figure 1a) and during a spring tidal cycle on 28 January 1994 (Figure 1b).

The neap tide recordings of 22 January 1994 were mainly used to estimate the required corrections for the level differences between the positions along the estuary. It can be observed that the vertical water level variations of approximately 0.3 m are very similar for all four positions. The predicted tidal variation for Saldanha Bay was 0.49 m for this day. The predicted tidal variation for the spring tide on 28 January 1994 for Saldanha Bay was 1.54 m. The observed tidal variation just inside the mouth of the Olifants River was 1.28 m. It was gradually reduced further upstream to 0.94 m just upstream of the low water bridge at Lutzville.

The phase lags are interesting aspects of tidal movements in an estuary and those observed at high and low tide on 28 January 1994 are listed in Table 2 - this Annexure.

Table 1: Maximum depths and widths at MSL in the Olifants Estuary

Cross-section No.	Chainage (km)	Depth (m) - MSL	Width (m) - MSL
1	0.0	3.6	108
2	1.0	2.6	545
3	1.7	3.6	440
4	3.0	1.6	222
5	4.0	1.8	240
6	5.0	2.2	196
7	5.5	2.7	235
8	6.0	2.2	139
9	6.5	5.0	178
10	7.0	2.6	237
11	8.0	2.1	134
12	9.0	3.1	102

Cross-section No.	Chainage (km)	Depth (m) - MSL	Width (m) - MSL
13	10.0	4.3	68
14	11.0	4.1	66
15	12.0	3.3	73
16	12.8	2.8	93
17	13.5	3.1	80
18	14.5	3.9	68
19	15.5	3.0	74
20	16.5	3.1	60
21	17.5	3.6	58
22	18.5	6.6	47
23	19.0	2.3	77
24	19.5	2.2	63
25	20.0	3.0	63
26	21.0	2.9	51
27	22.0	2.5	48
28	23.0	2.5	47
29	24.0	2.3	81
30	25.0	2.4	36
31	26.0	4.2	46
32	27.0	1.9	47
33	28.0	2.4	36
34	29.0	1.7	33
35	30.0	1.3	33
36	31.0	1.9	34
37	32.0	2.0	32
38	33.0	2.3	29
39	34.0	2.4	28
40	35.0	2.2	19
41	35.9	0.9	22

Table 2: Observed phase lags for high and low tide on 28 January 1994

Saldanha Bay Predicted high tide: 16:03			Saldanha Bay Predicted low tide: 09:55		
Station	Time	Phase lag	Station	Time	Phase lag
1 (Mouth)	11:10	1:05	1 (Mouth)	16:45	0:42
2	11:30	1:35	2	16:50	0:47
3	12:45	2:50	3	17:45	1:42
4	14:00	4:05	4	18:50	2:47
5	15:00	5:05	5	19:00	2:57

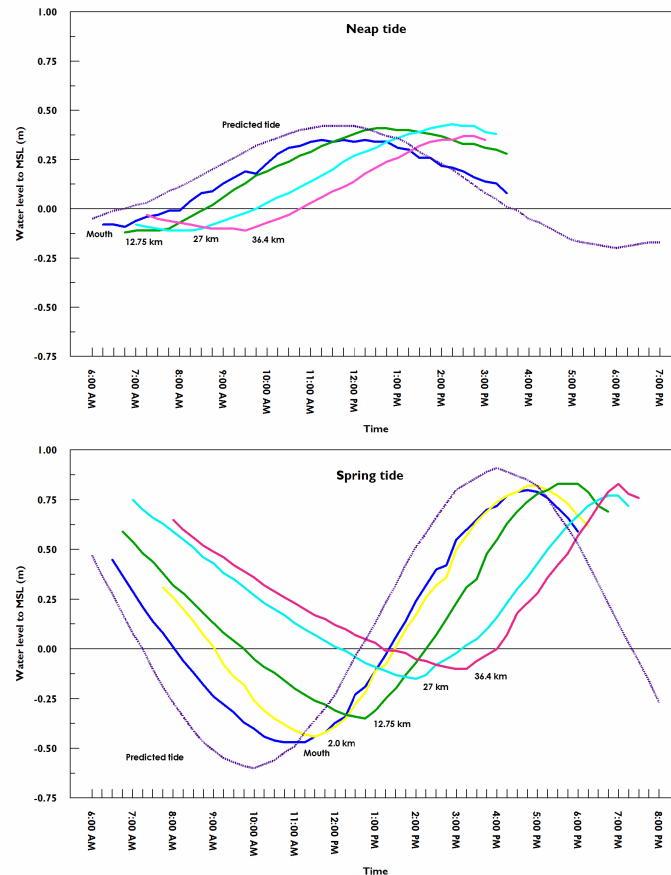


Figure 1: Water level recordings at neap tide (Figure 1a) and at spring tide (Figure 1b)

The model was calibrated for water levels using the field data collected on 22 and 28 January 1994. The comparisons are shown in Figures 1a and 1b. Overall an acceptable agreement between measured and simulated water level variations was obtained (See CSIR 1997).

3.3 Salinity distribution

To calibrate the model for salinity distribution in the estuary a relatively constant flow over the period that the data were collected is required. Such data were not available and an accurate calibration using the salinity data was therefore not possible. However, based on expertise obtained at previous model applications, assumptions could be made on the dispersion coefficient in the estuary. It is considered that salinity simulations can be undertaken with the model with a reasonable degree of accuracy (CSIR 1997).

Supporting these assumptions are a number of measured longitudinal salinity distribution profiles measured over a number of years (1990, 1991, 2004) (see main report for detail). The measured longitudinal salinity profiles showed that the system has some resilience in the salinity penetration in the inflow range between 1 – 2 m³/s (calibration flow range), i.e. the salinity profile does not move upstream significantly if flows are in this flow range for a few months.

3.4 Evaporation

Information on average evaporation, obtained from the Department of Agriculture of the University of Stellenbosch based on data collected at Lutzville, are summarised in Table 3. These data show maximum evaporation of 10.1 mm/day in December and 10.2 mm/day in January and a minimum evaporation of 3.4 mm/day in July.

Table 3: Evaporation rates in the Olifants Estuary

Month	mm/day	m ³ /s
Jan	10.2	0.4920
Feb	9.5	0.4583
Mar	8.0	0.3859
Apr	5.8	0.2798
May	4.3	0.2074
Jun	3.6	0.1737
Jul	3.4	0.1640
Aug	4.2	0.2026
Sep	5.5	0.2653
Oct	7.3	0.3521
Nov	9.3	0.4486
Dec	10.1	0.4872

3.5 Volume

To give an indication of the available water column habitat along the length of the estuary, the volume of water was calculated for every 5 kilometres for spring and neap tides (at high and low water conditions) during the low flow period (see Table 4). The maximum and minimum volumes achieved during the modelling sequence are also summarised. Figure 2 provides a graphic illustration of the accumulative volumes for spring and neap tides (low and high water conditions). The spring tidal prism is about $4.2 \times 10^6 \text{ m}^3$, with the volumes at spring high and low tide being about $8.9 \times 10^6 \text{ m}^3$ and $4.7 \times 10^6 \text{ m}^3$ respectively. This is nearly 50% more than the neap tidal prism of about $2.1 \times 10^6 \text{ m}^3$, with volumes at neap high and low tide being $7.4 \times 10^6 \text{ m}^3$ and $5.3 \times 10^6 \text{ m}^3$ respectively.

What is also clear from these calculations is that more 50% of the estuary's water column habitat occurs in the lower 10 kilometres, and between 65 and 76% in the lower 15 kilometres of the system. About 90% of the water column habitat is in the lower 25 kilometres of the estuary. Therefore, changes in the salinity distribution in the lower reaches of the estuary will have significant consequences for the estuarine biota dependent on water column habitat, e.g. microalgae biomass and fish distribution.

Table 4: Estimated volumes (m³) for 5 km reaches of the Olifants Estuary

Chainage (km)	Volume at Spring tide (m ³)			Volume at Neap tide (m ³)			Maximum	Minimum
	High tide	Low tide	Average	High tide	Low tide	Average		
5.00	3 589 057	1 393 930	2 491 494	2 892 703	1 804 623	2 348 663	3 862 359	1 276 464
10.00	1 765 801	868 384	1 317 092	1 419 942	947 919	1 183 931	1 891 573	767 971
15.00	1 121 132	758 370	939 751	973 115	780 803	876 959	1 178 303	677 819
20.00	841 589	600 856	721 222	737 170	607 416	672 293	904 913	514 711
25.00	600 803	465 389	533 096	537 541	460 931	499 236	690 876	372 018
30.00	412 099	352 485	382 292	382 483	345 861	364 172	504 392	276 548
35.00	245 665	228 473	237 069	234 949	221 394	228 171	350 153	168 283
36.40	34 121	31 820	32 970	32 548	30 564	31 556	51 118	21 049
Side channel	258 060	45 855	151 957	169 912	54 454	112 183	297 558	31 485
Total	8 868 327	4 745 562	6 806 945	7 380 364	5 253 966	6 317 165	9 731 243	4 106 348

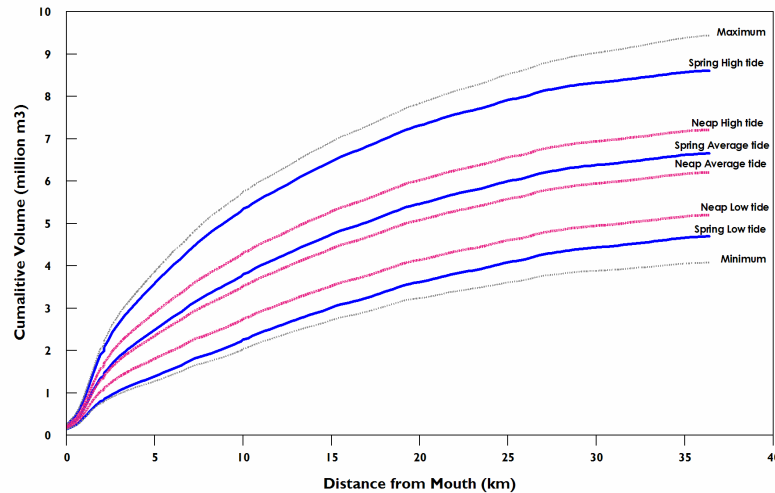


Figure 2: Graphic summary of the accumulative volume in the Olifants Estuary for spring and neap tides (high and low tides) and the maximum and minimum volumes

3.6 Run-off

The run-off of the Olifants River varies significantly seasonally. High flows and major floods occur during the winter months and low flows during summer. At present, return flow in the form of irrigation seepage contributes substantially to summer baseflows and ensure that some river flow is even observed at the end of summer at the Lutzville low-water bridge. Unfortunately, direct abstraction from below the Bulshoek dam has reduced the baseflows significantly reaching the estuary in the last few years.

Monthly simulated runoff data (73-year period) for the Olifants Estuary, under the Present State indicated that the present mean annual runoff (MAR) is 715 Million m³ in comparison with 1070.1 Million m³ under the Reference Conditions. This represents a 33.2% reduction from the natural flow conditions. A summary of the MAR and the percentage reduction is provided in Table 9.1 (Appendix C).

4. MODEL RESULTS OF SALINITY DISTRIBUTIONS UNDER DIFFERENT FLOW CONDITIONS

4.1 Salinity distribution

Changes, especially increases in salinity concentrations, in the estuary relates to reductions in river flow. This is notably the case for low flow (baseflow) conditions. The effects of several low flow conditions on the salinity distributions were simulated for the Olifants estuary (also see CSIR 1997).

Low flow conditions occur mainly during the summer months. This is also the period when the evaporation rates are highest and this can affect the salinity distributions. The evaporation rates (Table 3) were therefore included in the model simulations.

The duration of low period was shorter under reference conditions and lasted approximately three months from January till March. Under the present conditions the low flow period is for approximately seven months. The low flow period varies between four to ten months for the simulated future scenarios. The base flows in summer range between 0.6 and 4.5 m³/s for the various simulated scenarios.

Model simulations were therefore undertaken for flows of ranging between 0.5 and 50 m³/s for a period up to 6 months to develop an understanding of the Olifants estuary's salinity distribution in relation to river inflow.

The results show that the estuary remains fresh high upstream and a so-called full salinity gradient exists for all these run-off conditions, but the extent of saline intrusion depends strongly on the baseflow. This intrusion increases considerably at lower river flows.

The results show that the estuary remains fresh higher than 25 km upstream at a flow of 1 m³/s and 18 km upstream at a flow of 2 m³/s. The increase in river flow from 1 m³/s to 2 m³/s results in a reduction of saline intrusion by approximately 3 to 5 km. The results compare well with the salinity concentrations recorded in the estuary in 1990, 1991 and 2004 while the river flow was about 1 - 2 m³/s. At flows of about 2 m³/s the longitudinal salinity profiles are stabilised and hardly any difference is observed between the results of December to April. Some small increase in salinity penetration were noted for 6 month simulation of 1 m³/s.

The results for a flow of 0.5 m³/s shows a significant increase in salinity intrusion in a very short period (~ month) than has been measured in the estuary to date. Further reduction in baseflow under future conditions can therefore result in a considerable increase in salinities upstream in the estuary.

In addition, model simulation indicate that evaporation has little accumulative effect on the salinity distributions under these flows. This result is also support by the fact that no hyper-salinity values were recorded for the system in available historical data.

Table 5: Summary of salinity penetration for various flow ranges based on modelling results

Flow range (m ³ /s)	Distance from mouth (km)							
	High tide				Low tide			
	<30ppt	<20ppt	<10ppt	<0.5 ppt	<30ppt	<20ppt	<10ppt	<0.5 ppt
50	2.5	3.3	4	5.8	-	-	0 (1.4 ppt)	2.0
30	3.2	4.2	4.9	6.8	-	-	0 (5.7 ppt)	2.2
20	3.5	4.6	5.4	7.3	-	0 (11.7ppt)	0.25	2.3
10	4.1	5.2	6.2	8.4	0 (22.7ppt)	0.25	1.6	3.8
5	4.7	5.9	7.2	9.9	0 (28.9ppt)	1.6	2.6	6.5
2	5.8	7.5 – 9.2	9.2 -11.1	14.8 – 17.5	1.0	3	5.4	12.5
1	8	8.7- 11	10.4 - 14.2	16.0 - 23.3	1.0	3.2	7	18.4
0.5	8.8-10.4	14.1 – 15.3	19.1 – 21.0	31.0- 32.0	2.6	7.8	14.1	28.12

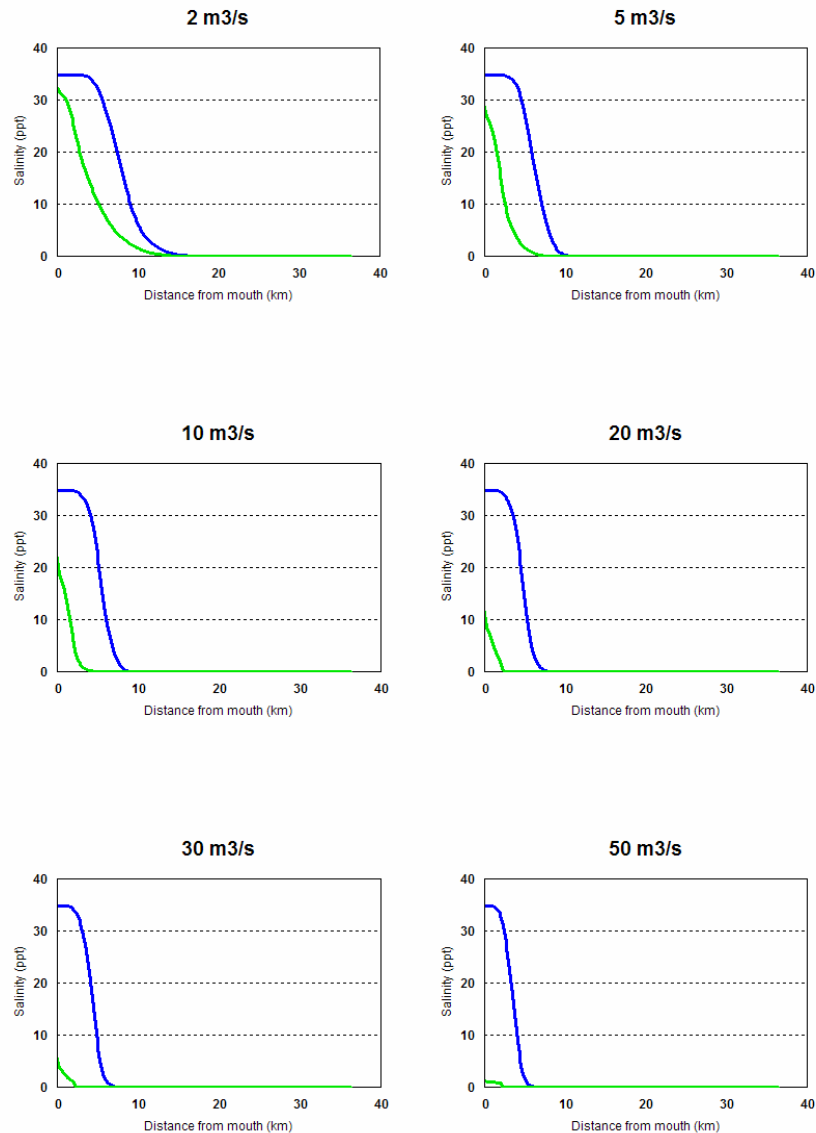


Figure 3: Illustrating some of the numerical modelling results for a 3 month period (high tide – blue, low tide – green)

In summary:

- At river inflow of more than of 20 m³/s limited saline intrusion occurs in the lower reaches of the Olifants Estuary, i.e. saline penetration is ~ 7.0 km or less on the high tide and negligible on the low tide.
- At a flow of less than 20 m³/s saline intrusion on the low tide becomes more persistent
- At flows of less than 5 m³/s there is a significant salinity intrusion into the lower reaches of the estuary.

- At flows of about 2 m³/s the salinity profile is still reasonable stable, with only limited additional intrusion if the simulation period is extended from 2 months to 6 months, i.e. ~2 – 3 km.
- At flows of about 1 m³/s the salinity profile becomes very sensitive to the duration of the simulations and extending the period of the simulation from 2 to 6 months, increases the extent of salinity penetration by 4 km (10ppt) and 7 km (0.5 ppt).
- At flows of 0.5 m³/s salinities rapidly increases to 32 km upstream of the mouth.

4.2 Abiotic States

Based on measured salinity distributions (see main report for detail) and modelling results the following typical river inflow ranges versus salinity distribution was observed (Table 6).

Table 6: Abiotic states for the Olifants Estuary

State	Name	Flow range (m ³ /s)
1	Marine dominated	<2.0
2	Gradient in lower estuary	02.0-5.0
3	Gradient in middle estuary	5.0-20.0
4	Freshwater dominated	>20.0

Based on the identified abiotic states for the Olifants Estuary (Table 6), the following states were highlighted for the various simulated monthly flow scenarios in Table 7 (see main report for more detail).

Table 7: Summary of the typical abiotic states for the various simulated flow scenarios based on the median monthly flow conditions

Scenario	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Reference	17.21	9.06	4.36	2.27	2.41	2.76	5.51	19.34	57.95	63.32	50.62	34.87
Present	6.49	0.76	0.74	0.75	0.70	0.57	0.51	2.19	21.22	40.66	43.61	24.82
2	10.11	2.93	1.50	1.51	1.34	1.42	2.84	6.19	37.99	51.82	47.54	22.18
7	9.33	3.29	1.90	1.91	1.71	1.77	2.86	5.48	38.23	51.94	47.57	16.21
5	4.36	1.42	1.52	1.53	1.41	1.32	1.23	2.33	14.39	22.60	27.35	13.96
17	1.75	1.87	1.52	1.53	1.41	1.32	1.15	0.78	12.54	20.11	21.10	10.19
10	1.24	1.36	1.52	1.53	1.41	1.32	1.15	0.67	2.20	4.53	13.11	6.36

4.3 Volume and area for the various Abiotic States

Modelling results were used to calculate the volume (m³) and area (m²) for the different states (see Table 8). This was done to assist the various biotic components in calculating the changes in relevant estuarine habitat for the various flow scenarios under evaluation (see Table 9).

As was indicated before about three quarters of the estuarine habitat is in the lower 15 kilometres of the system. Therefore, the changes in the salinity distribution predicted between the various simulated flow scenarios (see Table 9) will have significant consequences for the estuarine biota, e.g. microalgae biomass and fish distribution.

For example, at present only about 40% of the freshwater area (0ppt) remains in comparison with the Reference conditions. By comparison, the marine area (>30 ppt) has increase by nearly 80%.

Table 8: Estimates of the Olifants estuary's volume (m³) and area (m²) based on model simulations for the various abiotic states

Flow conditions		Average low flow conditions (~4 months)			**Extended low flow periods (> 4 months)		
State 1	Salinity Zone	Penetration (km from mouth)	Volume (m ³)	Area (m ²)	Penetration (km from mouth)	Volume (m ³)	Area (m ²)
	30 ppt	7	2 921 000	2 454 331.00	10	3 612 200	2 842 831.00
	20 ppt	10	691 100	388 500.00	15	908 400	372 374.90
	10 ppt	13	562 800	221 218.50	20	696 800	312 250.00
	5 ppt	15	345 500	151 156.40	23	306 900	154 000.00
	0.5 ppt	20	696 800	277 000.00	32	667 400	385 500.00

State 2	30 ppt	5.8	2 290 600	2 271 331.00
	20 ppt	7	630 500	183 000.00
	10 ppt	9	446 500	303 500.00
	5 ppt	13	807 500	306 218.50
	0.5 ppt	16	488 700	222 656.40

State 3	30 ppt	4	2 083 800	1 324 475.00
	20 ppt	5.25	349 400	154 937.50
	10 ppt	6	215 300	677 418.50
	5 ppt	6.8	195 400	183 000.00
	0.5 ppt	9	523 500	303 500.00

State 4	Lower Flow ranges				*Higher flow range		
	30 ppt	3.5	1 995 000	1 206 725.00	-	-	
	20 ppt	4.5	284 300	232 250.00	-	-	
	10 ppt	5.4	283 600	211 250.00	-	-	
	5 ppt	6	144 300	621 106.00	0.25	268 300	81625
	0.5 ppt	7.3	337 600	183 000.00	2.2	1 119 000	565000

Table 9: Average area for various salinity zones under the different simulated runoff scenarios

Scenario	Average Area	Total Area	Fresh zone
*Reference		2 192 221	1 975 685
30 ppt	1 198 602		
20 ppt	112 646		
10 ppt	326 973		
5 ppt	190 281		
0.5 ppt	363 719		
**Present		3 345 758	822 148
30 ppt	2 123 308		
20 ppt	291 766		
10 ppt	308 285		
5 ppt	324 804		
0.5 ppt	297 596		
Scenario 2		2 970 518	1 197 388
30 ppt	1 819 653		
20 ppt	263 240		
10 ppt	307 643		
5 ppt	338 957		
0.5 ppt	241 026		
Scenario 7		2 986 268	1 181 638
30 ppt	1 829 466		
20 ppt	256 797		
10 ppt	346 490		
5 ppt	302 448		
0.5 ppt	251 068		
Scenario 5		3 143 498	1 024 408
30 ppt	2 027 587		
20 ppt	289 281		
10 ppt	309 304		
5 ppt	260 632		
0.5 ppt	256 693		
**Scenario 17		3 560 914	606 992
30 ppt	2 317 087		
20 ppt	312 781		
10 ppt	356 278		
5 ppt	236 684		
0.5 ppt	338 083		
**Scenario 10		3 699 643	468 263
30 ppt	2 494 522		
20 ppt	304 573		
10 ppt	371 653		
5 ppt	184 203		
0.5 ppt	344 693		

**State 4 volumes and areas are based on the higher flow ranges experienced under Reference Conditions.*

***State 1 volumes and areas are based on the extended low flow period distribution*

5. RECOMMENDATIONS

The overall confidence in the modeling results are low due to the low confidence in the river inflow data. It is crucial that accurate river inflow data be collected at a site above the Lutzville low water bridge. This data can then be used to scale the historical river inflow data from the Olifants and Doring catchments respectively to provide a more accurate long-term record of what has reached the estuary. This data set can also be correlated with historical measure longitudinal salinity distribution in the system.

In addition, topographical (cross section) data and water level recordings along the length of the estuary are nearly ten years old. It is therefore strongly recommend that this exercise be repeated in the near future to provide a more accurate picture of the hydrodynamics of the system.

The Mike 11 1-Dimensional modelling package was used in this investigation as the focus of the study was the increase in salinity penetration due to reduction in baseflows during the summer. If more detail should be required by biotic components on the transitional seasons (autumn and spring) a more detailed investigation would be needed on stratification in the estuary. This would require 3-Dimensional modelling to improve the confidence in the results.

ACKNOWLEDGEMENTS

The cross-sections of the Olifants Estuary used for the set-up of the model were surveyed as part of a monitoring programme undertaken by the CSIR for the Department of Environment Affairs and Tourism.

The hydrological simulation data used in this report were provided by Mr A Sparks, Ninham Shand Consulting Engineers.

The Water level recorders at the mouth of the Olifant Estuary and the Lutzville bridge were installed by the Hydro section, DWAF, Bellville office, Mr Mouski and are regularly serviced by Mr L de Wet and Mr C Botma. We thank them for their generous effort in collating the data.

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APPENDIX D

SPECIALIST REPORT: MICROALGAE

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INTRODUCTION

Field trips as part of this study were undertaken in March and August 2004. Sampling also occurred on 21 June 2001 as part of a Water Research Commission research project. In this earlier study (Bate et al. 2004), 5 intertidal sites and 5 subtidal sites were sampled, as was the river. The site locations for that earlier study are shown in Table 1.

Table 1. Co-ordinates, salinity and number of diatom taxa found at intertidal and sub-tidal sites in the Olifants Estuary in 2001 (After Bate et al. 2004) (See Fig.1).

Site	Co-ordinates		Salinity	No. of
	Latitude	Longitude	(ppt)	Taxa
Subtidal	(S)	(E)		
1	31° 41' 30"	18° 11' 51"	25	25
2	31° 40' 02"	18° 11' 53"	20	10
3	31° 38' 38"	18° 11' 54"	14	10
4	31° 37' 50"	18° 11' 55"	9	11
5	31° 36' 44"	18° 12' 07"	1	16
Intertidal				
1	31° 41' 30"	18° 11' 51"	24	31
2	31° 40' 02"	18° 11' 53"	16	21
3	31° 38' 38"	18° 11' 54"	12	16
4	31° 37' 50"	18° 11' 55"	5	20
5	31° 36' 44"	18° 12' 07"	1	22

The implications of this earlier study are that the salinity gradient was typical of an estuary with a good freshwater input at the head, a consistent salinity gradient increasing to seawater at the mouth. The number of benthic diatom taxa was typical of a normally functioning estuary and the species identified showed nothing out of the normal.

MATERIALS AND METHODS

Collection sites



Figure 1. Sites 1-8 on the Olifants Estuary where samples were collected. The co-ordinates of the collection sites are shown in Table 1. Sites 8 and the “Blind Arm” are shown together as coloured squares because they are situated too close together for adequate resolution. (Map source: MS Encarta Interactive World Atlas 2001. Positions located using GPS co-ordinates obtained in the field).

Samples were collected from the sites shown in Figure 1 in March and August 2004 corresponding to summer (March) and winter (August).

Physico-chemical factors

Physical parameters (conductivity, salinity, dissolved oxygen content, total dissolved solids and pH) were measured using a YSI multiprobe. Measurements were taken every half a meter from the surface at each site. Water transparency was measured with a Secchi disc.

Water samples were collected at each site (500 ml) using a weighted pop-bottle. This water was filtered through Whatman (GF/C) filters and preserved using mercuric chloride before being frozen and transported to the laboratory in Port Elizabeth.

Microphytobenthic biomass

Microphytobenthic biomass was estimated using benthic chlorophyll *a* ($\mu\text{g chl-}a$ per gram of freeze dried sediment; expressed as $\mu\text{g g}^{-1}$). Four 1 cm deep intertidal and subtidal sediments cores were collected from each site, then frozen and kept in the dark before being freeze-dried in a Secfroid Lausanne Suisse freeze-drier. The process of freeze-drying eliminates the errors related to the water holding capacity of different sediment types and organic content. Once freeze-dried, 4 ml of ethanol (Merck 4111) was added to approximately 100 mg of sample and the pigment was left to extract in a refrigerator for 24 hours.

After extraction, the samples were well mixed using a whirl-mixer (WM/250/SC/P) and the extract injected into a high performance liquid chromatograph (HPLC) attached to Waters-Lambda-Max 481 LC spectrophotometer and Waters LM-45 solvent delivery system for chlorophyll-*a* analysis. A 30% methanol and 70% acetone mixture was used as the carrier. The system was calibrated using the chlorophyll *a* of red seaweed, (*Plocamium collorhiza*) because it contains no chlorophyll *b* that might interfere with the chlorophyll *a* reading at 665 nm. Chlorophyll *a* absorbance was measured at 665 nm and the chlorophyll *a* concentration determined from the absorbance reading using a modified equation of Nusch (1980):

$$\text{Chl-}a \text{ biomass } (\mu\text{g. g}^{-1}) = [((E_{Ploc665} - (E_{Ploc665}/1.7)) \times 29.6] \times (V/M) \times E_{HPLC}$$

Where: $E_{Ploc665}$ = *Plocamium collorhiza* chlorophyll *a* absorbance measured using the spectrophotometer at 665 nm (calibration formula in squared brackets)

29.6 = constant calculated from the maximum acid ratio (1.7) and the specific absorption coefficient of chlorophyll *a* in ethanol ($82 \text{ g. l}^{-1} \text{ cm}^{-1}$)

V = volume of ethanol used to extract pigment (ml)

M = mass of freeze-dried sample (g)

E_{HPLC} = HPLC absorbance value

Phytoplankton biomass

Water column samples were collected from the surface and bottom and then gravity filtered through plastic Millipore towers using Whatman (GF/C) glass fiber filters. The samples were collected using a 500ml weighted pop-bottle. Chlorophyll *a* was extracted by placing the filters into glass vials containing 10 ml of ethanol (Merck 4111). The samples were then stored overnight at 1 - 2 °C to extract. The contents of the vials were filtered and the light absorbance of the supernatant at 665 nm was determined within 24 hours, before and after the addition of 0.1N HCL, using a spectrophotometer. The equation used was that of Hilmer (1990), derived from Nusch (1980):

$$\text{Chlorophyll } a \text{ biomass } (\mu\text{g l}^{-1}) = (E_{b665} - E_{a665}) \times 29.6 \times (v/(V \times l))$$

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

E_{a665} = absorbance at 665 nm after acidification

v = volume of solvent used for the extraction (ml)

V = volume of the sample filtered (l)

L = path of spectrophotometer cuvette (cm)

29.6 = constant calculated from the maximum acid ratio (1.7) and the specific absorption coefficient of chlorophyll-a in ethanol ($82\text{g.l}^{-1} \cdot \text{cm}^{-1}$)

Determination of microalgal groups

Water samples for phytoplankton identification. (500 ml) were collected from each site and preserved with one drop of glutaraldehyde solution. Two drops of Rose Bengal were added to each of 60 ml of preserved water sample, which was poured into a 26.5 mm internal diameter Utermohl settling chamber. The cells were left to settle for 24 hours before being identified using a Zeiss IM 35 inverted microscope at the maximum magnification of x 630. A minimum of 200 cells were counted for each sample and the cells were classified according to different microalgal groups; i.e. flagellates, diatoms, dinoflagellates, cyanophytes (blue-green algae), chlorophytes (green algae).

The numbers of cells were calculated in 1 ml using the formula:

$$\text{Cells.ml}^{-1} = ((\pi r^2)/A) \times C/V$$

Where: A = area of each frame (mm²)

C = number of cells in each frame

V = volume of sample in settling chamber (ml).

Benthic diatom collection and processing

The methods employed in this project were the same as those reported for Water Research Commission project K5/814 but with some modifications. They are reproduced here for the sake of completeness. The epipelon (diatoms living on the surface sediment) was sampled as described by Round (1981).

The selection of sites from which the sediment samples were taken was determined depending upon the state of the tide. Sub-tidal samples were always taken below the low tide level. Where the banks are very steep, the sampling procedure is complicated because very deep samples in some estuaries may result in there being no diatoms because the light extinction point has been passed. This is especially true in very sediment-rich estuaries. In order to make the sampling procedure relatively similar in all estuaries, the sub-tidal samples were taken at about 2 m below the spring high tide mark. Intertidal samples were taken above the low tide mark, either with the tube sampler or by scraping the sediment surface if sampling was at minimum low water.

Samples were taken in using a length of tube that was drawn across the sediment and allowed to fill with a mixture of surface sediment and water. This was repeated up to five times in different positions in order to get a composite sample that is representative of the different micro-habitats. The mixture was stored in a plastic sample container (250 ml). In a field laboratory, a sample was placed in a petri dish. The sediment was allowed to settle. Most of the supernatant was drawn off and 5 clean and degreased cover slips (covering ca. 40% of the sediment surface) were placed on top of the wet sediment. On the same day (ca. 2 hours later) the cover slips were carefully removed with as little sediment as possible. In this way, only living cells that had attached to the cover slips were sampled. The technique largely

eliminates phytoplankton cells. The five cover slips from each sample were placed in glass bottles and transported to the laboratory. There is no time limit at this stage to process the diatoms further. To each glass bottle containing the cover slips, 2 ml of KMnO_4 (saturated) and 2 ml of HCl (10 M) was added. This mixture was heated on a hot plate at ca. 60°C until the solution went clear (~20-40 minutes). The digest was transferred with 2-3 washings to a centrifuge tube. All acid cleaned samples were washed with distilled water using 5 consecutive spins (2000 rpm for 10 minutes). After each centrifugation, the supernatant was drawn off leaving about 1 ml with the centrifuged pellet intact. The pellet was then mixed and the centrifuge tube filled with distilled water before being centrifuged again. This process is required to remove all salts that would otherwise interfere with the microscopic identification of the diatoms.

Permanent light microscopy slides were made with 1 drop of the diatom pellet 'digest', placed onto an acid-washed cover slip (stored in methanol before use) and allowed to dry in air. Cover slips treated and stored in this same manner allow the drop of sample to spread more evenly. When completely dry, a small amount of Naphrax^R mounting medium (Northern Biological Supplies, U.K.) was dotted onto a glass microscopy slide and the cover slip placed over it. Air trapped under the slide and the Naphrax was dispersed by heating the slide on a hot plate (approx. 60° C). The Naphrax was allowed to dry for 2-3 days on a warm plate. The slides were logged and stored in a slide library, to form a permanent record.

Diatom identification and enumeration

Diatom frustules were examined under a Zeiss Axioplan light microscope with Differential Interference Contrast (DIC) optics. Using a television camera (JVC KY-F3), images of the dominant species were visualised using the AnalySIS image analysis programme (©1999, Soft Imaging System GmbH). If these images did not provide enough detail for species identification, a sample was prepared for viewing in a Scanning Electron Microscope (SEM, Philips XL 30). The light and SE microscope images were catalogued according to river/estuary and genus. Information regarding habitat, site of origin, taxonomic name, authority and source of reference was saved with each image.

Diatom valves were counted in each sample using 1000x magnification until an obvious dominant was established. At least one of each taxon was made into a digital image. All the images were then printed onto paper and used in the counting procedure. This achieves two important aspects, (1) a digital image of each taxon and (2) a count of the total number of taxa. Other taxonomic works consulted included Archibald (1983), Hustedt (1976), Lange-Bertalot & Krammer (1989), Simonsen (1987) and various articles on the South African diatom collections of R.E.M. Archibald, B.J. Cholnoky and F.R. Schoeman (e.g. Cholnoky, 1960; Schoeman and Archibald, 1976).

RESULTS

Summer 2004 (March)

Physico-chemical data

The distribution of salinity at different depth for March 2004 is shown in Table 2.

Table 2. Salinity values of the water column at different depth and stations in March 2004

Station	Depth (m)					
	0	1	2	3	4	5
1	3.2	3.2	-	-	-	-
2	5.5	5.8	6.3	15.9	-	-
3	6.3	6.7	14.8	-	-	-
4	14.4	15.6	16.7	20.4	-	-
5	20.2	20.2	21.7	-	-	-
6	24.5	26.0	28.6	-	-	-
7	30.0	30.6	-	-	-	-
8	31.4	33.3	-	-	-	-
BA	32.3	33.3	34.9	35.1	-	-

The microalgal population in the water column is the result of species arriving from the freshwater flowing from land, the seawater, the mixture of the two, and those species that grow at the place in question. At any moment in time, therefore, it is difficult to interpret the ecological conditions that give rise to the dominance of any one algal community. Bearing in mind this difficulty, the following sequence of events has been observed in the past in South African estuaries:

A dominance of flagellates commonly occurs when the water column is made up of fresh water from the land. This dominance generally declines as the water body moves down towards the mouth. At some point in the estuary where the salinity is between 10-15 ppt, diatoms are commonly dominant. This point is referred to as the River Estuary Interface Region (REI) and phytoplankton biomass as measured by chlorophyll-a is maximal in this area.

If the freshwater flowing into the estuary is rich in macronutrients, especially nitrogen and phosphorus, the density of microalgal cells is high. However, if the level of macronutrients is very high there is the possibility that dinoflagellates may increase in number. If the inflowing water is especially eutrophic, there is a possibility that toxic dinoflagellates may develop into

a red tide. Red tides have been observed from the air in both the Sundays Estuary and the Gamtoos Estuary. It is unlikely that a bloom of dinoflagellates would be recognized from the side of an estuary or from a boat unless the cell density was very high.

Phytoplankton group counts

Table 3. Proportions of the different phytoplankton groups found in the Olifants Estuary water column in March 2004. The data are presented both with and without the flagellate counts because the latter make up such a large proportion of the cells counted.

Site no.	Flagellates	Diatoms	Dinoflagellates	B/Greens	Greens	Total
1	612	355	0	0	29	958
2	7013	228	4	7	85	7332
3	13412	28	391	1	11	13843
4	3900	11	216	0	1	4128
5	624	8	15	0	0	646
Total	25561	630	626	8	126	26907
% Inc Flagellates	95	2	2	0	0	26907
% Excluding Flagellates	-	47	47	1	9	1346

The data in Table 3 show that the flagellate numbers were overwhelmingly dominant. The data also indicate that there were high numbers of dinoflagellates in the Olifants Estuary in March 2004 and these were concentrated mainly in sites 3 and 4, whereas the diatoms were concentrated mainly at sites 1 and 2. The greatest number of flagellates was found with the dinoflagellates at sites 2, 3 and 4. Flagellates far out-numbered all the other groups. It is unfortunate that it is not possible to distinguish between flagellated phytoplankton groups in these counts. This type of ecological analysis does not appear to have previously reported on from South African estuaries.

The number of flagellates in estuary samples from near the head is often very much higher than the numbers of other cells. This is not the case in the March sampling. Diatom numbers are highest at site 1 (Figure 2) and decreased to site 5. Green algal numbers peaked at site 2 while flagellates and dinoflagellates peaked at site 3. Site 4 is where the depth-integrated salinity in March 2004 was 16.3 ppt (See Table 6). The interpretation is that this was the River-Estuary Interface Region or REI.

Diatom species

The species of diatoms found as dominants and sub-dominants in the estuary in March 2004 (Summer) are shown in Table 4. Knowing these species is useful because they are indicators of the salinity ranges that have occurred in the estuary in the recent past (Bate et al. 2004). Diatom species, as indicators of fresh water quality, can be determined by reference to the suite of "indicator species" found on the sediment. In South Africa, it is possible to utilise the data from the "Cholnoky Collection" to make these assessments (Harding et al. 2004). Unfortunately, a similar data set for estuaries is not yet available.

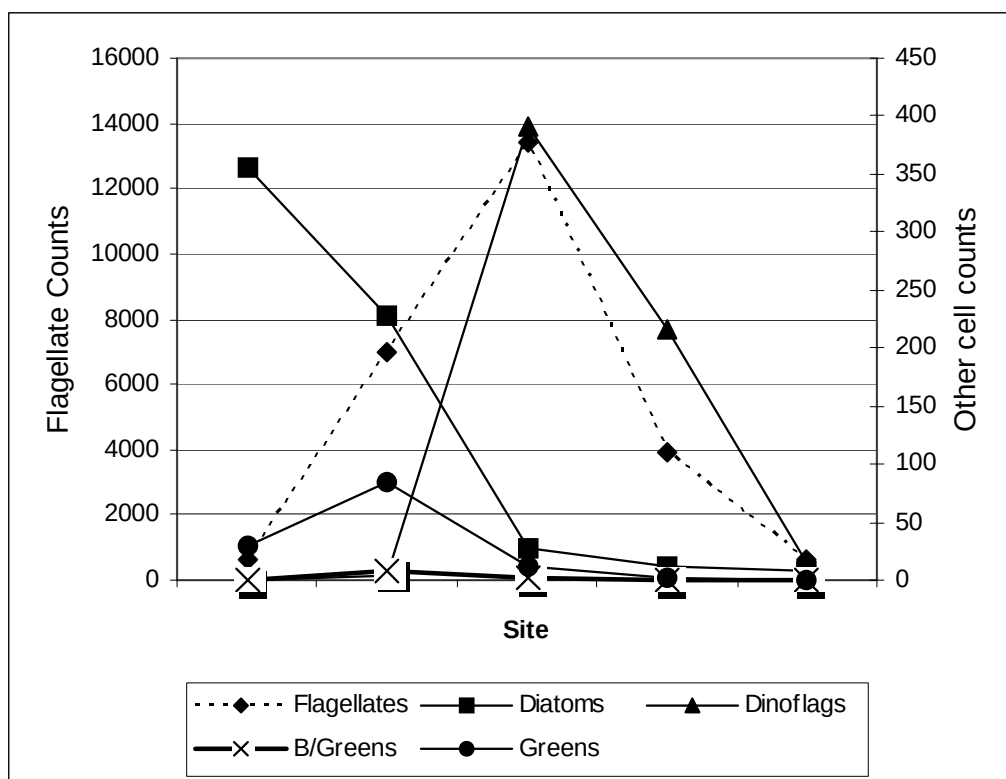


Figure 2. Numbers of micro-algal cells (including non-algae) within the microalgal groups found at the different sites in March 2004. Note that there are two axes in order to accommodate the very large flagellate numbers by comparison with the other microalgal types.

Table 4. Dominant and sub-dominant benthic diatom species in the Olifants Estuary in March 2004. Site 1 was at the head of the estuary in low salinity. Site 8 was near the mouth with a salinity value close to that of seawater. The dominance presented is calculated as the percentage of total cells counted.

Olifants Estuary March 2004					
Site	Salinity	Genus	Species	Dominance	Number
Intertidal	(ppt)			%	of taxa
1	3	<i>Navicula</i>	<i>phyllepta</i>	98	28
2	6	<i>Navicula</i>	<i>phyllepta</i>	85	
	6	<i>Amphora</i>	<i>coffeaformis</i>	10	16
3	14	<i>Nitzschia</i>	<i>frustulum</i>	53	
	14	<i>Achnanthes</i>	<i>engelbrechtii</i>	20	31
4	21	<i>Nitzschia</i>	<i>aff. perindistincta</i>	14	15
	21	<i>Navicula</i>	<i>gregaria</i>	10	
	21	<i>Amphora</i>	<i>coffeaformis</i>	10	
5	30	<i>Navicula</i>	<i>gregaria</i>	20	15
	30	<i>Navicula</i>	<i>salinicola</i>	19	
6	31	<i>Navicula</i>	<i>gregaria</i>	40	15
	31	<i>Surirella</i>	<i>atomus</i>	40	
7	33	<i>Amphora</i>	<i>caroliniana</i>	50	20
	33	<i>Amphora</i>	<i>sublaevis</i>		
8	35	<i>Navicula</i>	<i>gregaria</i>	30	18
	35	<i>Nitzschia</i>	<i>hustedtiana</i>	30	
	35	<i>Navicula</i>	<i>cf. arenaria v. rostellata</i>	11	
Subtidal					
1	3	<i>Navicula</i>	<i>phyllepta</i>	95	13
2	7	<i>Navicula</i>	<i>phyllepta</i>	80	14
3	16	<i>Achnanthes</i>	<i>engelbrechtii</i>	28	21
	16	<i>Amphora</i>	<i>coffeaformis</i>	23	
	16	<i>Navicula</i>	<i>gregaria</i>	15	
	16	<i>Nitzschia</i>	<i>frustulum</i>	13	
4	21	<i>Navicula</i>	<i>gregaria</i>	30	20
5	30	<i>Navicula</i>	<i>salinicola</i>	50	11
	30	<i>Nitzschia</i>	<i>frustulum</i>	20	
	30	<i>Amphora</i>	<i>coffeaformis</i>	12	
6	33	<i>Navicula</i>	<i>salinicola</i>	20	19
	33	<i>Navicula</i>	<i>gregaria</i>	14	
7	34	<i>Amphora</i>	<i>caroliniana</i>	90	15
8	35	<i>Navicula</i>	<i>gregaria</i>	37	8
	35	<i>Nitzschia</i>	<i>aff. perindistincta</i>	33	
	35	<i>Nitzschia</i>	<i>hustedtiana</i>	10	

Navicula phyllepta is a species that has been shown in previous studies (Bate et al. 2004) to be found at sites with freshwater or low salinity water. In those studies, it was found as a dominant in the Mzimkulu Estuary in KwaZulu-Natal in both the intertidal and sub-tidal sites 4 and 5. Lange-Bertalot (2000) considered the species indicative of brak to marine salinity, while Sims (1996) considered it indicative of freshwater.

Nitzschia frustulum has previously been identified from sediments taken in Durban Bay, the Keurbooms Estuary (Intertidal site 2) and the Kowie Estuary (Subtidal site 3) at salinity values of 29 and 38 ppt (Bate et al. 2004). Lange-Bertalot (2000) considered the species indicative of brak to marine salinity, while Sims (1996) considered it indicative of freshwater to brak conditions.

Achnanthes engelbrechtii was previously found as a dominant by Bate et al. (2004) in the Keurbooms Estuary at a salinity of 16 ppt.

Nitzschia aff. *perindistincta* has not been found before in the estuarine samples reported by Bate et al. (2004).

Navicula gregaria (Subtidal site 4, 21 ppt; Intertidal sites 5 & 6) is an interesting species because it was found often in the Olifants Estuary in 2002. It was also found as a dominant in the Breede Estuary, the Mngazi Estuary, Mtata Estuary, Sundays Estuary, Swartkops Estuary, Bushmans Estuary, Kowie Estuary, Mpekweni Estuary and Gouritz Estuary at a wide range of salinity values from 1 - 36 ppt. (Bate et al. 2004). These authors concluded it to be a poor indicator of habitat because of the wide range of salinity and habitats in which it has been found.

Navicula salinicola is a species found previously (Bate et al. 2004 - pg 70) in numerous South African estuaries in both intertidal and subtidal sites but always at salinity values between 27 - 33 ppt. It is considered to indicate "brak" conditions by Archibald (1983), Krammer & Lange-Bertalot (1986), but as freshwater to brak by Lange-Bertalot (2000) and Patrick & Reimer (1975).

Amphora caroliniana (Giffen) was found for the first time in South African estuarine waters during this study. It was identified from Lange-Bertalot (2000, Pg 132 Plate 167, Figure 2).

Microphytobenthos Chlorophyll-a

Microphytobenthic biomass was estimated using sediment chlorophyll-a data. In order to be able to convert these data to biomass per unit area, the assays are often reported in units of mg chlorophyll-a.m⁻². These data were, however, measured in units of µg chlorophyll-a.g⁻¹ dry mass of sediment. This provides a more accurate assessment of the biomass because of the density of the sediment. Whichever units are chosen to estimate the biomass, it is necessary to relate the values to other sites. This comparison is provided in the discussion.

Table 5. Values of chlorophyll-a found at intertidal and sub-tidal sites in the Olifants Estuary in March 2004. Values reported in units of µg chlorophyll-a.g⁻¹ dry mass of sediment. SEM = standard error of the mean

Site	Intertidal	SEM	Subtidal	SEM
1	7.55	2.80	8.67	3.48
2	0.97	0.39	10.58	2.20
3	15.40	1.32	11.48	1.65
4	15.38	2.27	11.55	2.05
5	9.06	0.98	3.40	0.70
6	5.39	0.27	5.61	0.50
7	6.31	1.02	2.67	0.31
8	14.67	1.00	7.06	1.33

The analysis of these data showed that there was no significant statistical difference in biomass measured as chlorophyll-a between intertidal and subtidal sites (P=0.265).

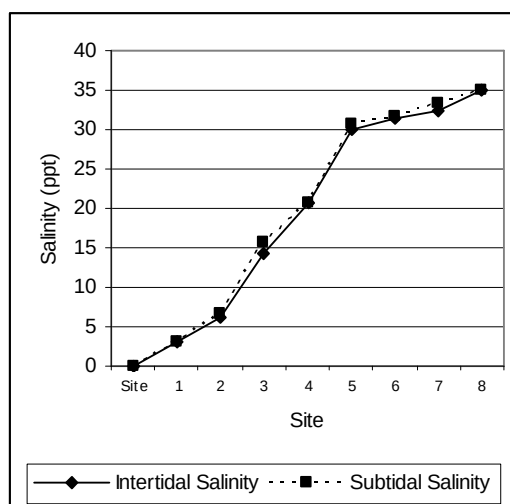


Figure 3. Salinity values for the actual samples (i.e. in the collection bottles) collected for the sub- and intertidal sites at the Olifants Estuary in March 2004.

Phytoplankton Chlorophyll-a

Phytoplankton chlorophyll-a in the water column was measured at each of the sites and the data in Table 6 show the maximum water depth at that site, the depth-integrated salinity, the chlorophyll-a per unit water volume, the secchi disc reading and the light extinction coefficient (K_d) calculated from the difference in light between the surface and the bottom.

Table 6. Values of the average phytoplankton chlorophyll-a content of the water column at different sites in March 2004. The table shows the maximum depth at the site, the average salinity, the Secchi depth and the light extinction co-efficient (K_d).

Site	Depth Max (m)	Salinity Ave (ppt)	Chla Ave (ug.l-1)	Secchi Disc	K_d
1	2	3.2	10.3	1.0	2.2
2	2	14.8	4.3	1.1	1.6
3	3	16.3	1.9	1.3	2.2
4	2	21.4	1.9	0.5	2.0
5	1	30.3	1.7	0.5	2.4

The data in Table 6 show that the phytoplankton biomass was highest near the head of the estuary and decreased steadily towards the mouth. This illustrates the importance of freshwater in stimulating phytoplankton biomass.

Winter 2004 (August)

Physico-chemical data

The distribution of salinity at different depths for March 2004 is shown in Table 7.

Table 7. The salinity values of the water column at different depth and stations in August 2004

Station	Depth (m)					
	0	1	2	3	4	5
1	0.2	0.2	0.2	-	-	-
2	0.2	0.2	0.2	0.2	0.2	0.2
3	0.2	0.2	0.2	-	-	-
4	0.2	0.2	10	22.7	-	-
5	1.2	6.6	22.6	-	-	-
6	4.9	28.3	-	-	-	-
7	10.7	31.3	34.6	-	-	-
8	24.4	34.9	35.7	35.8	-	-

Phytoplankton group counts

The proportions of the different phytoplankton groups found in the water column in August (winter) 2004 are shown in Table 8.

Table 8. Proportions of the different phytoplankton groups found in the Olifants Estuary water column in August 2004. The data are presented both with and without the flagellate counts because the latter make up such a large proportion of the total cells counted.

Site no.	Flagellates	Diatoms	Dino-flagellates	Blue Greens	Greens	Others	Total
1	552	80	0	0	8	801	1441
2	740	58	0	32	22	524	1376
3	1059	240	2	142	11	0	1454
4	836	78	0	0	12	307	1233
5	781	82	0	281	6	0	1150
6	-	-	-	-	-	-	0
7	1394	38	0	77	12	360	1881
8	1041	22	0	25	4	0	1092
Total	6403	598	2	557	75	1992	9627
% Incl. flagellates	66.5	6.2	0.0	5.8	0.8	20.7	-
% Excl. flagellates	-	18.5	0.1	17.3	2.3	61.8	-

The data in Table 8 show that flagellates far out-numbered all the other groups. This is often the case but, as mentioned before, it is not possible to distinguish between the different types of flagellated phytoplankton. When the site is considered without the flagellates, diatoms and blue-green algae are almost equal in number. The totals of all cells was approximately equal at the different sites while the diatoms had maximal numbers at site 3 and blue-green algae at sites 3 and 5. There were a high number of "other" cells in these samples that could not be identified.

Diatom species

The species of diatoms found as dominants and sub-dominants in the estuary in August 2004 (Summer) are shown in Table 9.

The following (August) species were recorded by Bate et al. (2004) in their study of estuarine flora around the coast of South Africa.

Amphora cognata Sundays River and Kruger National Park at DWAF site B7H015. This makes it a freshwater species. *Navicula clamans* was found in the Sundays Estuary. *Nitzschia fontifuga* was found in the Gouritz Estuary. *Diploneis smithii* var *smithii* was found in the Sundays Estuary. *Navicula salinicola* is a species found previously (Bate et al. 2004 - pg 70) in numerous South African estuaries in both intertidal and subtidal sites but always at salinity values between 27 - 33 ppt. *Navicula gregaria* - see earlier comments in the summer results. *Haslea ostrearia* was found in the Swartkops Estuary.

Table 9. Dominant and sub-dominant benthic diatom species in the Olifants Estuary in August 2004. Site 1 was at the head of the estuary in low salinity. Site 8 was near the mouth with a salinity value close to that of seawater. The dominance is the percentage of total cells counted, that were found to be the species indicated. The "Blind Arm" was a small cut-off channel near the mouth running in an approximately north/south direction. This "Blind Arm" was affected by the tidal water level change but not estuary flow.

Site	Salinity	Olifants estuary August 2004		Dominance	No.
Intertidal	(ppt)	Genus	Species	%	Taxa
1	0	<i>Amphora</i>	<i>cognata</i>	43	13
2	0	<i>Planothidium</i>	<i>aff. engelbrechtii</i>	53	36
		<i>Navicula</i>	<i>phyllepta</i>	10	
		<i>Amphora</i>	<i>libyca</i>	10	
		<i>Amphora</i>	<i>cognata</i>	10	
3	0	<i>Navicula</i>	<i>salinarum</i>	30	39
		<i>Navicula</i>	<i>cincta</i>	13	
		<i>Bacillaria</i>	<i>paxillifer</i>	12	
4	0	<i>Navicula</i>	<i>clamans</i>	33	26
		<i>Planothidium</i>	<i>aff. engelbrechtii</i>	33	
		<i>Nitzschia</i>	<i>fontifuga</i>	10	
5	0	<i>Navicula</i>	<i>clamans</i>	40	27
		<i>Planothidium</i>	<i>aff. engelbrechtii</i>	40	
6	10	<i>Cocconeis</i>	<i>scutullem var parva</i>	28	28
		<i>Navicula</i>	<i>salinicola</i>	20	
7	6	<i>Nitzschia</i>	<i>fontifuga</i>	40	37
		<i>Amphora</i>	<i>subacutiuscula</i>	30	
8	24	<i>Amphora</i>	<i>subacutiuscula</i>	34	21
Blind Arm	18	<i>Diploneis</i>	<i>smithii var smithii</i>	23	20
		<i>Achanthes</i>	<i>minutissima v gracillima</i>	23	
		<i>Nitzschia</i>	<i>hustedtiana</i>	14	
		<i>Nitzschia</i>	<i>frustulum</i>	10	
Subtidal					
1	0	<i>Cocconeis</i>	<i>sp.04</i>	25	32
		<i>Nitzschia</i>	<i>frustulum</i>	17	
		<i>Synedra</i>	<i>fasciculata</i>	11	
		<i>Amphora</i>	<i>libyca</i>	10	
2	0	<i>Planothidium</i>	<i>aff. engelbrechtii</i>	30	32
		<i>Amphora</i>	<i>libyca</i>	23	
		<i>Synedra</i>	<i>fasciculata</i>	10	
3	0	<i>Navicula</i>	<i>salinicola</i>	42	30

Site	Salinity	Olifants estuary August 2004		Dominance	No.
		<i>Nitzschia</i>	<i>frustulum</i>	27	
		<i>Synedra</i>	<i>fasciculata</i>	10	
4	0	<i>Nitzschia</i>	<i>fontifuga</i>	18	35
		<i>Navicula</i>	<i>clamans</i>	14	
		<i>Synedra</i>	<i>fasciculata</i>	10	
5	1	<i>Navicula</i>	<i>gregaria</i>	37	33
		<i>Nitzschia</i>	<i>frustulum</i>	20	
6	22	<i>Nitzschia</i>	<i>sp.03</i>	17	31
		<i>Cocconeis</i>	<i>sp.05</i>	14	
		<i>Navicula</i>	<i>gregaria</i>	12	
		<i>Tabularia</i>	<i>ktenoeides</i>	10	
7	22	<i>Nitzschia</i>	<i>sp.03</i>	35	11
		<i>Navicula</i>	<i>salinicola</i>	28	
		<i>Haslea</i>	<i>ostrearia</i>	12	
8	30	<i>Amphora</i>	<i>cf. aff flebilis</i>	55	33
		<i>Amphora</i>	<i>helenensis</i>	15	
		<i>Amphora</i>	<i>coffeaformis</i>	11	
Blind Arm	19	<i>Haslea</i>	<i>ostrearia</i>	38	24
		<i>Navicula</i>	<i>salinicola</i>	29	
		<i>Diplonies</i>	<i>elliptica</i>	18	

None of the other species have previously been found in South African estuaries although they are to be found in the international literature. Three species (*Cocconeis* sp 04, *Cocconeis* sp 05 and *Nitzschia* sp 03) were seen for the first time in a South African estuary and may be new to science. There were no dominant species found in the March 2004 sampling that could not be identified from the literature.

Microphytobenthos Chlorophyll-a

Salinity values recorded during physico-chemical sampling for water quality in the center of the estuary are seldom the same as the values recorded from the bottle in which the sediment samples were held. The actual values for each of the sediment samples during the August sampling are shown in Figure 3.

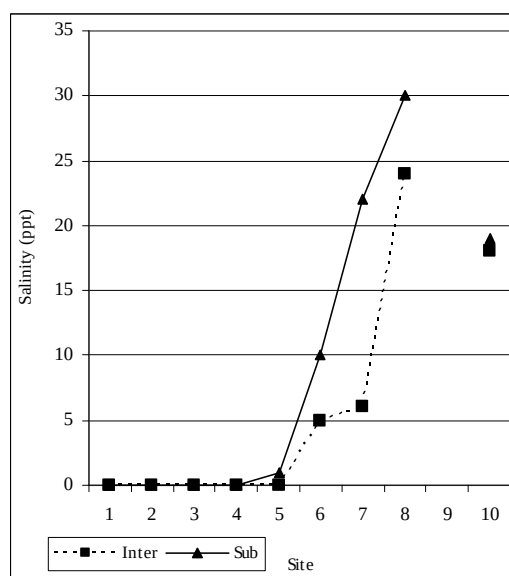


Figure 4. Salinity values for the actual samples (i.e. in collection bottles) collected for the sub- and intertidal sites at the Olifants Estuary in August 2004.

The chlorophyll-a values measured from the sediment samples in August 2004 are presented in Table 10.

Table 10. Values of chlorophyll-a found at intertidal and sub-tidal sites in the Olifants Estuary in August 2004. Values reported in units of μg chlorophyll-a.g⁻¹ dry mass of sediment. SEM = standard error of the mean.

	Intertidal		Subtidal	
Site	Chloro phyll-a	SEM	Chloro phyll-a	SEM
	($\mu\text{g.g}^{-1}$)		($\mu\text{g.g}^{-1}$)	
1	1.03	0.20	26.12	13.55
2	2.99	0.65	12.43	3.44
3	27.06	1.56	7.91	0.66
4	3.10	0.87	9.13	0.41
5	0.71	0.28	0.68	0.35
6	2.78	2.14	0.48	0.35
7	1.52	0.39	2.12	0.18
8	7.21	2.24	5.95	1.78

The analysis of these data showed that there was no statistical difference in biomass measured as chlorophyll-a between intertidal and subtidal sites ($P=0.265$).

Phytoplankton Chlorophyll-a

Chlorophyll-a values in the phytoplankton were highest at site 1. Sites 2-5 had approximately the same level of chlorophyll-a, but sites 6-8 showed a steady fall-off in biomass. These data are shown in Figure 5.

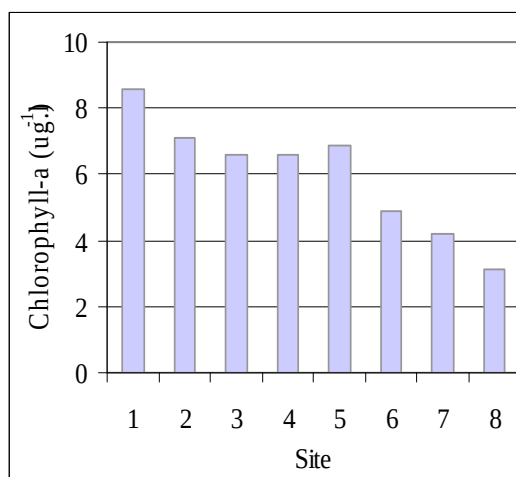


Figure 5. Average phytoplankton chlorophyll-a values in the Olifants Estuary at different sites in August 2004. (Site 1 at the head of the estuary; Site 8 near the mouth of the estuary).

The data in Figure 6 show that the average phytoplankton chlorophyll-a values at the different depths varied little between 5.8 - 6.6 $\mu\text{g.l}^{-1}$.

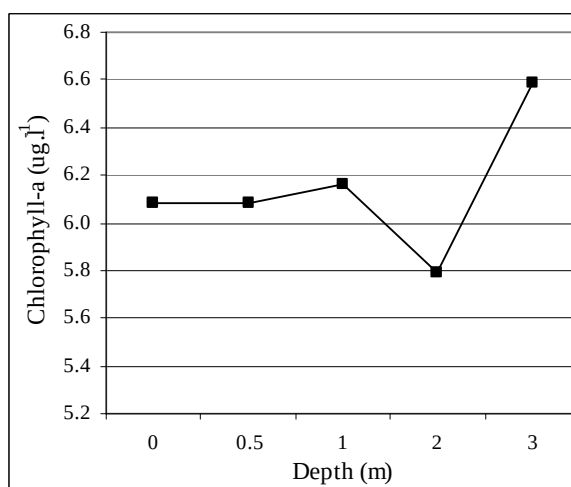


Figure 6. Average phytoplankton chlorophyll-a values in the Olifants Estuary at different depths in August 2004.

DISCUSSION

Location

The mouth of the estuary is about 250 km north of Cape Town "as the crow flies", and it flows into the Atlantic Ocean. The total length of the estuary from the mouth to the head is about 35 Km. In a study in 2001 (Bate et al. 2004) the estuary was considered to extend only as far as the salinity gradient extended. Above that, the water was fresh and, since the purpose of the study was an examination of estuarine epipelagic diatoms, samples were not taken above that point. The sites for the 21 June 2001 study were as shown in Table 11.

Table 11. Sites of the diatom sample sites in the Olifants Estuary in 2001, showing the co-ordinates, the salinity of the water in the sample bottle and the number of taxa found.

Site	GPS co-ordinates		Salinity (ppt)	Number of taxa
Subtidal 1	32° 41' 30" S	18° 11' 51" E	25	25
Subtidal 2	31° 40' 02" S	18° 11' 53" E	20	10
Subtidal 3	31° 48' 38" S	18° 11' 54" E	14	10
Subtidal 4	31° 37' 50" S	18° 11' 55" E	9	11
Subtidal 5	31° 36' 44" S	18° 12' 07" E	1	16
Intertidal 1	32° 41' 30" S	18° 11' 51" E	24	31
Intertidal 2	31° 40' 02" S	18° 11' 53" E	16	21
Intertidal 3	31° 48' 38" S	18° 11' 54" E	12	16
Intertidal 4	31° 37' 50" S	18° 11' 55" E	5	20
Intertidal 5	31° 36' 44" S	18° 12' 07" E	1	22

The data in Table 11 show that on 21 June 2001 the freshwater penetrated to about the 11.5 km mark as shown on the map in Appendix C of this report. This is about the same penetration as in March 2004. In August 2004, the freshwater penetration was further down towards the mouth as would be expected during the winter rain period.

Physico-chemical results

At the conclusion of this present survey, the microalgae in the Olifants Estuary will have been sampled three times since 2001. Although there are differences in physico-chemical characteristics between the different sampling dates, the general impression from the microalgal perspective, is one of a normally functioning permanently open estuary (POE) with freshwater flowing in at the head and a strong tidal flow during each flood from the sea. The result of this is a well-developed, but not eutrophic, REI region.

Phytoplankton groups

Hilmer (1990) working in the Sundays Estuary reported “Dinoflagellates -dominated the community, especially *Katodinium rotundatum*. Very small flagellates falling into the picoplankton range (<5µm) were also usually prominent (eg. *Pyramimonas* sp.). Larger flagellates (>10µm) were also always present, but at concentrations similar to the diatoms. Cyanophytes were only recorded in the upper half of the estuary. The formation of flagellate blooms was a common occurrence . . . and most were caused by *K. rotundatum*, but other phytoplankton species were often co-dominants. He listed diatoms, dinoflagellates, euglenoids, chlorophytes and cyanophytes as making up most of the phytoplankton community. The situation in the Olifants Estuary seem to be rather similar to conditions and species in the Sundays River.

According to Chapman and Chapman (1973), there may be up to 7500 species of cyanophytes, more than 7000 species of chlorophytes, 400 euglenophytes and 1100 pyrrophytes (including the dinoflagellates). Many of these are planktonic and marine or freshwater. The great abundance of these organisms is the reason why so little ecological work has been done on them in South Africa.

The comments of Barnes (1974) are also relevant to the status of the Olifants Estuary in 2004 “The plankton of estuaries is usually sparse in numbers of species, although frequently rich in numbers of individuals: a phenomenon we have also noted in the estuarine benthos. In some estuaries (mainly in the tropics), however, at least the diatom flora is characterized by the presence of many species, each with a comparatively small population. As in lakes and in the sea, an annual cycle of phytoplankton abundance is present in estuaries.

During the last quarter of the year, phytoplankton numbers are low, probably as a result of reduced light intensities and increased turbidity. A bloom occurs in late winter or spring in which the numbers of diatoms increase rapidly, the increased light intensity triggering the bloom. During the summer months, grazing pressure exerted by copepods, and possibly the depletion of essential nutrients by the bloom, causes decreased phytoplankton densities, although a second bloom occurs in some estuaries in the autumn. Diatoms frequently dominate the phytoplankton, but small dinoflagellates often show irregular and localized blooms through the year and in many estuaries this group is dominant. The degree of turbidity and the water circulation play marked roles in determining the nature of the phytoplankton composition and abundance, and consequently estuaries differ considerably with respect to the amount of phytoplankton production". Unfortunately, the comments by Barnes (1974) do not allow us a deeper interpretation of the conditions in the Olifants Estuary at the present time. Together with the reports by Hilmer (1990), it is possible to have some confidence that the Olifants Estuary is functioning "normally" at the time of sampling in 2004.

Benthic diatoms

The diatom taxa found during the March and August 2004 sampling dates were relatively dissimilar considering that they were collected from the same estuary and approximately the same site positions. However, the freshwater flow was different, which most likely accounts for the differences. The March 2004 and June 2001 freshwater penetration was similar at those moments in time, and the benthic diatom flora might be expected to be similar, but they were not. Different species were dominant at each of those times.

Navicula phyllepta, the dominant at intertidal Site 1, only occurred as a sub-dominant at intertidal site 2 and nowhere else. *Nitzschia frustulum*, the dominant at intertidal Site 3, occurred as a sub-dominant at Site 8 in the intertidal and Sites 1,3 and 5 in the subtidal but not as a dominant. *Nitzschia* aff. *perindistincta* did not reappear in the August sampling. *Navicula gregaria* was the dominant at sites 4, 5, 6 and 8 in March. It is a commonly occurring species in both the rivers and estuaries of South Africa. Despite this, it only occurred in August as the dominant at Site 5 in the sub-tidal sediments and site 6 as a sub-dominant. *Amphora caroliniana* was not found in August, nor was *Achnanthes engelbrechtii*. *Navicula salinicola* the sub-tidal dominant at Site 6 in March was the dominant at site 3 and a subdominant at Site 7 and the Blind Arm near the mouth in August.

The fact that so many taxa have not previously been reported as dominants in South African estuaries illustrates the importance of investigations associated with RDM studies. They are one of the only ways that such data are likely to be accumulated. They will be very important indicators of past water quality when the associations between diatom taxa, salinity and water quality is well understood. At present there are no data at all on the mineral nutrient content of estuary water and the taxa found.

Phytoplankton biomass

In the April 2004 study, the highest phytoplankton chlorophyll-a content in the water column was just over $10 \mu\text{g.l}^{-1}$ near the head of the estuary. This concentration decreased by station 2 to just over $4 \mu\text{g.l}^{-1}$ and by station 3, it was just under $2 \mu\text{g.l}^{-1}$. This indicates a low flow of riverine water with a relatively low level of inorganic mineral nutrients entering from the river. In the August 2004 study, the phytoplankton chlorophyll-a concentration was approximately the same at station 1 as it was in March but the level was maintained much further down the estuary. This implies that the freshwater flow was higher than in March

The value of $10 \mu\text{g.l}^{-1}$ of phytoplankton chlorophyll-a in the Olifants Estuary is low by comparison with the values found in Lake St. Lucia (Bate and Perissinotto, 2005 unpublished), where values of $1 - 140 \mu\text{g.l}^{-1}$ have been recorded. Values from the Kromme Estuary that was almost completely freshwater-deprived were similar to those measured in this Olifants study, viz., $2-8 \mu\text{g.l}^{-1}$ (Snow et al. 2000). In a survey of phytoplankton biomass Adams et al. (1999) quoted various references that showed chlorophyll-a values in estuaries in South Africa varies between $0 \mu\text{g.l}^{-1}$ in the Great Fish Estuary (Allanson & Read, 1995) and $210 \mu\text{g.l}^{-1}$ for a bloom in the same estuary (Lucas 1986).

Hilmer (1990) described conditions in the Sundays Estuary where the phytoplankton chlorophyll-a concentration was inversely related to salinity, with values near the mouth of about $2 \mu\text{g.l}^{-1}$ at 34 ppt to over $20 \mu\text{g.l}^{-1}$ near the head of the estuary at about 4 ppt. These data might be taken to imply that high salinity water does not encourage high phytoplankton biomass. However, this is not the case as Bate and Perissinotto (unpublished data) have measured $37 \mu\text{g.l}^{-1}$ at 137 ppt in Lake St. Lucia in 2004. What appears to be happening is that the species change with increasing salinity and the biomass is a function of macro-nutrient concentration and grazing pressure.

Microphytobenthic biomass estimates

Adams et al (1999) reported values for seven estuaries. The average values were Berg Estuary 56 mg.m⁻², Goukou 115 mg.m⁻², Gouritz 138 mg.m⁻², Great Brak 163 mg.m⁻², Keurbooms 138 mg.m⁻², Gamtoos 106 and Sundays 197 mg.m⁻². The values in this study are not comparable because the units are in µg chlorophyll-a per gram dry mass of sediment and not mg.m⁻². Fortunately, comparative values in units of µg chlorophyll-a per gram dry mass of sediment are available from other estuaries. These latter data are Keurbooms Estuary 9.5, Sundays 9.5, Swartkops 10.3, Mngazi 12.9, Gamtoos 19.0 and Mngazana 21.8 µg chlorophyll-a per gram dry mass of sediment. These data illustrate that the values of 1-15 µg chlorophyll-a per gram dry mass of sediment in the March 2004 study are very representative of other well functioning estuaries. The August (winter) values from the Olifants of 0.4 – 27 µg chlorophyll-a per gram dry mass of sediment are quite high.

Salinity tolerance of phytoplankton and microphytobenthos

Recent studies at St. Lucia have shown that high salinity does not inhibit the development of high levels of chlorophyll-a. In August 2004, the average salinity at 14 sites was 15.6 ppt and the average phytoplankton chlorophyll-a level was 39.7 µg.l⁻¹. The highest salinity at any site was 25.8 ppt and the corresponding chlorophyll-a level was 93.2 µg.l⁻¹. The minimum values were 0.5 ppt and 4.4 µg.l⁻¹ respectively. In November 2004, the average salinity at 15 sites was 39.3 ppt and the average phytoplankton chlorophyll-a level was 44.7 µg.l⁻¹. The highest salinity at any site was 133.7 ppt and the corresponding chlorophyll-a level was 141.8 µg.l⁻¹. The minimum values were 9.3 ppt and 1.2 µg.l⁻¹ respectively. A similar situation is evident in the microphytobenthos.

The foregoing data suggest that a high salinity value in the water column promotes a high level of chlorophyll-a. It is unlikely that this is the case. As salinity increases, the evidence shows that the dominant species of phytoplankton and microphytobenthos change. As salinity rises, there is no evidence that primary productivity rises at the same time. What is known is that the level of chlorophyll-a increases. This may be the result of reduced faunal consumption. Indeed, in St. Lucia, when salinity values are too high for the survival of many faunal species, the level of chlorophyll-a that accumulates is very high. The details of these changes requires attention.

There is no evidence to indicate that high salinity levels in an open estuary are likely to be inhibitory to either phytoplankton or microphytobenthos.

The probable effect of reduced freshwater flow on the microalgae in the Olifants Estuary

If freshwater flow is reduced from the present level to a lower level, the average salinity in the estuary will rise and the extent of seawater penetration up the length of the estuary will increase. The levels of chlorophyll-a in the estuary will likely remain unchanged unless the available mineral nutrient levels change. If reduced flow is accompanied by an increase in the concentration of minerals resulting from agricultural through-flow, there will likely be an increased chlorophyll-a level at some position in the estuary where the REI is functioning. The species of phytoplankton and microphytobenthos will change but not necessarily to a point where food supplies will run out. The main inhibitory effect will be on the fauna.

The level to which chlorophyll-a concentration develops depends on the availability of minerals. These minerals can arrive either in freshwater or because of faunal and microbial remineralisation. Hence, in an open system where mineral nutrients are arriving from the riverwater, the flow rate and the mineral concentration determines the primary productivity. As the system changes with reduced inflow from riverine sources, the availability of food for fauna declines and the system will change from “new” resources to “recycled” resources. In the latter case, primary production no longer determines consumption; rather it depends upon it.

Future monitoring in the Olifants Estuary

The measurement and identification of both benthic and planktonic microalgae should be a component of any monitoring programme implemented in the Olifants Estuary regardless of the freshwater flow scenario selected by DWAF. The most important area requiring monitoring will be upper section near the head, where high levels of minerals emanating from agricultural through flow could produce unacceptably high levels of phytoplankton and filamentous algae.

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APPENDIX E

SPECIALIST REPORT: MACROPHYTES

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SUMMARY

The Olifants Estuary is located approximately 250 km north of Cape Town. It occurs in the cool temperate geographical region and receives low winter rainfall. The mouth of the estuary is permanently open and the estuary is tidal for 36 km upstream. The Olifants is ranked third in terms of conservation importance of all estuaries in South Africa. It has the largest supratidal (143 ha) and floodplain (797.1 ha) salt marshes in the country. Intertidal salt marsh covers 91.94 ha, reeds and sedges 60.05 ha and the submerged macrophyte, *Zostera capensis*, 47.72 ha. Dams and water abstraction in the catchment have reduced freshwater input to the estuary. Low flow periods ($<5 \text{ m}^3/\text{s}$) have increased from 4 months (December – March) under the natural condition to 7 months (November – May) under the present state. Water residence time in the upper reaches has increased from 1-4 weeks to greater than 4 weeks. These low flow conditions in addition to nutrient rich agricultural return flow have increased the growth of macroalgae and submerged macrophytes. There has been an increase in saline intrusion particularly during the dry summer months, which would impact the brackish salt marsh, reeds, sedges and pondweed, *Potamogeton pectinatus*. A single salt marsh species, *Sarcocornia pillansii*, is dominant in the supratidal and floodplain areas. This plant cannot grow in the hypersaline surface soils present during the dry period of the year (> 8 months) and utilizes the saline (< 50 ppt) groundwater to survive. A future threat is further reduction in freshwater input and an increase in water column salinity which would increase groundwater salinity. *Sarcocornia pillansii* is possibly the only plant adapted to grow in this harsh environment and its loss would lead to the formation of bare, dry salt pans as has occurred at the Orange River mouth.

1. INTRODUCTION

The Botany Department of the Nelson Mandela Metropolitan University was contracted by the CSIR to undertake the macrophyte component of the Ecological Water Requirement study on the Olifants/Doring Catchment commissioned by the Department of Water Affairs and Forestry. This was a comprehensive ecological reserve assessment.

The Olifants Estuary is located approximately 250 km north of Cape Town on the west coast of South Africa. It is located in the cool temperate geographical region and receives winter rainfall. The Olifants River has the second largest catchment in the country. The estuary is tidal for approximately 36 km upstream and saline water has been reported at Lutzville. The mouth of the estuary is permanently open and its position is maintained by a rocky platform on the northern bank. The estuary is approximately 100 m wide in the upper reaches and increases in width to 250 m in the middle and lower reaches. In the lower reaches numerous erosional and deposition events have shaped and reformed the area (CSIR 1984). Three channels occur in the mouth area, of which only one is open to the sea, one is blind and receives only tidal water and the third has not functioned as a proper estuary channel in the last 130 years (CSIR 1984). The Bulshoek irrigation barrage (with a capacity of $7.5 \times 10^6 \text{ m}^3$)

and the Clanwilliam dam (with a capacity of $127 \times 10^6 \text{ m}^3$) regulate flow into the estuary.

Coetzee *et al.* (1997) developed a botanical importance rating system for Cape estuaries and the Olifants Estuary received the highest score because of its extensive unimpacted salt marshes particularly in the lower reaches of the estuary. Turpie *et al.* (2002) ranked the Olifants Estuary third in terms of conservation importance of estuaries in South Africa.

In 1997 a preliminary investigation of the freshwater requirements of the Olifants Estuary was undertaken. The importance of the large salt marsh areas was obvious but their freshwater requirements were unknown. A PhD study was completed on the freshwater requirements of this habitat (Bornman 2002) and our understanding of the structure and function of these vast areas was improved. Four of the vegetation transects set up in 1999 were re-surveyed in this study (Transect 3, 4, 7 and 8, Bornman 2002) to assess whether there have been any changes over time. The objectives of this study were:

1. to determine the species richness, present and past distribution and area covered by the different plant community types in the Olifants Estuary,
2. to produce accurate maps of the vegetation of the estuary, and
3. to investigate the spatial and temporal variations in vegetation cover and sediment characteristics along transects.

These data were used to determine the present health and importance of the macrophytes of the Olifants Estuary and to set the ecological water requirements (the reserve).

2. DISTRIBUTION OF MACROPHYTES AND RESPONSE TO CHANGES IN FRESHWATER INPUT

Figure 1 indicates the distribution of the different plant community types in the Olifants Estuary. The Olifants is a large permanently open estuary and therefore the species richness is greater than most other estuaries. Seven of the nine possible plant community types occur here; only the subtropical swamp forest and mangrove communities are absent. The large intertidal salt marsh areas are important, as only 18% of South African estuaries are permanently open with intertidal salt marsh, they can thus be considered rare. The Olifants Estuary has the largest supratidal / floodplain salt marsh in South Africa. On parts of the floodplain Strandveld is present that has a high species richness of more terrestrial type species. Overall the salt marsh had naturally low species diversity as these highly saline areas generally have few competitors. Table 1 indicates the area covered by the different plant community types.

Table 1 Area (ha) covered by different plant community types in the Olifants Estuary. Percentages in brackets indicate the percentage area covered by that plant community type compared to the total estuarine plant area (1139.8 ha).

Estuarine plant community types		Other	
Water	227.86	Saltpan (at mouth)	56.79
Mudbanks	54.53	Strandveld (on floodplain)	10.44
Sandbanks	22.47	Dune vegetation	29.81
<i>Zostera capensis</i>	47.72 (4.2%)		
Intertidal salt marsh	91.94 (8.1%)		
Supratidal salt marsh	143 (18%)		
Floodplain salt marsh	797.1 (70%)		
Reeds and Sedges	60.05 (5.2%)		

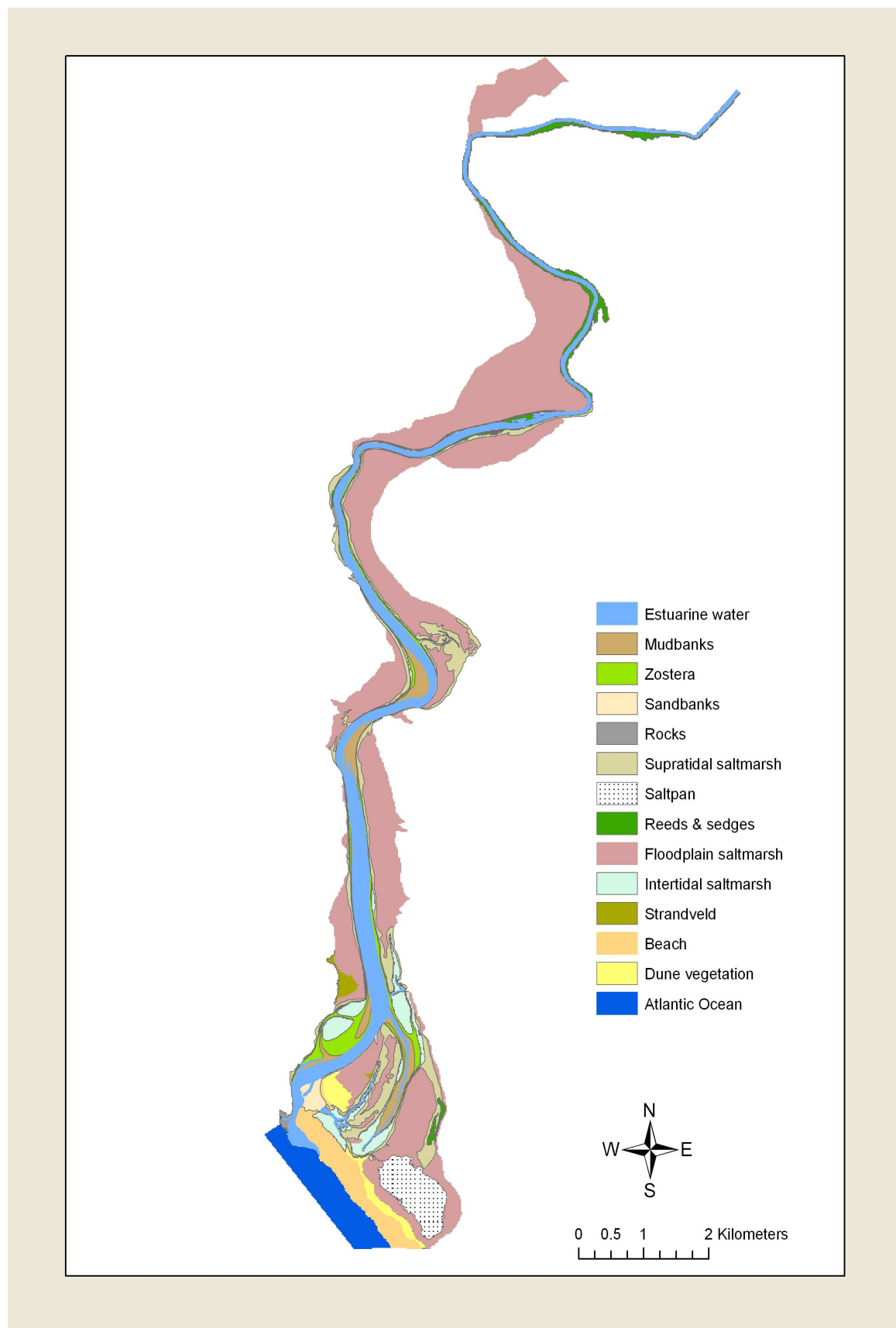


Figure 1 Distribution of different plant community types up the length of the Olifants Estuary.

2.1 Macroalgae

Macroalgae are rarely a dominant feature in South African estuaries. However in the Olifants Estuary particularly during the summer survey species were prolific with a diversity of types. A species list (Table 2) was therefore compiled for both surveys, the species were identified and their importance as indicators described.

Azolla filiculoides (duckweed, water fern) is included in the macroalgal list, however it is in fact a macrophyte. It is a mat-forming, free-floating fern that has been known to form dense mats in South African water bodies resulting in economic losses to water users due to increased siltation, canal clogging, loss of water quality and loss of biodiversity (McConnachie *et al.* 2003). *Azolla filiculoides* is a declared weed (Category 1) and is prohibited in South Africa. Its presence in the upper reaches of the Olifants Estuary in both summer and winter indicate nutrient enrichment.

Certain of the filamentous green algae e.g. *Enteromorpha* sp. (possibly *prolifera*) occurred throughout the estuary in summer. *Enteromorpha* spp. have a very broad salinity tolerance range and can extend upstream into areas that are brackish or virtually fresh. In marine or saline systems with little circulation e.g. lagoons, estuaries or harbours, these algae have been responsible for forming large, dense biomass accumulations, especially under increased nutrient loads. When this happens it often leads to a reduction in water quality, clogging of pipes, inlets, and pumps, and fouling of propellers. This genus has recently been included in the genus *Ulva*.

Oscillatoria sp. and *Spirogyra* sp. were only found in the middle-upper reaches of the Olifants Estuary in summer. *Oscillatoria* belongs to the division Cyanophyta (blue-green algae) and species within this genus are considered important indicators of organically polluted stagnant water. Some species are able to produce toxins that may be harmful to animals or humans.

Spirogyra is a common fresh water macroalgae, distinguished by the large spiral chloroplast that occupies each cell in the filament. These filaments are never branched, and may contain a number of pale coloured pyrenoids. This alga reportedly occurs in moderately polluted water (Entwistle 1989 in Joska and Bolton 1993). Species of this genus have been found growing in freshwater environments including water with low pH, high conductivity and moderate flow rates (Joska and Bolton 1993). In summer the species occurred in water with a salinity of 6.3 ppt.

Although *Rhizoclonium riparium* was only found at Site 4 (Table 1) there may be some confusion with the identification of this species and *Cladophora*. They belong to the same family and are very similar in appearance. *Rhizoclonium* is described as being seldom branched (Joska and Bolton 1993, Stegenga *et al.* 1997), whereas *Cladophora* typically forms branched filaments (Stegenga *et al.* 1997). The preservation technique had led to colour loss, and a change in the texture of the cell content,

making it hard to distinguish between the two species. Separation in this report was based on the presence or absence of branching in the thallus.

Site 5, the middle reaches of the estuary where salinity fluctuations are the greatest had high species richness in summer. In summer this was the only site where *Ceramium (arenarium)*, *Ulva fasciata*, *Polysiphonia urbana* and *Ectocarpus siliculosus* were found. The latter species were however found upstream and downstream of this site in winter (Table 2). *Ceramium arenarium* is typically a marine alga found along most of the South African coast. It is common in sand-binding algal turfs from Swakopmund south and eastwards around the coast to East London. The specimen found in the estuarine samples was most likely washed in on the tide, resulting in the poor condition of the algal fragments found in the sample. It was not common in the sample taken at Site 5, and was only found in that one sample.

Ectocarpus siliculosus is a predominantly marine alga that occurs epiphytic on a variety of seaweeds, and probably also seagrasses. It is also common in brackish habitats and attains its maximum size under these conditions. It is found in lagoons and marine habitats from Port Nolloth to the Eastern Cape.

Polysiphonia sp. (urbana) is a small marine algal species that most resembles what Bolton *et al.* (1997) describe as *Polysiphonia urbana*. It is a common sand-binding alga found on rocky shores in the lower intertidal and extending up into some rock pools. Its distribution has not been confirmed, but it is thought to occur from the Eastern Cape up into Namibia

Much of the filamentous macroalgae found in the estuary appeared upon initial inspection to be related to *Ectocarpus* spp. of the division Phaeophyta. This initial assessment was based on the fact that the algae were the right size, and texture; and had exhibited the typical brown colour. After closer examination most of the algae was found to be of the genus *Cladophora*, and the brown colour was the result of dense growths of an epiphytic diatom (or diatoms) on the algal surface.

Thalassiosira sp., a chain forming diatom, was common among the *Enteromorpha* found in the channels near the Olifants River mouth. The usefulness of the species as a water quality indicator is unknown. A number of *Thalassiosira* species have been documented as bloom forming in Korean waters (Lee *et al.* 2005), and South African species may, similarly, have the potential to become nuisance algae.

Porphyra spp. are large red seaweeds common along most of the South African coastline. Historically all have been considered to be of the species *P. capensis*, but recently a number of separate species have been described. The specimens from the Olifants River appear to be *P. capensis*. *Porphyra* is not described as an estuarine alga, as for example *Gracilaria gracilis* would be, however in other parts of the world, viz. Japan and China, the genus is commonly cultivated in estuarine systems. The

reason for the apparent lack of *Porphyra* in our estuaries may be a result of a lack of solid substrate for anchorage at the appropriate elevation. *Porphyra* requires periodic tidal emersion. The heavy epiphytic load and poor condition of the specimens collected in the estuary suggest that these are algae that were detached from the rocky intertidal areas near the mouth and washed into the estuary by the tide.

Gracilaria verrucosa / *Gracilariopsis* sp. are seaweeds that are normally found attached or buried in the sandy substrate, in sheltered areas along the coast of South Africa (Swartkops River to Langebaan Lagoon). Both have been recorded in a variety of estuaries, bays and lagoons, and the two genera are often confused, as they are virtually identical in appearance. Positive identification is based upon sections of the reproductive structures, which were lacking in the specimens collected in the Olifants River.

The analysis of the macroalgae indicated that in the upper reaches there were species indicative of nutrient enrichment. In the lower reaches a number of marine species were found that were probably not resident in the estuary. The resident species would include the filamentous macroalgae *Enteromorpha* sp. (possibly *prolifera*), *Rhizoclonium riparium* and *Cladophora* sp. (possibly *isaacii*). These algae require a firm substrate for initial cell attachment and filament growth, thereafter they can be free floating with their distribution controlled by wind and flow.

Increasing availability of inorganic nutrients (especially N and P) is known to stimulate the abundance of ephemeral and epiphytic macroalgae in shallow coastal waters (Sand-Jensen and Borum 1991, Duarte 1995, Valiela *et al.* 1997, Karez *et al.* 2004). Mass accumulations of fast-growing algae are most often due to the foliose or uniserate filamentous green algae belonging to the genera *Ulva*, *Enteromorpha* or *Cladophora* (Fletcher 1996, Raffaelli *et al.* 1998 cited in Karez *et al.* 2004). The thin filamentous algae grow faster, require more nutrients per unit of time and biomass and have higher nutrient uptake rates than thick algae.

Freshwater flow in the Olifants Estuary would be important in flushing out the accumulated macroalgae. Their current high biomass particularly of the resident filamentous green algae is indicative of nutrient enrichment and low flow. Species are present that indicate stagnant organically polluted water.

Table 2 Macroalgal species found in the Olifants Estuary in summer (April 2004, ✓) and winter (August 2004, ✓)

	SITES						
	1	2	3	4	5	6	7
GPS position	S31.56926 E18.23114	S31.58945 E18.22695	S31.61187 E18.20599	S31.63075 E18.19887	S31.6657 E18.19797	S31.68147 E18.19746	S31.69393 E18.19484
Location	Upper reaches	Middle reaches	Middle reaches	Middle reaches	Middle reaches	Lower reaches	Mouth area
Salinity (ppt, summer)	3.2	6.3	14.4	20.7	29.9	35	35
Salinity (ppt, winter)	0.19	0.2	0.2-22	1-25	5-28	11-34	24-35
Species							
<i>Azolla filiculoides</i> *	✓ ✓						
<i>Enteromorpha</i> sp. (<i>prolifera</i>)	✓		✓		✓	✓	✓ ✓
<i>Oscillatoria</i> sp.		✓					
<i>Spirogyra</i> sp.		✓					
<i>Rhizoclonium riparium</i>				✓			
<i>Ceramium</i> (<i>arenarium</i>)					✓		
<i>Cladophora</i> sp. (<i>isaacii</i>)					✓	✓	✓ ✓
<i>Ulva fasciata</i>					✓		
<i>Polysiphonia urbana</i>					✓	✓	
<i>Ectocarpus siliculosus</i>				✓	✓		✓
<i>Ulva capensis</i>						✓	✓ ✓
<i>Porphyra</i> sp. (<i>capensis</i>)						✓	✓
<i>Gracilaria</i> sp. (<i>verrucosa</i>)							✓ ✓
* <i>Azolla filiculoides</i> is a floating macrophyte and not a macroalgae, it has roots, stems and leaves.							

2.2 Submerged macrophytes

Submerged macrophyte beds support diverse and abundant invertebrate and juvenile fish communities (Whitfield 1984, 1989). Primary productivity of submerged macrophytes is high and on par with the most productive plant habitats in marine and terrestrial ecosystems (Day 1981, Fredette *et al.* 1990).

The submerged macrophytes were distributed along the salinity gradient with pondweed *Potamogeton pectinatus* forming dense beds in the upper reaches and *Zostera capensis* (eelgrass) distributed in the lower and middle reaches of the estuary. Pondweed grows best in salinity less than 10 ppt and eelgrass at salinity between 25 – 40 ppt. *Zostera capensis* covered an area of 47.72 ha. Water clarity made it impossible to map the pondweed accurately but it probably has a similar cover to that of eelgrass. In March 2004 it occurred from approximately 10 km upstream and filled the water column and channel at approximately 18 km upstream. Thereafter *Potamogeton* together with *Azolla* occurred in dense patches to the head of the estuary at Lutzville, a further 15 km upstream. It could have covered an area of approximately 66.2 ha, compared to 7.2 ha under natural conditions when the plant was restricted to the estuary banks. High densities of aquatic plants can have detrimental localized effects on fish by reducing available habitat and oxygen concentrations. Perna and Demilio (1986) found that dissolved oxygen concentrations in the Ticino River, Italy, with submersed aquatic plants, changed by up to 4.0 mg l⁻¹ between day and night. Maximum oxygen concentrations occur in the afternoon, early in the morning the water can be deoxygenated.

Submerged macrophytes are sensitive to increases in water turbidity and therefore the high flow winter season could result in seasonal decreases in biomass and distribution, although this has not been recorded. Damming of the Doring River will result in changes in turbidity as the main stem (Olifants River) is fairly clear (draining hard, well-leached sandstone and quartzites of the Table Mountain Group) in contrast to the Doring River (a main tributary) being more turbid (draining mainly soft, leachable shales) (DWAf, 1997 cited in CSIR 2005). The ECRU survey in 1980 collected *Potamogeton* sp. near Ebenhaeser but they noted that the growth of this plant was probably limited by the turbidity of the water and the dense reeds lining the banks of the river. Recent reductions in flow have resulted in a clearer estuary. The low flow nutrient rich conditions have encouraged the growth of *Potamogeton* in the upper reaches of the estuary from 18 to 36 km upstream of the mouth. Elevated nutrient levels were already reported from the ECRU survey in 1980. At that time it was stated that if the scale of fertilizer utilization were to increase, problems with eutrophication of the river, particularly in summer, could occur (CSIR 1984). There is now strong evidence for this.

The changes in flow have probably had little influence on the *Zostera capensis* beds that are controlled more by the strong tidal flows in the lower reaches of the estuary. However they would increase in distribution further upstream as conditions become more saline. The distribution and biomass of *Zostera* is also controlled by flooding. In estuaries where floods have been reduced and

salinity and sediment have become more stable an increase in *Zostera* colonization and biomass has been recorded e.g. Kromme and Nahoon estuaries.

2.3 Reeds and sedges

Reeds and sedges act as natural biological filters, they are important for bank stabilisation and they contribute to the diversity of aquatic life (particularly avifauna) (Coetzee *et al.* 1997).

Phragmites australis and *Schoenoplectus scirpoideus* are the common reed and sedge species found in the Olifants Estuary and they cover an area of 60.05 ha (Table 1). They usually occur in the upper reaches of estuaries where salinity is less than 15 ppt. In the Olifants Estuary the reeds are found from 8.5 km upstream. During a spring high tide (January 1990) salinity at this site has been measured at 26 ppt whereas at low tide salinity was approximately 10 ppt (CSIR 2005). Winter sampling (August 2004) indicated that despite strong freshwater input there is vertical stratification and water at depth is approximately 25 ppt at 8.5 km from the mouth. The reeds and sedges can tolerate these salinity fluctuations.

Alternatively these plants can survive tidal inundation with saline water if their roots and rhizomes are located in freshwater (Adams and Bate 1999). They are therefore good indicators of sites of freshwater seepage. Although not measured in the reed beds, Bornman (2002) has shown that the groundwater of the supratidal and floodplain areas is saline, therefore the reeds in the Olifants Estuary are probably influenced more by the salinity of the water column.

Laboratory studies indicated that as early as the 2nd day after *Phragmites australis* plants were exposed to saline water (20 ppt) they showed signs of stress (i.e. decrease in fluorescence). After the second week of receiving 20 ppt salinity stem elongation was significantly reduced compared to plants treated with freshwater (Adams and Bate 1999). Lethal salinity levels for *P.australis* are considered to be greater than 30 ppt. Slow die-back of *P.australis* was recorded at greater than 46 ppt in Lake St Lucia. From laboratory studies Benfield (1984) found the minimum concentration of NaCl that was lethal to *P. australis* seedlings was 21.3 ± 1.7 ppt. The LC50 (that level of the environmental entity beyond which 50% of the population cannot live for an indefinite time) for NaCl was at 16.7 ppt. From these data the rule used for the response of *Phragmites* to increased salinity in the Olifants Estuary was that after 3 months at 20 ppt the plants would die-back.

Under reference conditions the estuary was freshwater dominated and salinity less than 20 ppt occurred from 6.5 km upstream. Reeds would have occurred from 6.5 to 36 km upstream to the head of the estuary, a distance of 29.5 km. Presently salinity could remain at 20 ppt for greater than 4 months at 12-14 km upstream. This represents a potential loss of 6.5 km of reeds and sedges (22% of total area, Table 3). The present patchy distribution of reeds and sedges in the middle reaches of the estuary can possibly be attributed to the increase in saline intrusion. Table 3 indicates the salinity conditions and potential loss of reeds for the different run-off scenarios considered in the comprehensive reserve determination.

Table 3 Salinity conditions and potential reed loss for the different freshwater run-off scenarios.

SCENARIO	Reeds lost (km)	Occurrence of 20 ppt salinity
Present	$13 - 6.5 = 6.5$	4 months 12-14 km from mouth
2	$10 - 6.5 = 3.5$	1 month 10 km from mouth
7	$10 - 6.5 = 3.5$	1 month 10 km from mouth
5	$12 - 6.5 = 5.5$	3 months 12 km from mouth
17	$14 - 6.5 = 7.5$	5-6 months 12-16 km from mouth
10	$14.5 - 6.5 = 8$	4 months 11 km 4 months 13 km 6 months 14-17 km

High nutrient loads to the estuary from agricultural fertilizers would promote the growth and expansion of *Phragmites australis* (reeds). A reduction in the frequency of floods and the accumulation of sediments in the upper estuary would also result in encroachment into the main estuary channel.

2.4 Salt marsh

Salt marshes are a source of primary production; they provide habitat and food for a variety of faunal species. They are important inorganic and organic nutrient sources for estuaries, although the degree of tidal flushing is important in determining how much of the nutrient is released to the water column (Childers and Day 1990). An open mouth is important as this maintains the intertidal salt marsh community. Salt marsh plants are distributed away from the water's edge along an inundation gradient. Distinct zones of intertidal and supratidal plants were found. Tidal exchange is important for maintaining nutrient exchange between the marsh and the estuary.

In the Olifants Estuary the salt marsh vegetation is distributed in three distinct zones i.e. intertidal, supratidal and floodplain. The Olifants Estuary has the largest supratidal and floodplain salt marsh in South Africa (143 ha and 797.1 ha respectively, Table 1). The intertidal salt marsh covers an area of 91.94 ha. The supratidal zone refers to the area that is situated above the intertidal zone and is only normally flooded during spring tide and other associated high water levels. The floodplain (1.34 m above MSL) is the area adjacent to the supratidal area (0.53 m MSL) and is normally elevated above the rest of the estuary. This area is normally covered with water only during large flood events. It has not been flooded for a long time and can be considered to be a paleofloodplain.

The intertidal salt marsh area is small (1 – 10 m in width) and divided into different zones. *Sarcocornia perennis*, *Triglochin bulbosa* and *Cotula coronopifolia* grow mixed closest to the water, followed by a band of *Chenolea diffusa*. *Limonium scabrum* normally associated with the outer fringe of the intertidal area has the highest cover in the supratidal zone and is also present in the wetter areas of the floodplain. The small supratidal zone is dominated by dense monospecific stands of *Sarcocornia*

pillansii and associated large quantities of organic litter. The floodplain is also dominated by *S. pillansii*, although its cover is greatly reduced. The floodplain has large areas of bare ground. Other species commonly found on the floodplain include *Salsola* sp., *Frankenia capitata*, *Limonium scabrum*, the annual *Mesembryanthemum nodiflorum*, *Lycium tetrandrum* and *Lycium cinereum* (Bornman 2002).

Sarcocornia pillansii was the dominant species in both the supratidal and the floodplain areas sampled. On the floodplain, *Salsola aphylla* occurred as co-dominant. Bornman (2002) studied the freshwater requirements of this habitat and showed that the survival of the plants was dependent on the utilization of saline groundwater particularly during the dry period (8 months) of the year. Winter rainfall accumulated on the surface sediments and was utilized by the dimorphic root system. The plants occur in a very stressful environment and any change in the groundwater depth or salinity will influence them. Flooding in the estuary is important as it lowers the salinity of the water column which influences groundwater salinity (Figure 2). Flooding during spring tide would raise the water level in the estuary to cover the supratidal areas with less saline water and also significantly decrease the depth to the water table in the floodplains. If this flooding does not occur the plants would die which would lead to desertification, similar to what has occurred at the Orange River mouth (Bornman *et al.* 2004). The conservation value of this vegetation lies in the fact that halophytes are the only plants adapted to grow in these harsh environments and the loss of this vegetation would lead to the formation of bare, dry salt pans that are more easily eroded by wind and water.

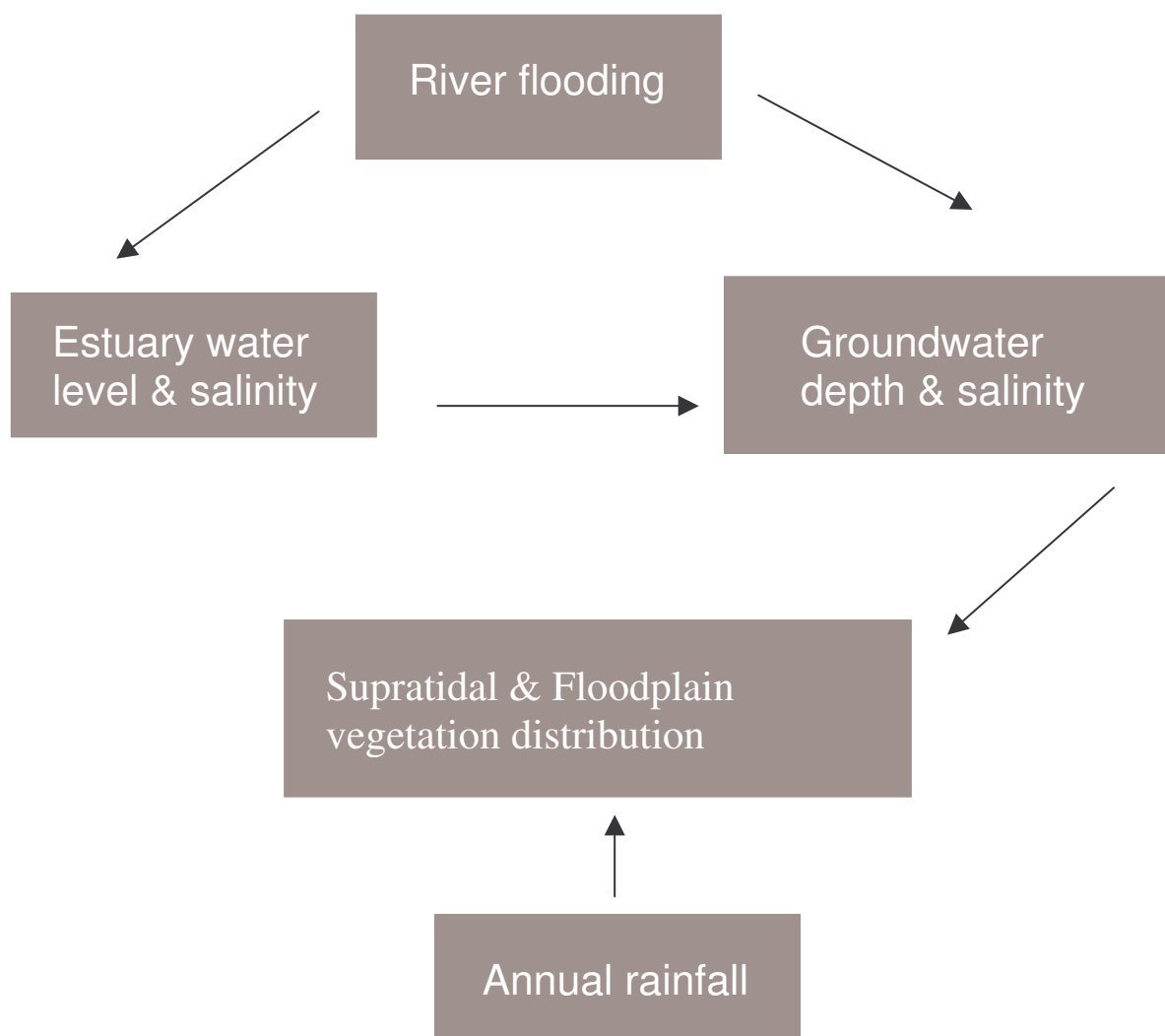


Figure 2. Simplified flow diagram indicating the different components that influence the distribution of supratidal salt marsh and floodplain vegetation in the Olifants Estuary.

3. TEMPORAL CHANGES IN MACROPHYTE DISTRIBUTION AND COVER

Analysis of past and present aerial photographs indicated very little change in the vegetation cover and structure of the floodplain over the last 60 years. This could be as a result of reduced flooding. The last large flood that breached the sand spit through the central arm in the mouth region occurred in 1925 before the building of the Clanwilliam dam (1932) (CSIR 1984). Most changes have occurred in the dynamic lower / mouth reaches of the estuary. Figure 3 is an overlay of the 1942 aerial photograph and the present (2004) vegetation map and is used to illustrate these changes. Approximately 8 ha of “Die Eiland” has eroded on the south bank. This has been replaced by 8 ha of mud and eelgrass (*Zostera capensis*) on the north bank of the main channel (Figure 3). The Blind arm appears to be slowly filling up. In the past there was 28 ha of water in this area that now consists of mud and intertidal salt marsh (increase in 5 ha). Aerial photograph analysis also showed that there

has been an increase in the area covered by reeds and sedges in the middle – upper reaches of the estuary. The 1942 photograph shows 15 ha of bare mudflat that is now colonized by reeds. Changes in the cover of these macrophytes are mostly related to the last flooding event. Increased sediment and nutrient run-off from agricultural activities on the banks could also have led to favourable conditions for reed expansion.

Bornman (2002) found no seasonal change in vegetation cover of the salt marsh over a three-year period. This study investigated four of the same transects as Bornman (2002) and showed that there has been little change over time. However there appears to have been an increase in the bare ground areas of the floodplain salt marsh when the estuary was visited in 2004. In this year rainfall was below average. It has been thought that the perennial vegetation has adapted to the harsh climatic conditions and responds slowly to change. However recent observations at the Orange River mouth indicate an increase in water column salinity and a rapid die-back of reeds and salt marsh. Although seasonal changes were visible in the green growth after the winter rains this did not result in a significant temporal or spatial increase in salt marsh cover in the Olifants Estuary.

Anthropogenic impacts are fairly limited. The local fishermen clear large areas of supratidal salt marsh to build windbreaks and as a source of firewood (Bornman 2002). In the lower reaches of the estuary the salt marsh is used for grazing sheep. In the middle reaches both cattle and sheep graze the salt marsh

The major saltmarsh near the mouth has been disturbed by the salt pan and production of salt. This has removed 56.79 ha of salt marsh. In the middle upper reaches a large area of supratidal and floodplain salt marsh was removed when a dam was constructed. Without recent aerial photographs it is difficult to determine the area covered by this dam but it could be anything between 20-50 ha. The Ebenhaeser settlement has also resulted in the loss of some riparian vegetation most likely reeds and sedges. Alien invasive plants e.g. *Sesbania punicea* and *Eucalyptus* spp. are common in the riparian zone indicating disturbance. Despite these disturbances, compared to other South African estuaries the Olifants is largely natural with little of the floodplain and salt marsh vegetation disturbed over time.

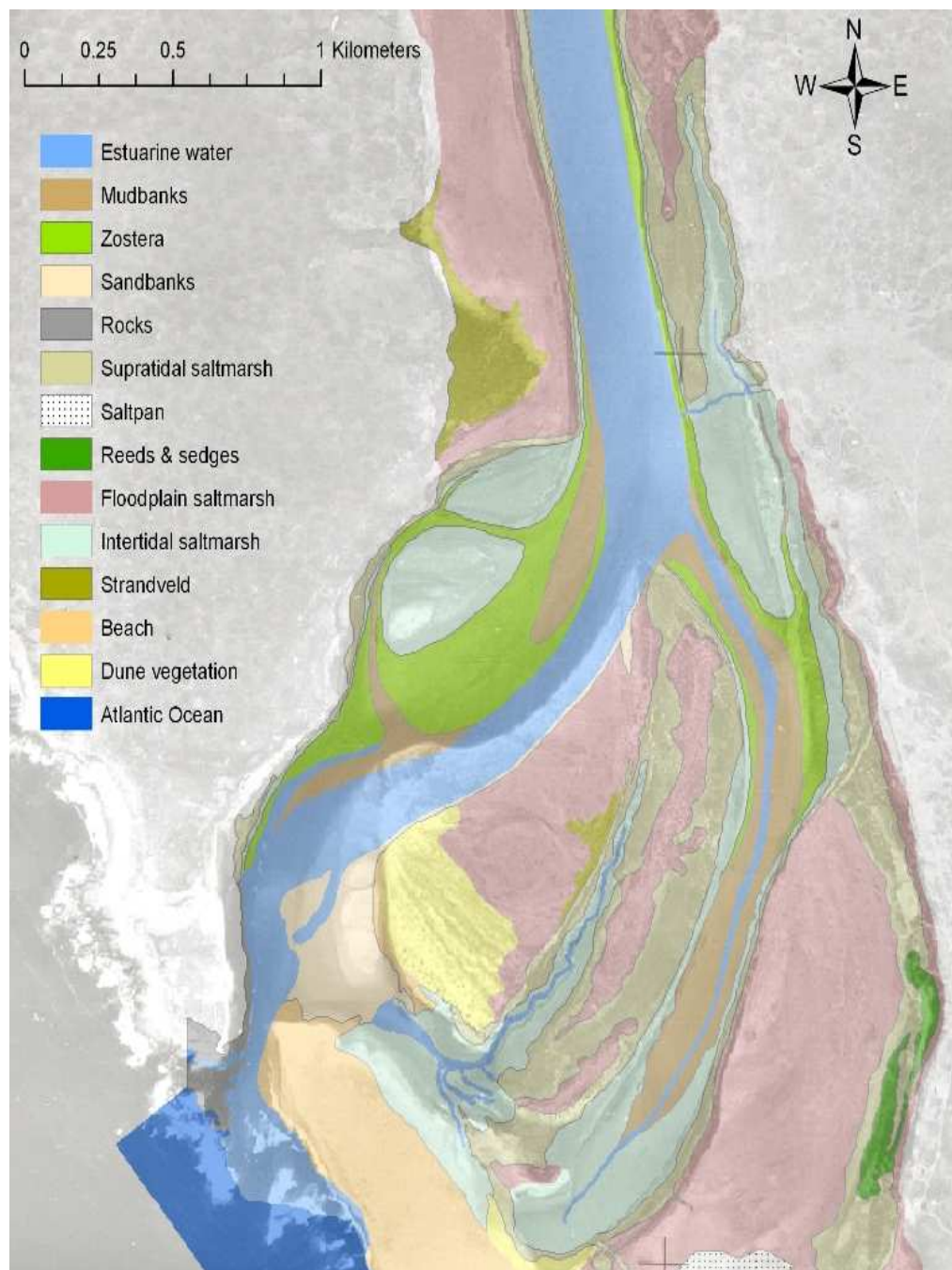


Figure 3 Lower reaches of the Olifants Estuary indicating the present distribution of vegetation in relation to the 1942 aerial photograph.

4. FIELD STUDY: SALT MARSH TRANSECTS

The objective of the field study was to investigate the spatial and temporal variations in vegetation cover and sediment characteristics along transects in the salt marsh. These data were used to determine the present health of the macrophytes of the Olifants Estuary and to set the ecological water requirements.

4.1 Materials and Methods

Four permanent transects were established in the Olifants Estuary. Two transects were situated in the lower reaches and two in the middle reaches of the estuary in close proximity to the sites used by Bornman (2002). The profile and elevation above mean sea level for each transect was determined using a theodolite (Sokkisha TM 6). Vegetation changes were analysed by determining the percentage cover of the vegetation in a permanent quadrats (1 m²) located every 20 m along the transect. The patchiness of the vegetation necessitated the use of random quadrats to establish a more accurate assessment of the percentage cover, species richness and diversity along each transect. Therefore, in addition to the permanent quadrats, four random quadrats (using a random number table) were located around the permanent quadrats and the percentage cover determined in each. The permanent quadrats were used to assess whether there were any seasonal changes in vegetation cover. Global Positioning System (GPS) coordinates at the first and last markers in each transect were recorded.

4.1.1 Vegetation Analysis

Percentage cover was determined in summer (March 2004) and winter (August 2004). The vegetation data collected along each transect was analysed using Detrended Correspondence Analysis (DCA) to determine if vegetation changes occurred over the two sampling periods. Only the vegetation cover at 100, 200 and 300 m along the transects were used in the Canonical Correspondence Analysis (CCA) to determine the influence of environmental variables on the vegetation distribution because these were the only sites where sediment variables were examined.

4.1.2 Sediment Analysis

Sediment samples were collected at three sites along each transect. At each site, samples were collected from three depths, i.e. 0 – 0.05 m, 0.05 – 0.15 m and 1.0 – 1.2 m. Three replicates of each sample were collected. Samples were sealed and transported to the laboratory where analyses of sediment moisture content, organic content, electrical conductivity and particle size were undertaken.

4.1.3 Sediment moisture content

Sediment moisture content was determined according to the methods set out by Black (1965). Into a crucible, 10 g of each sediment sample was weighed and placed in a drying oven for 48 hours at 100 °C. The samples were reweighed and the moisture content was determined using the following equation:

$$\left(\frac{M_w - M_d}{M_w} \right) * 100$$

Where M_w is the initial wet mass and M_d is the mass after drying.

4.1.4 Sediment organic content

Sediment organic content was determined according to the method of Briggs (1977). The dried sediment samples from the sediment moisture content experiment were placed in a muffle furnace (ashing oven) for 8 hours at 550 °C. The crucibles were removed from the ashing oven and placed in a desiccator containing anhydrous silica crystals until cool. The percentage organic matter was calculated as a loss of mass during ashing as a percentage of the initial mass using the following equation:

$$\left(\frac{M_d - M_a}{M_d} \right) * 100$$

Where M_d is the initial dry mass and M_a is the mass after ashing.

4.1.5 Sediment electrical conductivity

Sediment electrical conductivity (mS.cm^{-1}) of the sediment rather than salinity (ppt) was measured because, although seawater and saline groundwater are dominated by sodium and chloride, salts normally precipitate out as calcium sulphate and sodium chloride, both contributing to the ion concentration of the sediment. Sediment electrical conductivity increases proportionally with the salt concentration. Although only sediment electrical conductivity was recorded, salinity and electrical conductivity are used interchangeably where exact values are not of importance, e.g. general discussions.

Sediment electrical conductivity of a saturated paste was determined according to the method by Barnard (1990). An air-dried sediment sample (250 g) was placed in a beaker and de-ionised water was added until saturated. The sediment was tested for the properties of a saturated paste, i.e. no excess water on the surface of the sediment, and if too dry more de-ionised water was added. The amount of de-ionised water used to attain saturation for each sample was recorded. The saturated paste was allowed to stand for at least one hour. The saturated paste was then filtered through a Bachman filter using Whatman No. 40 filter paper. The electrical conductivity of the filtrate was measured using a YSI 30M/10FT hand held conductivity meter.

4.1.6 Sediment particle size

The hydrometer method, as set out by Gee and Bauder (1986) and ASTM (1985), was used. Approximately 40 g of sediment, previously air-dried, was accurately weighed out in a pre-weighed beaker and allowed to equilibrate with the atmosphere overnight. To this sample was added 100 ml of a 50 g.l⁻¹ solution of Sodium hexametaphosphate (NaPO₃)₆ and 250 ml distilled water. The beakers were placed on a mechanical shaker for 1 hour prior to the start of the experiment. The sediment mixture was then placed in a 1 l measuring cylinder and the volume made up to 1 l with distilled water. The cylinder was closed off at the mouth and shaken by hand for at least 1 minute. Two drops of amyl alcohol were added to remove the foam on top of the sample. A hydrometer was inserted after 30 seconds, 60 seconds, 3 minutes, 1.5 hours and 24 hours. A blank containing a similar solution was also prepared but without sediment. The temperature of the solutions was taken using a mercury thermometer. The readings were then used in the following equations to calculate the percentage size fractions in the sample.

Determine C, the concentration of sediment in suspension in g.l⁻¹, using:

$$C = R - RL$$

Where R is the uncorrected hydrometer reading (in g.l⁻¹) and RL is the hydrometer reading of the blank solution.

The determination of P, the summation percentage for the given time interval, using:

$$P = \left(\frac{C}{C_o} \right) * 100$$

Where C_o is the oven dried weight of the sample.

Determine X, the mean particle diameter in suspension in µm at time t using:

$$X = \theta t^{-1/2}$$

Where θ is the sedimentation parameter (µm min^{1/2}) and is a function of the hydrometer settling depth, solution viscosity and particle and solution density.

$$\theta = \left(\frac{18\eta h'}{[g(\rho_s - \rho_l)]^{1/2}} \right)$$

Where h' is the hydrometer settling depth (cm), ρ_s = sediment particle density (g/cm³), ρ_l = solution density (g/cm³), g = gravitational constant (cm/s²) and η = fluid viscosity in poise (g.cm⁻¹.s⁻¹).

The relationship of the settling depth to the hydrometer dimensions were approximated by:

$$h' = -0.164R + 16.3$$

Where R is the uncorrected hydrometer reading.

The summation percentage was calculated as follows:

$$P_{2\mu m} = m \ln \left(\frac{2}{X_{24}} \right) + P_{24}$$

Where X_{24} is the mean particle diameter in suspension at 24 hours, P_{24} is the summation percentage at 24 hours, and m was determined using the following equation:

$$m = \frac{P_{1.5} - P_{24}}{\ln(X_{1.5} - X_{24})}$$

Where m is the slope of the summation percentage curve between X at 1.5 hours and X at 24 hours. $X_{1.5}$ is the particle diameter in suspension at 1.5 hours, and $P_{1.5}$ is the summation percentage at 1.5 hours. This procedure was repeated for the 30 second and 60 second readings.

4.1.7 Water table analysis

Bornman (2002) suggested the possibility of groundwater as a source of moisture for supratidal vegetation. It was therefore decided to include depth to the water table and groundwater electrical conductivity in the analysis of environmental variables that might influence the distribution of the salt marsh plants. Depth to groundwater and groundwater electrical conductivity were determined by manually auguring down to the water table. Readings were taken at the same sites from where the sediment samples were collected. Three replicate holes were augered at each site.

4.1.8 Statistical analysis

Correlation analysis were run for the Olifants Estuary, using Statistica (Statistical software developed by Statsoft, Inc.), on all variables tested at all sites over both sampling periods. Variables included in the analysis were: season (to determine if any variables changed over time); distance inland from the estuary channel; depth below the sediment surface (sediment samples were collected along three depths); percentage sediment moisture; sediment electrical conductivity; percentage sediment organic content; percentage sand fraction of the sediment; percentage silt fraction of the sediment; percentage clay fraction of the sediment; rainfall; depth to groundwater and groundwater electrical conductivity.

The seasonal species and environmental were analysed using CANOCO for Windows (version 4.0, ter Braak 1997). Detrended Correspondence Analysis (DCA) was used to identify patterns in species distribution and cover over time. Canonical Correspondence Analysis (CCA) was used to obtain an ordination of the vegetation data constrained by environmental variables. Monte Carlo permutation tests (999 permutations) were performed to assess the significance of the canonical axis showing the

relationship between species and the selected environmental variables. The result of the CCA was plotted as a two-dimensional graph using CANODRAW (Version 3.1, 1997). The environmental variables were plotted as arrows originating from the center of the graph. The origin represents the mean value of each separate variable and the direction of the arrow line represents an increase in the value of that particular variable. The length of the environmental arrow indicates the importance of the variable and is equal to the multiple correlation of the variable with the displayed ordination axes. Statistical results were displayed in a table below each CCA ordination diagram. This information is required for the correct interpretation of the ordination diagram. The correlation matrixes were run using Statistica (Version 6, 2001), Statsoft, Inc.

4.2 Results

The mean monthly rainfall for the year 2004, as well as the mean monthly rainfall over a 50 year period for the Vredendal/Doringbay area is given in Figure 4. The Olifants Estuary receives its highest rainfall in winter. According to the data collected by the South African Weather Services, the study area received below average rainfall during 2004 (mean annual rainfall from 1951-2003 was $16.03 \text{ mm} \pm 3.3 \text{ mm SE}$).

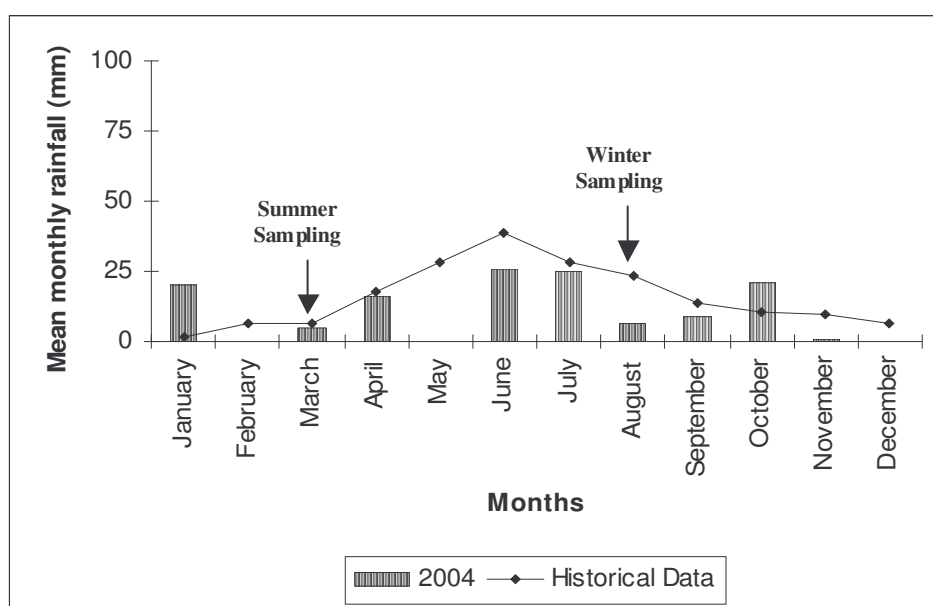


Figure 4 Mean monthly rainfall for the Vredendal/Doringbay area (1951-2004, South African Weather Services).

4.2.1 Transect data

Transect 1 and 2 in the Olifants Estuary were both 340 m long and extended from the intertidal area of the blind arm to the floodplain (Plate 1). They were situated parallel to each other, approximately 400 m apart. During summer (Figure 5 and Figure 6) *Triglochin bulbosa* and *Sarcocornia perennis* made up the intertidal component of the vegetation in both transects. Both these species are low intertidal saltmarsh species and are generally associated with high sediment electrical conductivity as they

occur close to the estuary channel. Transect 1 consisted mainly of monospecific stands of *Sarcocornia pillansii* with a high percentage of bare ground in between (Plate 2). *Sarcocornia pillansii* occurs above the mean high water spring level, where the sediments are salinised with little free water available. This is due to occasional flooding by salt water followed by evaporation. *Limonium scabrum* occurred in small pockets where the sediment moisture was highest. *Lycium tetrandrum* was restricted to the elevated area at the end of the transect. In Transect 2 *Sarcocornia pillansii* was dominant, except between 20 m and 100 m, where the co-dominant, *Salsola aphylla*, had the highest cover. Overall, *Salsola aphylla* had a much lower cover than *Sarcocornia pillansii* and appeared to grow on its own.

During winter (Figure 7 and Figure 8) only slight differences in vegetation cover was observed. There was a decrease in cover of the lower intertidal saltmarsh species, *Triglochin bulbosa* and *Sarcocornia perennis*, in both transects. In the Knysna Estuary salt marsh around Thesen Island Muir (2000) showed a similar response for *Triglochin bulbosa*. In spring / summer this species colonized new areas that were formed as a result of sedimentation and the shifting in creeks and channels. Adams and Bate (1994) showed that *Sarcocornia perennis* growth increased at lower salinity levels and saturated sediment conditions. Sediment analysis showed that sediment electrical conductivity was lower during summer. *Sarcocornia pillansii* cover increased within the first 40 m of the transects and decreased thereafter. Bornman (2002) showed that there was an increase in *Sarcocornia pillansii* with an increase in sediment moisture. This study showed a similar response.



Plate 1 Zonation at Transect 1 and Transect 2 in the Olifants Estuary.



Plate 2 Monospecific stands of *Sarcocornia pillansii* interspersed with a high percentage of bare ground.

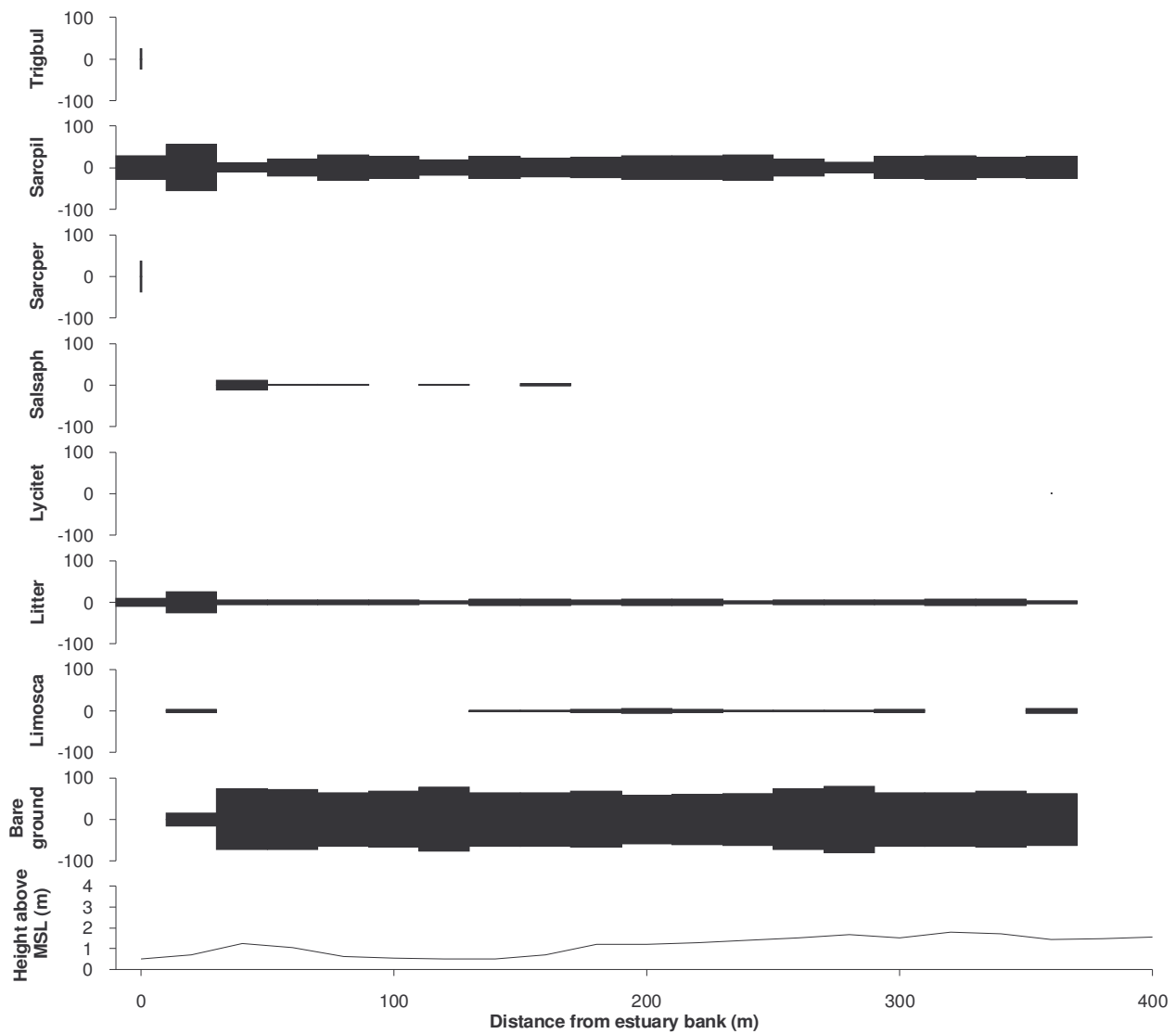


Figure 5 Kite diagram showing the distribution of vegetation along Transect 1 in the Olifants estuary during summer (full species names are available in Annexure 1).

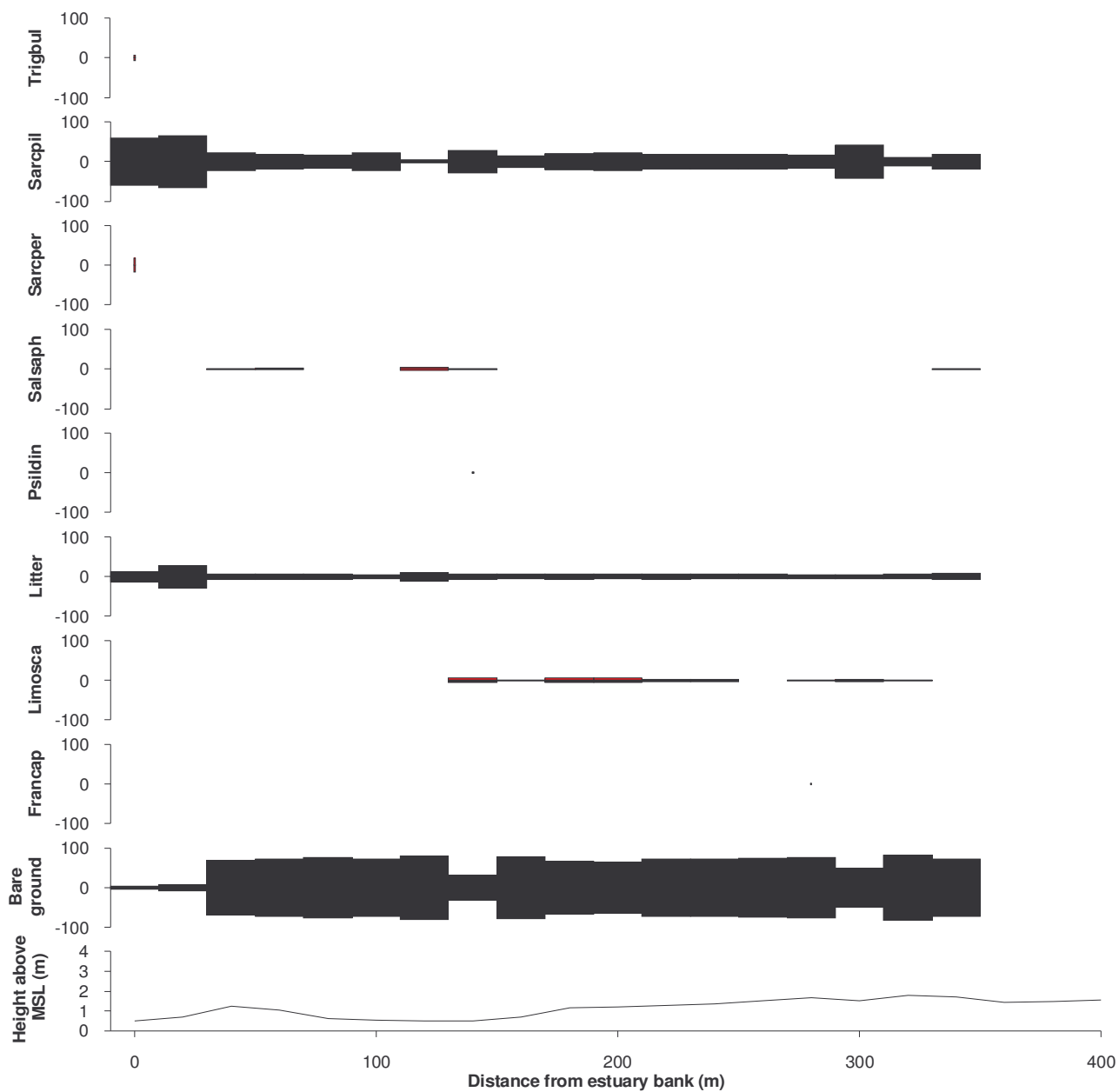


Figure 6 Kite diagram showing the distribution of vegetation along Transect 1 in the Olifants estuary during winter (full species names are available in Annexure 1).

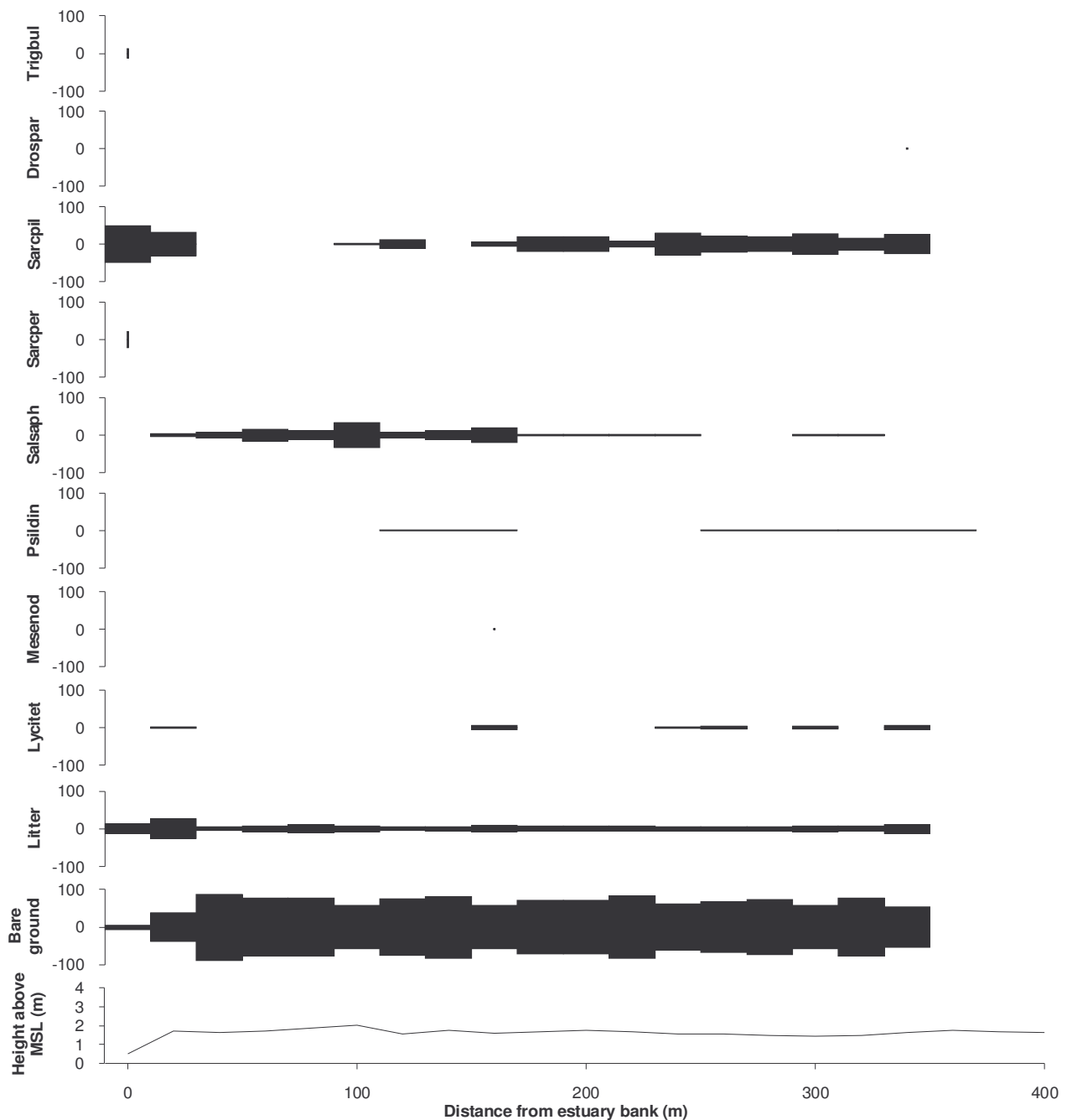


Figure 7 Kite diagram showing the distribution of vegetation along Transect 2 in the Olifants estuary during summer (full species names are available in Annexure 1).

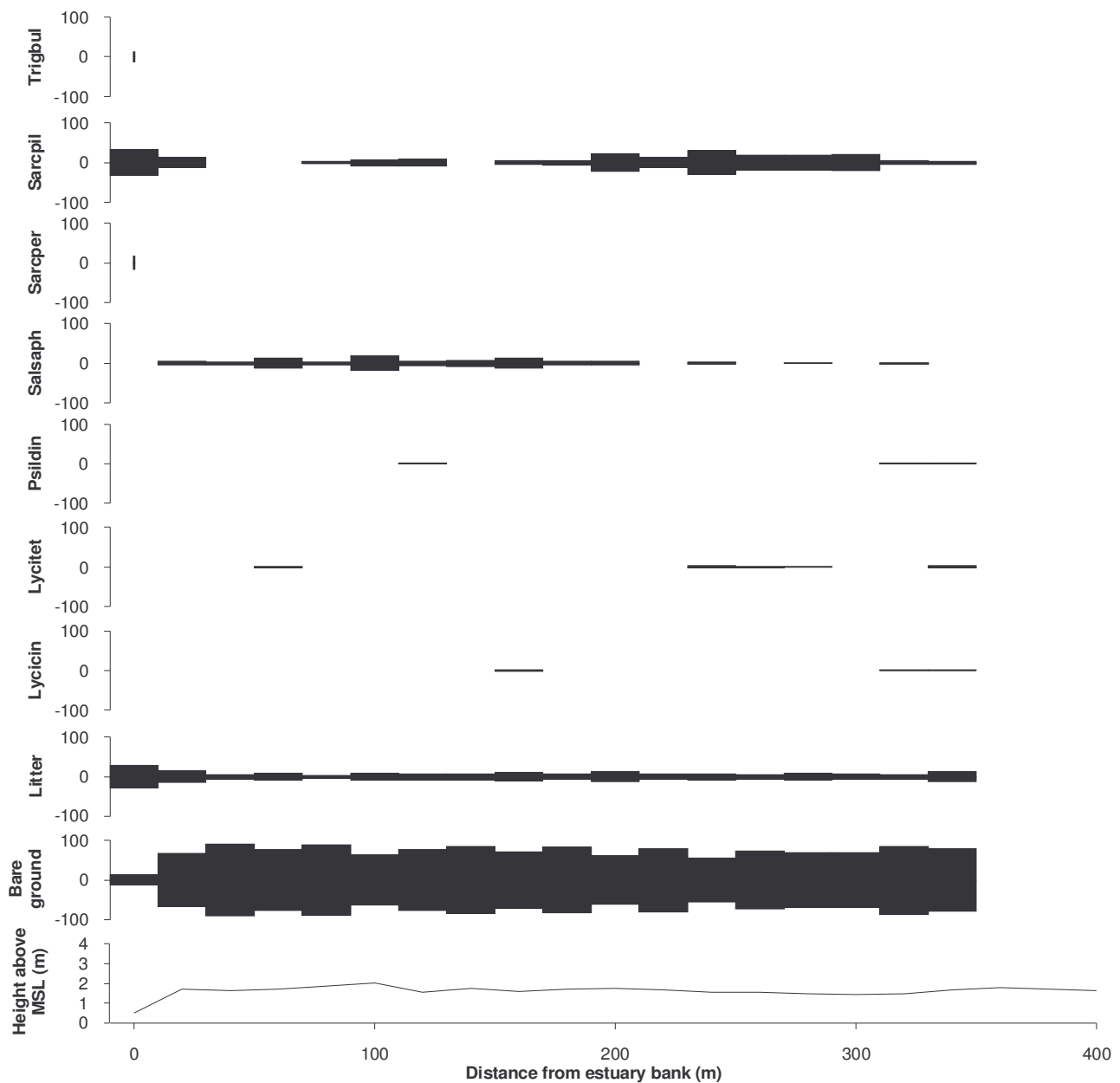


Figure 8 Kite diagram showing the distribution of vegetation along Transect 2 in the Olifants estuary during winter (full species names are available in Annexure 1).

Transect 3 and 4 were both 360 m long and extended from the intertidal area through to the 15 m high contour gravel terrace. They were situated parallel to each other, approximately 200 m apart. During summer (Figures 7 and 8) the first 5 m of the transects consisted of the submerged macrophyte, *Zostera capensis*. *Sarcocornia perennis* was dominant throughout the intertidal salt marsh. *Triglochin bulbosa* and *Limonium scabrum* were only present in Transect 4. *Limonium scabrum* occurred on the edges adjacent to the supratidal area and was a good indicator of wet sediment conditions. In both Transect 3 and 4 *Sarcocornia pillansii* was the dominant species in the supratidal area and on the floodplain. High percentage cover was recorded for *Sarcocornia pillansii* in the low lying areas. Less salinity tolerant and more moisture dependent species such as *Sporobolus virginicus* and *Juncus kraussii* were restricted to a small area adjacent to the cliffs and are probably supported by freshwater run-off from adjacent hard surfaces. The annual succulent, *Mesembryanthemum nodiflorum*, was also present in small numbers in Transect 4, usually in small depressions where water collected after rain.

During winter (Figures 6 and 8) only slight differences in vegetation cover was observed. There was a decrease in the lower intertidal saltmarsh species, *Sarcocornia perennis*, in both transects. *Sarcocornia pillansii* decreased whereas *Salsola aphylla* increased. Bornman (2002) showed that the distribution of *Salsola aphylla* was linked to the presence of other vegetation and that it appeared to grow only in areas devoid of other species. The annual, *Mesembryanthemum nodiflorum* died back and only small patches were observed during winter.

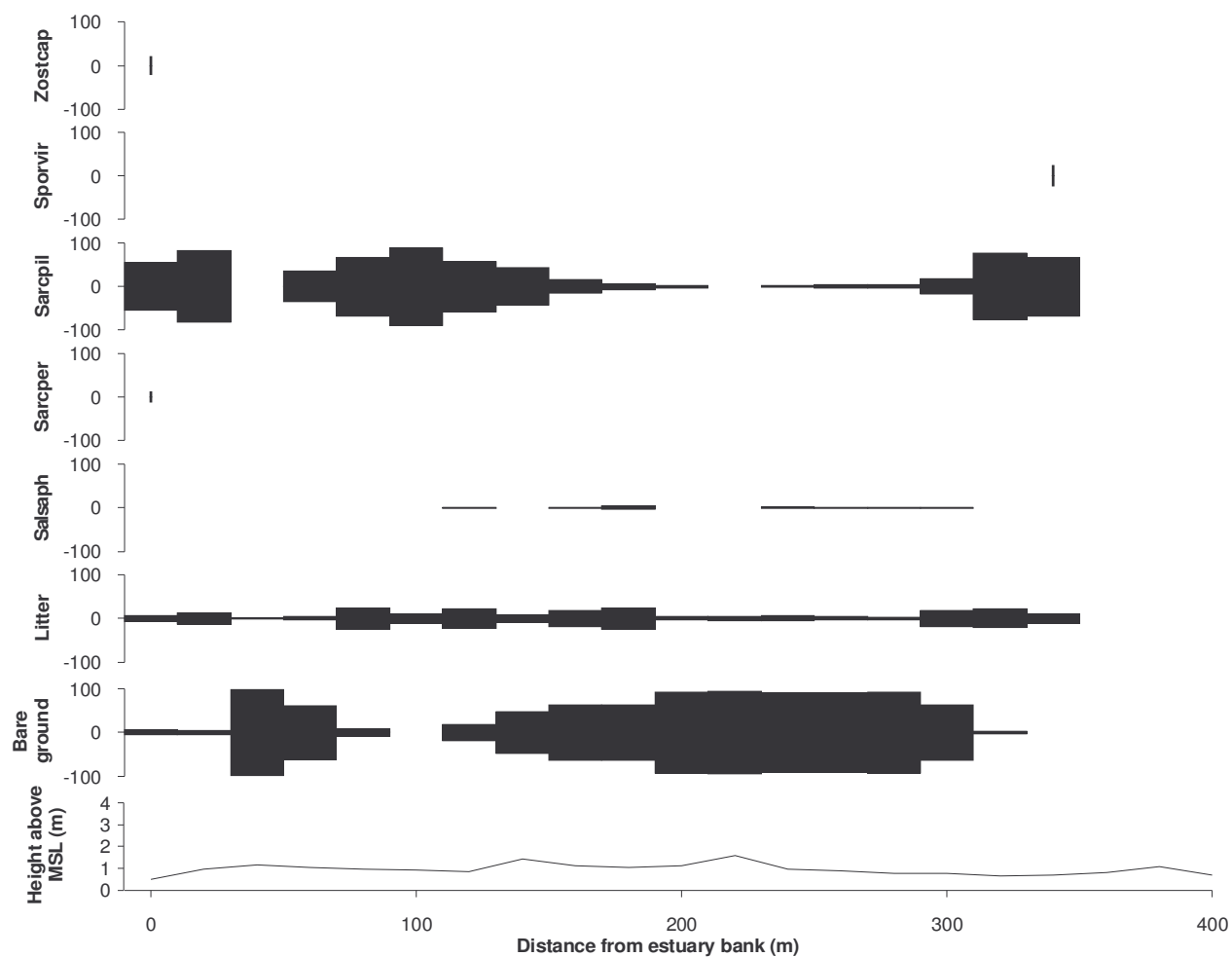


Figure 9 Kite diagram showing the distribution of vegetation along Transect 3 in the Olifants Estuary during summer (full species names are available in Annexure 1).

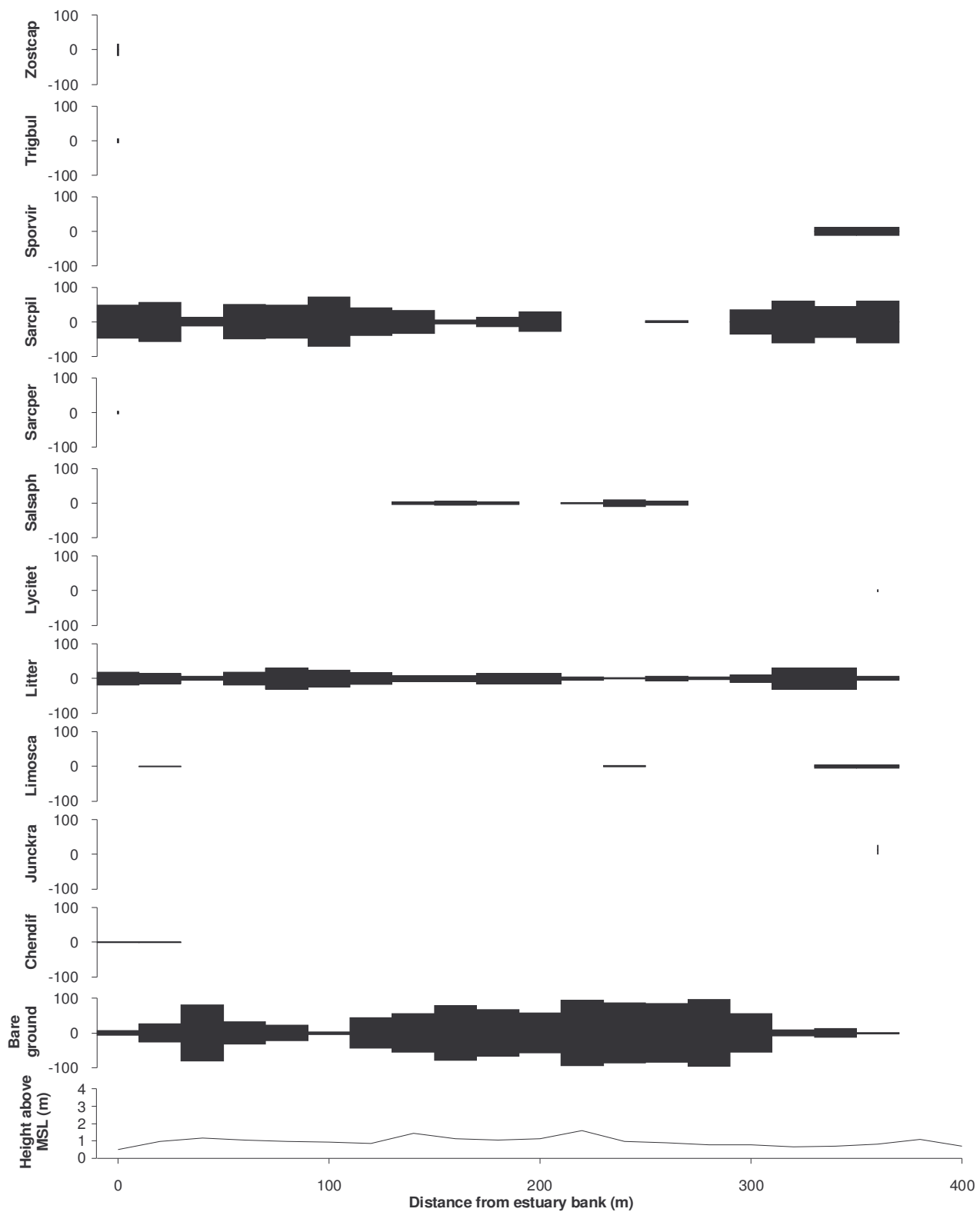


Figure 10 Kite diagram showing the distribution of vegetation along Transect 3 in the Olifants Estuary during winter (full species names are available in Annexure 1).

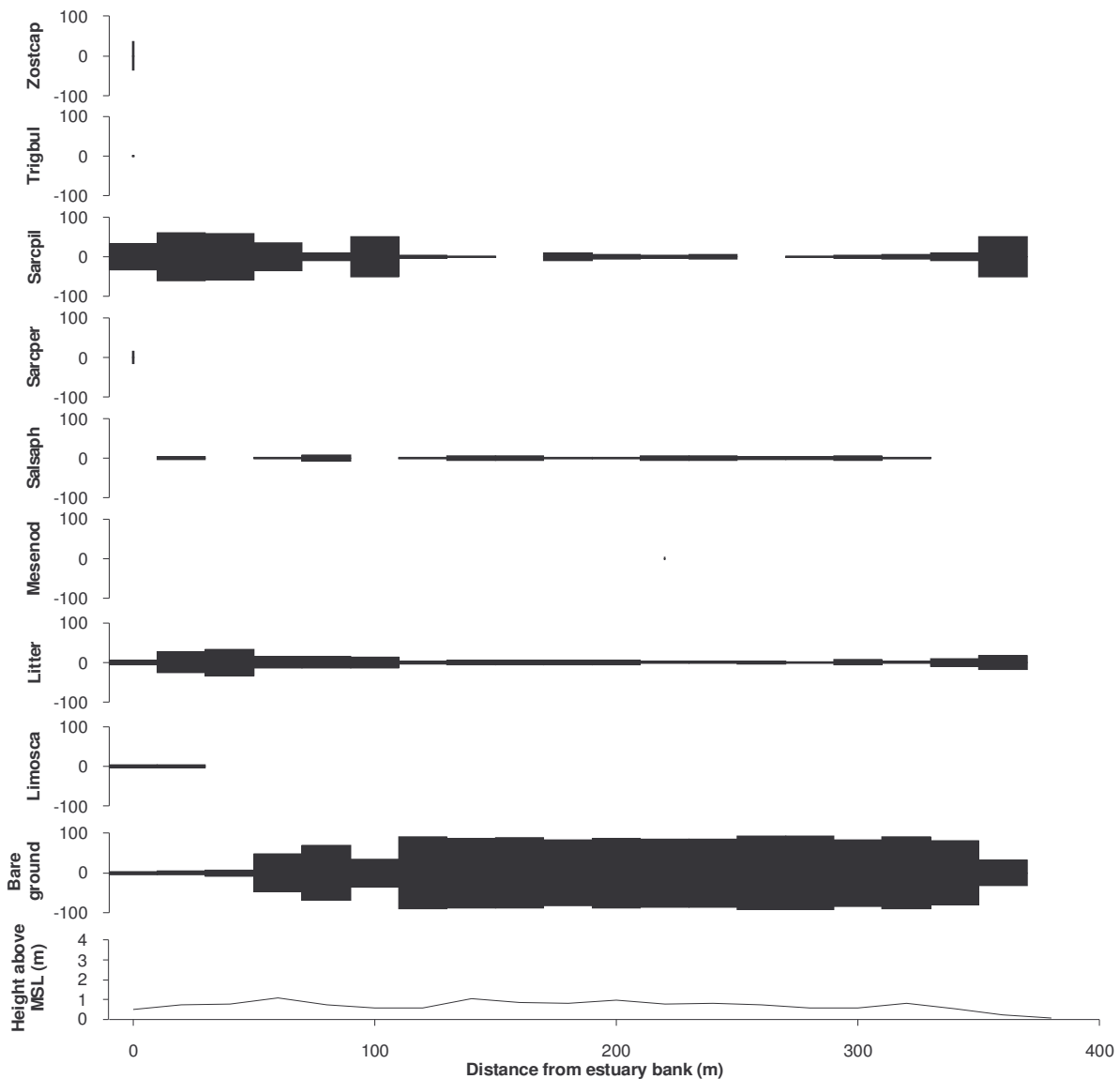


Figure 11 Kite diagram showing the distribution of vegetation along Transect 4 in the Olifants Estuary during summer (full species names are available in Annexure 1).

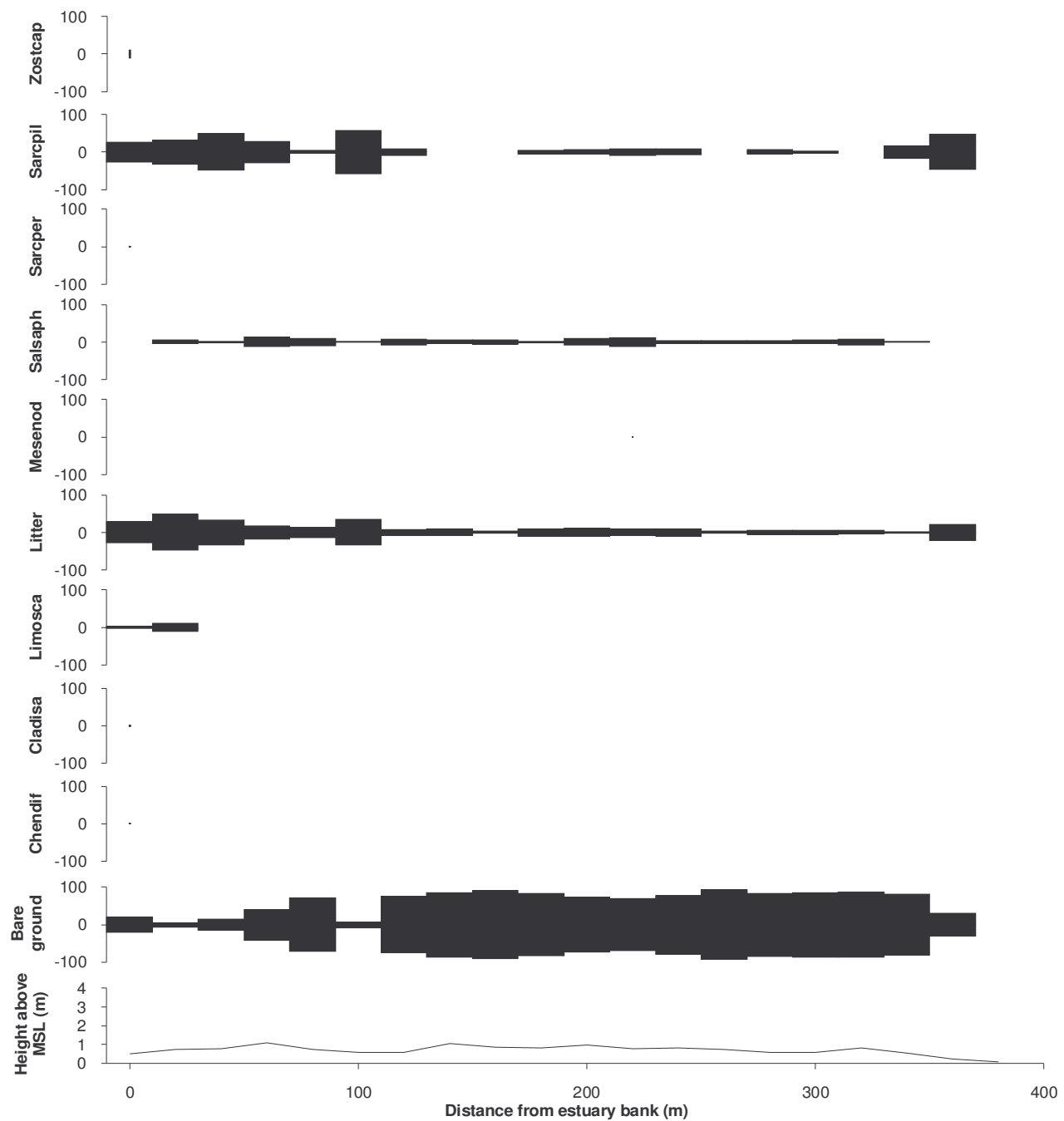


Figure 12 Kite diagram showing the distribution of vegetation along Transect 4 in the Olifants Estuary during winter (full species names are available in Annexure 1).

4.2.2 Vegetation distribution

Vegetation distribution was analysed using Detrended Correlation Analysis (DCA).

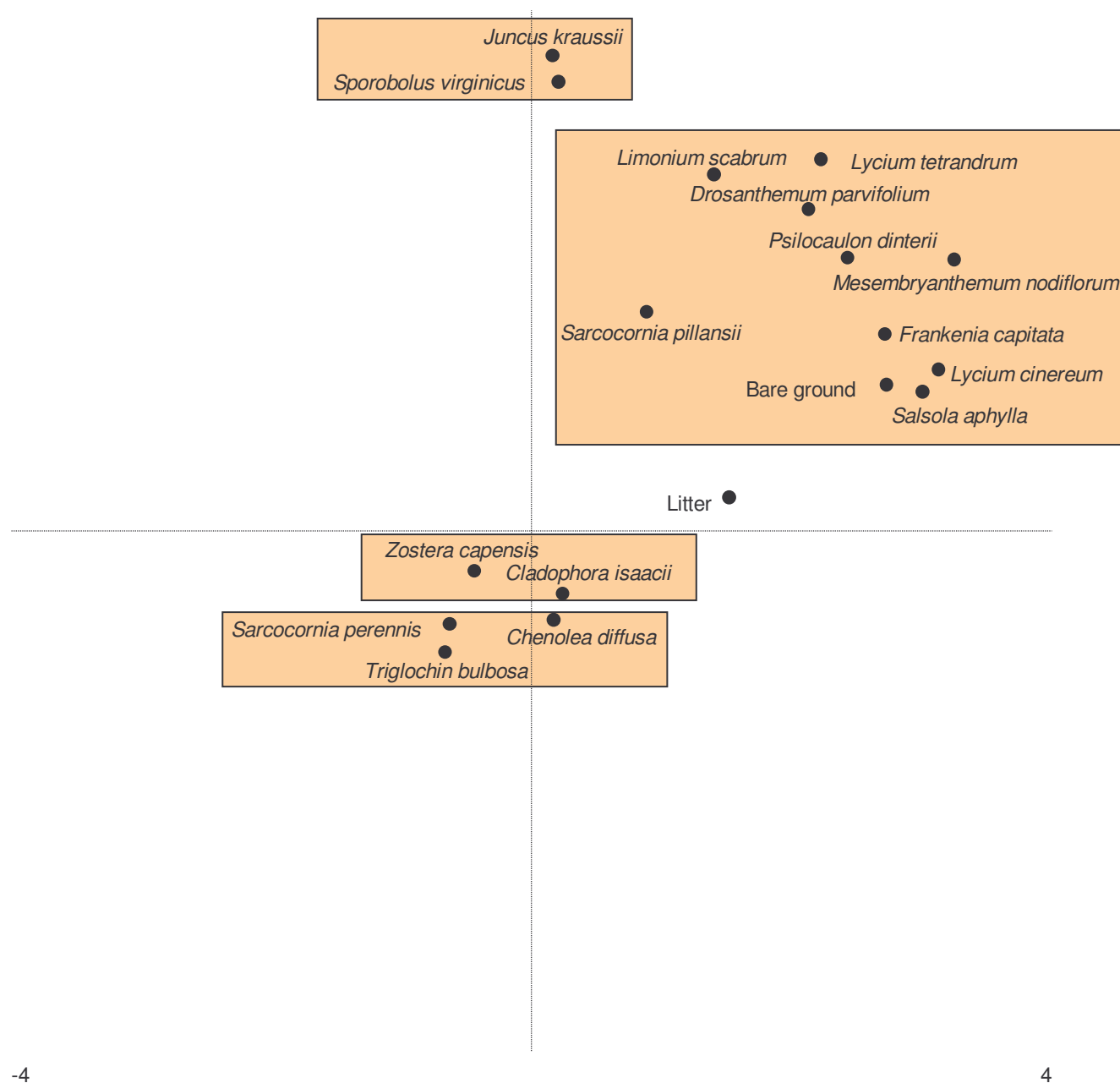


Figure 13 DCA ordination of sites for the Olifants Estuary over the two sampling periods. Eigenvalues: axis 1 = 0.479; axis 2 = 0.174.

4.2.3 Influence of environmental variables on vegetation distribution

The numerical results of the Canonical Correspondence Analysis (CCA) are shown in the table below the ordination diagram. A Monte Carlo permutation test of the trace (sum of eigenvalues of all canonical axis; 999 permutations) showed that vegetation distribution in the Olifants Estuary was significantly affected by distance from the estuary channel, groundwater electrical conductivity ($p = 0.001$) and depth to groundwater. Similar results were found in a study on the salt marshes of the Kromme Estuary, Eastern Cape. In the Olifants Estuary sediment organic content ($p < 0.05$) was also an important factor influencing species distribution.

The first canonical axis described 63% of the variation of the species – environment relation (Figure 14). This axis was negatively correlated with depth to groundwater (-0.52) and distance from the estuary channel (-0.34) and positively correlated with sediment organic content (0.35) and groundwater electrical conductivity (0.27).

The ordination diagram (Figure 14) showed that *Sarcocornia pillansii* was positively correlated with sediment moisture content and organic content. Bornman (2002) showed that areas of higher sediment moisture were also associated with lower sediment electrical conductivity, except in areas with high vegetation cover, where the sediment had a higher organic content, higher moisture and higher sediment electrical conductivity. This indicates that the vegetation retains more moisture by providing shade and higher sediment organic content. Bornman (2002) showed that *Sarcocornia pillansii* was found in areas that had high sediment moisture and high sediment electrical conductivity. Because these plants are halophytes growing in extremely dry environments, moisture was probably of more concern than high salinity to which they appear to be adapted.

Salsola aphylla grew in sediment with a high sand content and a low clay content. Although clay sediments retain moisture for longer, most of this moisture is not available to the plant and, together with the mechanical damage caused by the shrinking of clay sediments during drought, would prevent the successful establishment of plants in these sediments.

Both *Lycium tetrandrum* and *Limonium scabrum* were found to be outliers. Bornman (2002) found that *Lycium tetrandrum* was an ecotone species restricted to elevated areas or levees between different communities, whereas *Limonium scabrum* was only found on the edges adjacent to the supratidal area.

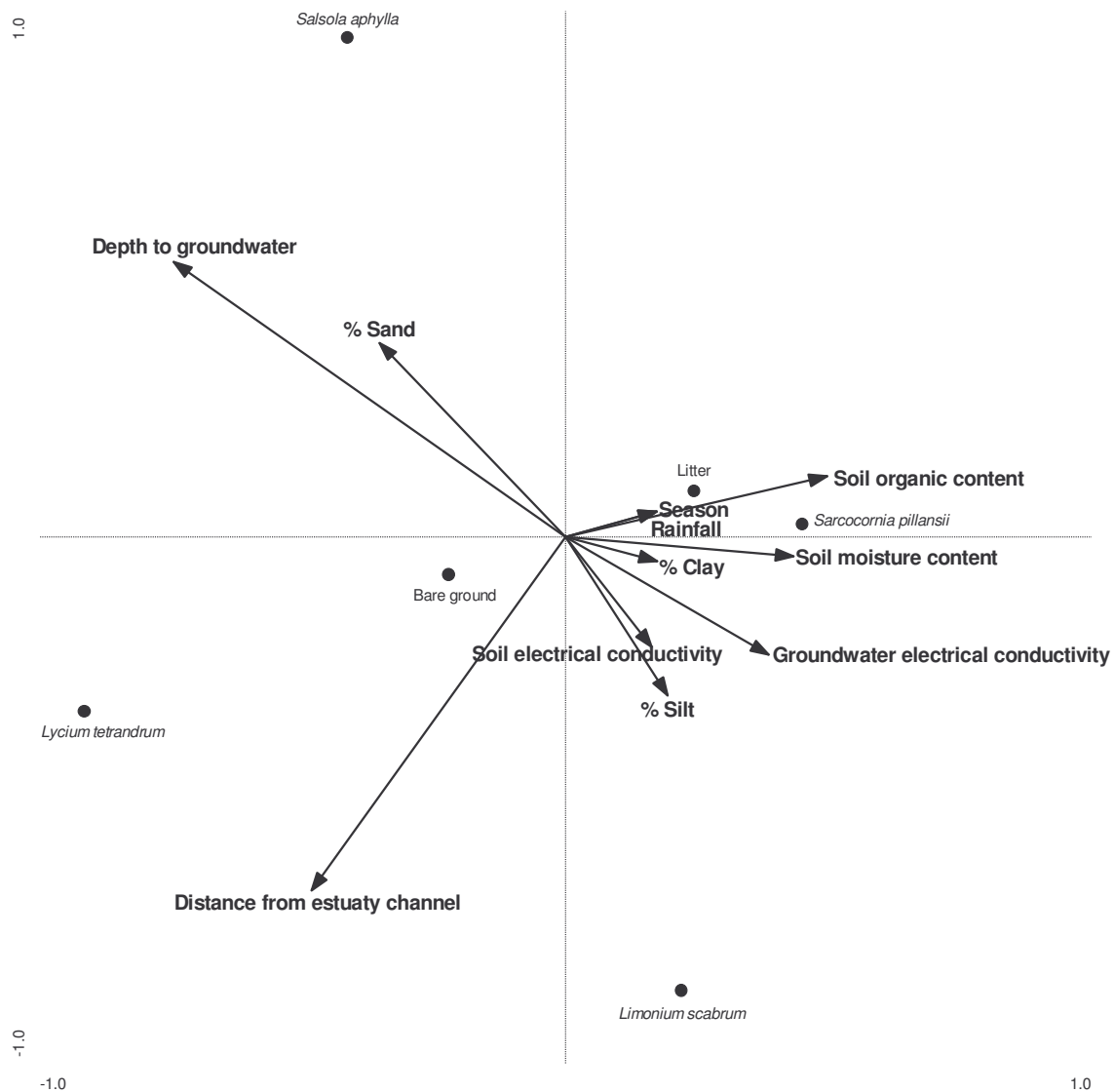


Figure 14 Ordination diagram based on a CCA of seasonal species and environmental data for the Olifants Estuary.

Table 4 Summary of CCA of seasonal species and environmental data for the Olifants Estuary ($p = 0.001$).

	Axis 1	Axis 2	Axis 3	Axis 4	Total Inertia
Eigenvalues	0.153	0.064	0.018	0.006	0.565
Species-environment correlation	0.704	0.673	0.631	0.388	
Cumulative percentage variance					
of species data	27.0	38.4	41.5	42.7	
of species-environment relation	62.9	89.3	96.6	99.3	
Sum of all unconstrained eigenvalues					0.565
Sum of all canonical values					0.243

4.2.4 Correlation Analysis

Correlation analysis made it possible to analyse the system as a whole and not as individual transects or single sampling periods that are difficult to compare. Only a few of the correlations were significant ($p < 0.05$) and due to the large sample size, the correlations were not very strong. The depth below the sediment surface was negatively correlated with percentage sediment moisture, percentage sediment organic content and the percentage clay fraction in the sediment and positively correlated with the percentage sand fraction in the sediment (Table 5). This indicates a decrease in percentage sediment moisture, percentage sediment organic content and the percentage clay fraction in the sediment, and an increase in the percentage sand fraction in the sediment with an increase in depth below the sediment surface. With an increase in distance inland from the estuary channel, the percentage silt fraction in the sediment increased. Percentage silt fraction in the sediment was the variable that showed the strongest correlations with other variables. Sediment organic content and percentage clay and sand fraction all decreased with an increase in percentage silt fraction in the sediment. Groundwater electrical conductivity and depth to groundwater both decreased with an increase in rainfall and a change of season (winter). Groundwater electrical conductivity was positively correlated with depth to groundwater, indicating an increase in groundwater electrical conductivity with an increase in depth to groundwater. Groundwater electrical conductivity also increased with an increase in sediment electrical conductivity. Percentage clay fraction in the sediment increased with a decrease in sediment electrical conductivity.

Table 5 Correlations among physico-chemical variables for the Olifants Estuary over both sampling periods. (Percentage sediment moisture content (% Moist), percentage sediment organic content (% OC), sediment electrical conductivity (EC), percentage clay fraction of the sediment (% Clay), percentage sand fraction of the sediment (% Sand), percentage silt fraction of the sediment (% Silt), groundwater electrical conductivity (GWEC), depth to groundwater (GW Depth), rainfall (Rain), seasons (Season), distance from estuary channel (Distance) and depth below sediment surface (Depth). Significant correlations, spearman r, are those for $p < 0.05$; $n = 864$).

	% Moist	% OC	EC	% Clay	% Sand	% Silt	GWEC	GW Depth	Rain	Season	Distance	Depth
% Moist	-											
% OC	N/S	-										
EC	N/S	0.36	-									
% Clay	N/S	0.33	N/S	-								
% Sand	N/S	N/S	N/S	N/S	-							
% Silt	N/S	-0.26	N/S	-0.41	-0.72	-						
GWEC	0.31	0.28	0.41	N/S	N/S	-0.25	-					
GW Depth	-0.43	-0.37	N/S	-0.30	0.37	N/S	-0.44	-				
Rain	0.40	N/S	N/S	N/S	N/S	N/S	N/S	N/S	-			
Season	0.40	N/S	N/S	N/S	N/S	-0.23	N/S	N/S	N/S	-		
Distance	N/S	N/S	N/S	N/S	N/S	0.26	N/S	N/S	N/S	N/S	-	
Depth	0.42	-0.56	-0.35	N/S	N/S	0.59	N/S	N/S	N/S	N/S	N/S	-

4.3 DISCUSSION

Salt marsh zonation is determined by the spatial and temporal variation in physico-chemical sediment properties (Van Diggelan 1991, Bornman 2002). Therefore to obtain a better understanding of the freshwater requirements of salt marsh in the Olifants Estuary, changes in vegetation cover and edaphic conditions were studied over time and space. The environmental variables that influenced the distribution of salt marsh vegetation were distance from the estuary channel, groundwater electrical conductivity, depth to groundwater, rainfall, percentage silt fraction in the sediment and sediment moisture content.

The supratidal macrophytes *Lycium tetrandrum*, *Salsola aphylla* and *Limonium scabrum* as well as the upper intertidal salt marsh species (mostly confined to the mid to upper levels of estuarine salt marshes) *Sporobolus virginicus*, *Disphyma crassifolia* and *Chenolea diffusa* were influenced by rainfall, whereas the lower intertidal salt marsh species were not. According to Adams *et al.* (1992) supratidal macrophytes are usually associated with low moisture content due to limited tidal flushing occurring in this area, thus rainfall and evaporation are more important in influencing the distribution of these species. Flooding can result in increased water levels and flooding of the supratidal area. This is important in flushing out salts from this habitat. According to Beeftink (1977) sediment salinity becomes increasingly influenced by the weather conditions from the mean high water upward. De Leeuw *et al.* (1991) found that weather conditions do not influence the production of salt marsh plant communities below mean high water (lower intertidal salt marsh), but their influence becomes significant moving upward from mean high water (upper intertidal and supratidal salt marsh). Adams *et al.* (1992) found that sediment salinities of the intertidal macrophyte communities were determined by the salinity of the adjacent water body, since these species are inundated daily by tides. Fluctuations in water column salinity would therefore raise and lower sediment salinities. This would influence macrophyte germination and growth.

The supratidal macrophytes were associated with low sediment and groundwater electrical conductivity, increased distance from the estuary channel and an increase in depth to groundwater, whereas the opposite was true for the intertidal species. Ursino *et al.* showed that subsurface (groundwater) flow depends on the distance from the nearest creek or channel and that the subsurface water movement near tidal creeks is both vertical and horizontal, while further from the creeks, it is primarily vertical. Bornman (2002) found that depth to the water table had the greatest influence on vegetation distribution in the Olifants estuary. Elevation and distance from the estuary channel influenced the distribution of *Sarcocornia pillansii* through their influence on the depth to groundwater. The depth to groundwater increases with an increase in distance from the estuary channel and a higher elevation. Therefore depth to the water table was a factor of elevation and distance. Bornman (2002) showed that the cover abundance of *Sarcocornia pillansii* was visibly reduced where the water table was deeper than 1.5m and/or where the electrical conductivity of the groundwater was accessible and had a high ion concentration ($> 80 \text{ mS.cm}^{-1}$). Sanchez *et al.* (1998)

and Rogel *et al.* (2001) found that groundwater salinity had a greater influence on the zonation of vegetation than water table depth in the intertidal area. This may be due to the fact that the depth to groundwater table in the intertidal zone is an insignificant variable to consider as moisture availability is not a problem due to daily tidal inundation.

Both the Kromme and the Olifants estuaries have relatively high surface sediment electrical conductivity when compared to other estuaries. As a result of this the salt marsh is characterized by numerous bare patches. Bertness (1991) found that hypersaline conditions limit the colonization of high marsh perennials into bare patches. Adams *et al.* (1992) found that no salt marsh plants grew in areas with high sediment salinity (> 45 ppt). Gough and Grace (1998) examined the effects of altered flooding and salinity on coastal marsh communities in Louisiana (USA) and found that an increase in salinity reduced species numbers and biomass, whereas a decrease in salinity had little effect on species numbers or biomass, but community composition changed.

In the Olifants Estuary rain had little influence on the soil moisture and EC values of the deeper layers compared to the surface and subsurface soil layers. Rainfall in this semi-arid region is too low to effectively leach salts out of the upper soil horizons and the large supratidal and floodplain salt marsh must therefore be managed to maintain a suitable water table level and salinity.

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ANNEXURE 1

Table 1 List of species, authorities, families and abbreviations as used in the text.

Species Name	Authority	Family	Abbreviation
<i>Bassia diffusa</i>	Thunb.	Chenopodiaceae	Bassdif
<i>Drosanthemum parvifolium</i>	(Haw.) Schwant.	Mesembryanthemaceae	Drospav
<i>Frankenia capitata</i>	L.	Frankeniaceae	Francap
<i>Juncus kraussii</i>	Hochst.	Juncaceae	Junckra
<i>Limonium scabrum</i>	(Thunb.) Kuntze	Plumbaginaceae	Limosca
<i>Lycium cinereum</i>	Thunb. (Sens. Lat.)	Solanaceae	Lycicin
<i>Lycium tetrandrum</i>	Thunb.	Solanaceae	Lycitet
<i>Mesembryanthemum nodiflorum</i>	L.	Mesembryanthemaceae	Mesenod
<i>Psilocaulon dinteri</i>	(Engl.) Schwant.	Mesembryanthemaceae	Psilden
<i>Salsola aphylla</i>	L.f.	Chenopodiaceae	Salsaph
<i>Sarcocornia perennis</i>	(Mill.) A.J. Scott	Chenopodiaceae	Sarcper
<i>Sarcocornia pillansii</i>	(Moss) A.J. Scott	Chenopodiaceae	Sarcpil
<i>Sporobolus virginicus</i>	(L.) Kunth.	Poaceae	Sporvir
<i>Triglochin bulbosa</i>	L.	Juncaginaceae	Trigbul
<i>Zostera capensis</i>	Setchell.	Zosteraceae	Zostcap

APPENDIX F

SPECIALIST REPORT: INVERTEBRATES

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1. INTRODUCTION

1.1 General characteristics of the Olifants river and catchment

The Olifants river has the second largest catchment of South African rivers (46 220 km², Morant 1984), most of which lies in arid country (Day 1981). The main catchment is southwest of the mouth and is composed mostly of quartzitic sandstone and quartzites of the Table Mountain Group. This accounts for the relatively low silt load initially carried by the river, although the silt load increases nearer the sea. Two dams are located along the main tributary; the Clanwilliam dam (127 x 10⁶ m³) and the much smaller Bulshoek dam (7.5 x 10⁶ m³). The Doring is a major tributary of the Olifants, joining the river below the Bulshoek dam. Old river terraces characterize the river valley below Bulshoek and these are intensively used for irrigated fruit farming.

Annual rainfall in the region mostly falls during the winter months. River flow is therefore highly seasonal, although summer floods do occur. Mean annual runoff for the entire Olifants catchment is 122 x 10⁷ m³ (Morant 1984).

1.2 General characteristics of the Olifants estuary

The permanently open Olifants estuary (Fig. 1) is tidal for about 32 kilometres, extending as far as the Lutzville bridge. However, the transition between brackish and freshwater usually occurs much further downstream. The location of this boundary zone is highly variable and very dependent on river flow (Morant 1984, Bornman et al. 2002).

The estuary mouth opens to the sea between a large sand peninsula and a rocky outcrop. The position of the mouth is deflected northwards, due to the northwest direction of the predominant longshore currents. A shallow blind arm of the estuary is located to the south of the sand peninsula (Die Dam, Fig.1) and represents a former channel established during strong river flooding. In 1925, this channel blocked off from the sea as a consequence of a violent storm (Day 1981). Remnants of other channels in this sector of the estuary are also still evident.

The estuarine floodplain is extensive and covered by saltmarsh vegetation (Bornman et al. 2002). Near the mouth the estuary is 1.5 km wide, although the main channel is considerably narrower (Morant 1984). Maximum water depth in the lower estuary is about 5-7 m (Morant 1984), decreasing to about 2-3 m in the upper estuary. Tidal range is about 1.3 m (quoted in Bornman 2002).

2. SAMPLING METHODS

The estuary was sampled on two occasions (March and August 2004) at ten sampling sites along the estuary (Fig. 1). Station 10 is located about 22 km from the mouth. At the time of sampling in March 2004, salinity at the uppermost site was brackish as a consequence of a relatively dry summer. Similarly, low winter rainfall prior to the August visit resulted in a relatively short downstream shift of the brackish water zone (only as far as Station 8).



Fig. 1. Map of the Olifants estuary. Distance from the mouth indicated in kilometers. Sites 1 to 10 refer to the subtidal invertebrate sampling stations selected for the monitoring programme - March and August 2004. Station co-ordinates are given in Table 1.

Table 1. Coordinates for sampling stations (1 – 10) shown in Fig 1.

Station	Latitude	Longitude
1	31° 41.775' S	18° 11.426' E
2	31° 41.156' S	18° 11.991' E
3	31° 40.351' S	18° 11.830' E
4	31° 39.250' S	18° 11.709' E
5	31° 38.027' S	18° 12.023' E
6	31° 37.220' S	18° 11.655' E
7	31° 36.726' S	18° 12.337' E
8	31° 35.968' S	18° 13.513' E
9	31° 35.089' S	18° 13.102' E
10	31° 34.197' S	18° 13.019' E

2.1 Abiotic measurements

A YSI 6600 multi-parameter sonde was deployed at all 10 stations (Fig. 1) during a continuous run up the estuary each trip. Table 2 summarizes general conditions that prevailed.

Table 2. Summary of general estuarine conditions when physico-chemical data were recorded. FM = Full Moon, NM = New Moon, LSW = Low slack water, HSW = High slack water

Date	Lunar phase	Starting time	Duration	General comments
2 March	3 days after 3 rd Q	11:06	4.5 h	Readings over HSW
9 Aug	1 day after 1 st Q	15:00	3.5 h	Readings over LSW

Variables were measured near the surface, at 0.5 m depth, at 1 m and thereafter at 1 m depth intervals. The following parameters were recorded at every level: Dissolved oxygen (percent saturation and in mg per litre), salinity (ppt), temperature (°C), conductivity (mS per cm) and pH. During the August visit, turbidity was also measured.

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

µm, 125 µm, 90 µm, 63 µm and <63 µm). General descriptive categories of particle size classes are shown in Table 3. Percent organic content was obtained after incinerating pre-weighed dry sediment samples (dried at 60°C) for 24 hrs at 660°C.

Table 3. General description of the different categories of particle size classes.

Particle size class	Category
< 2 mm	Very coarse sand
<1 mm	Coarse sand
<500 µm	Medium sand
<250 µm	Fine sand
<125 µm	Very fine sand
<0.63 µm	Silt/mud

2.2 Biological sampling

Collection of samples was done from the deck of a 4.5 m twin-hull fibreglass boat equipped with a 40 hp outboard motor at sites 1 – 10. Approximately 3-4 days were spent in the field on each sampling occasion. Two campaigns were undertaken in 2004; between 1 – 5 March and 7 – 11 August. The summer trip therefore took place during the low-flow season and the winter trip at a time when freshwater conditions normally dominate the estuary. Sampling for invertebrates included the zooplankton, hyperbenthos and the benthos, using appropriate gear described below.

Analysis of samples was completed in the laboratory. Invertebrates were identified to species level wherever possible and the data analysed using multivariate statistics from the statistical package, PRIMER V.5 (Plymouth Routines in Multivariate Ecological Research). If multivariate techniques were not appropriate, other packages using MS Excel or Statistica for Windows were used.

2.2.1 Macrozooplankton

Samples were all collected after dark using two slightly modified WP2 plankton nets (57 cm diameter and 200 µm mesh), fitted with calibrated Kahlsico flowmeters. Two replicates were collected per station. Each net was attached to a 1 m boom extending laterally on either side of the bow of a flat-bottomed boat (4.5 m length). Midwater net tows continued for 2 to 3 minutes (at a speed of 1 to 2 knots) at all 15 stations (Fig. 1). Although finer nets may be used, this usually leads to excess clogging of the mesh. Filtration efficiency is reduced and larger organisms such as small shrimps (e.g. mysids – often extremely abundant in estuaries) are then under-represented in samples because of increased net avoidance. Animals retained by nets were stored in 10% formaldehyde solution in 500 ml plastic bottles. In the laboratory animals were identified to species level under a microscope and final abundance expressed as the average number per m³ of water calculated from the two samples collected at each site.

2.2.2 *Hyperbenthos*

Hyperbenthic animals were sampled at all 10 subtidal stations (Fig. 1) using a sled mounted on broad skids. Two replicates were collected at each site. The rectangular opening to the sled measured 75 x 70 cm, to which is attached a 500 μ m mesh net. A calibrated Kahlsico 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 numbers per m^3 of water calculated from the two samples collected at each site. Animals captured in sled samples are usually fairly large, measuring up to 1-2 centimeters. Most of the smaller organisms such as copepods escape through the mesh and were therefore not enumerated or identified in sled samples.

2.2.3 *Subtidal benthic invertebrates*

Subtidal benthic invertebrates were collected using a Van Veen type grab and the contents sieved through a 500 μ m mesh screen bag. The grab has a 200 cm^2 bite that penetrated the sediment down to about 10 cm depth. Nine replicates were taken at each site during daylight hours. Replicates were collected over an area of about 10 m^2 in the channel area at each site. Animals retained by the sieve were stored in 500 ml plastic bottles and magnesium chloride solution added to relax the polychaete worms for later identification. Samples were later preserved after adding 10% formaldehyde solution. Final abundance was expressed as the average number of each species per m^2 of substratum at each site, calculated from the nine replicates per site.

3. RESULTS

3.1 Abiotic measurements

Abiotic measurements recorded during each visit are indicated in Tables 4 and 5 respectively. Data are mostly presented for different levels in the water column e.g., a mean value for the water column in addition to surface and bottom values. This format was used when links between the physico-chemical driving forces and biological community patterns were explored using the PRIMER package. Zooplankton may be more influenced by integrated salinity values compared to the benthos that may have a stronger link with bottom salinity values. The potential effects of salinity on different communities are likely to be exacerbated because of stratification in the water column.

Table 4. Abiotic measurements recorded in March 2004 for the 10 stations (see Fig. 1) at the Olifants estuary. Integrated readings refer to mean values for all readings in the water column at each station (see text). Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum.

Station	1	2	3	4	5	6	7	8	9	10
Salinity (integrated)	34.4	34.1	32.4	29.2	22.8	21.4	18.6	13.8	10	7.4
Salinity (surface)	34.4	33.7	32.4	29.2	22.7	20.1	16.5	10.7	6.9	5.7
Salinity (bottom)	34.4	34.1	32.4	29.2	22.8	23.1	20.3	17.7	15.7	11.4
Temperature (integrated °C)	12.6	13.8	18.4	20.9	21.8	22	22.5	23.4	23.7	23.8
Temperature (surface °C)	12.6	15	18.5	20.9	21.8	22.1	22.5	23.3	23.4	24
Temperature (bottom °C)	12.4	13.4	18.4	20.9	21.8	22.1	22.6	23.5	24	23.9
Oxygen (integrated mg/l)	10.2	8.9	7.5	7.6	7.8	7.5	7.6	8.2	8.2	9.6
Oxygen (surface mg/l)	11.2	9.2	7.5	7.7	8	8.7	9.7	9.1	9.6	11.6
Oxygen (bottom mg/l)	10	8.5	7.5	7.5	8	6.7	5.2	6.8	6.1	6.6
Oxygen (% saturation integrated)	95.5	89	79.5	83.4	91	85.3	85.8	95.3	95	112.5
Oxygen (% saturation surface)	103	90	80	86	92	99	111	106	112	136
Oxygen (% saturation bottom)	92	88	79	82	91	76	59	79	70	77
Depth (m)	1	1.75	1.9	1	2.3	3.4	3	3.3	3	2
pH (integrated)	8.2	8.1	8.2	8.3	8.4	8.5	8.5	8.7	8.8	8.8
Chlorophyll a (mg/l integrated)										
Chlorophyll a (mg/l maximum)										
Sediment - % mud (<0.065 mm)	2.37	5.37	32.21	1.89	25.64	17.38	5.06	5.23	2.40	0.53
Sediment - % sand (0.125 - 0.250 mm)	64.47	79.80	54.54	85.98	45.67	19.88	66.40	41.65	20.49	17.00
Sediment - % sand (0.355 - 0.500 mm)	29.54	2.40	2.72	6.08	19.83	58.69	28.59	49.98	74.46	75.85
Sediment organic matter (%)	0.74	1.65	2.50	1.16	3.13	1.81	1.71	1.57	1.23	0.70

Table 5. Abiotic measurements recorded in August 2004 for the 10 stations (see Fig. 1) at the Olifants estuary. Integrated readings refer to mean values for all readings in the water column at each station (see text). Surface readings refer to the top 15 cm of the water column; bottom readings reflect conditions just above the substratum.

Station 10	1	2	3	4	5	6	7	8	9	
Salinity (integrated)	13.7	17.2	20.7	28.1	2.7	15.7	0.3	0.2	0.2	0.2
Salinity (surface)	10.2	9.1	5.1	3.4	2.7	0.5	0.3	0.2	0.2	0.2
Salinity (bottom)	17.1	37.1	35.7	36.1	2.7	28.1	0.4	0.2	0.2	0.2
Temperature (integrated °C)	14.7	14.3	14.0	13.5	14.7	13.8	14.0	14.0	14.1	14.1
Temperature (surface °C)	14.8	15.1	15.1	15.0	14.8	14.5	14.1	14.1	14.2	14.2
Temperature (bottom °C)	14.5	13.0	13.1	13.0	14.7	13.4	13.9	14.0	13.9	14.1
Oxygen (integrated mg/l)	9.6	8.7	8.3	7.7	8.9	6.6	8.2	8.3	8.3	8.5
Oxygen (surface mg/l)	9.5	9.3	9.2	9.2	9.0	8.9	8.5	8.8	8.6	8.9
Oxygen (bottom mg/l)	9.7	7.9	7.6	7.3	8.7	4.6	8.1	8.2	8.1	8.5
Oxygen (% saturation integrated)	101.8	94.5	91.0	87.4	89.1	69.9	80.2	81.2	80.5	83.1
Oxygen (% saturation surface)	100.0	100.5	95.1	93.5	90.8	87.9	83.2	85.8	84.5	87.5
Oxygen (% saturation bottom)	103.6	93.6	89.8	87.3	87.4	52.5	78.6	79.6	78.7	82.3
NTU (Integrated)	6.0	29.0	31.7	60.1	14.3	59.8	31.1	7.7	52.1	56.7
NTU (Surface)	0.0	2.2	7.9	5.7	7.5	5.9	5.1	7.8	3.7	4.2
NTU (Bottom)	12.0	58.1	54.3	87.7	21.0	96.4	58.5	7.6	84.6	101.2
Depth (m)	0.5	1.3	1.5	3.4	0.5	3.5	1.5	2.5	3.0	4.3
pH (integrated)	8.1	7.9	8.0	7.9	7.9	7.7	7.9	7.7	7.6	7.5
Chlorophyll a (mg/l integrated)										
Chlorophyll a (mg/l maximum)										
Sediment - % mud (<0.065 mm)	1.2	44.7	18.0	41.4	75.5	43.9	2.0	89.5	22.6	5.0
Sediment - % sand (0.125 - 0.250 mm)	13.2	20.4	54.1	39.2	26.1	38.4	41.3	1.3	25.8	8.6
Sediment - % sand (0.355 - 0.500 mm)	76.4	3.8	16.9	5.1	1.9	1.4	50.7	0.7	11.2	70.6
Sediment organic matter (%)	0.7	3.9	0.6	3.6	1.6	4.0	2.0	8.3	2.1	2.5

3.1.1 Abiotic structures

Clear horizontal and vertical salinity gradients were apparent during both sampling trips (Figs 2A & 2B). In March, salinity ranged from 34.4 at the mouth to 5.4 ppt at Station 10. The water column tended to be well mixed for the first 7.5 km (up to Station 5 where the difference between surface and bottom values did not exceed 0.5 ppt). Stratification was well developed upstream of Station 5, with a maximum difference of 8.8 ppt at Station 9 (17 km from the mouth).

In August, low salinity values (<1 ppt) were recorded upstream of Station 6 due to increased river discharge during winter. Stratification was also more strongly developed compared to summer, particularly at Stations 3 and 4 (>30 ppt). Note that samples were collected in relatively shallow water at Stations 1 and 5 (see Table 5) and would therefore not reflect stratified conditions that were most likely present in deeper channel areas at the time.

The water column was generally well mixed with respect to temperature. In summer, vertical temperature differences did not exceed 0.2°C at most stations,. At Station 2, bottom waters were 1.6°C cooler than the surface. A strong temperature gradient was evident along the estuary, with the uppermost stations being about 11.5°C warmer than the mouth. The most

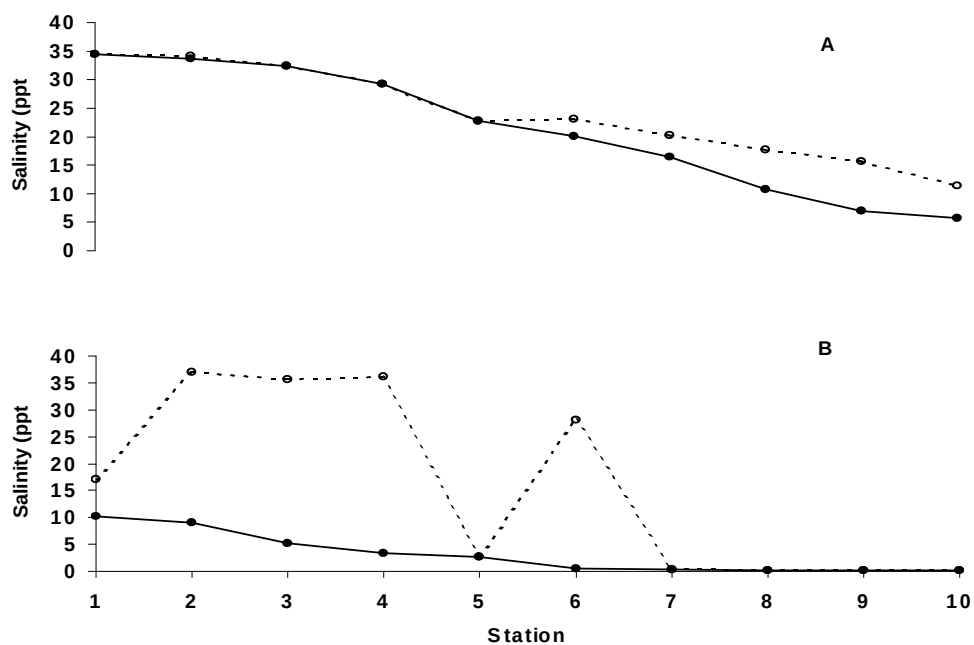


Fig. 2. Salinity values recorded in near-surface (solid line) and bottom waters (dashed line) at 10 stations in March (A) and August 2004 (B).

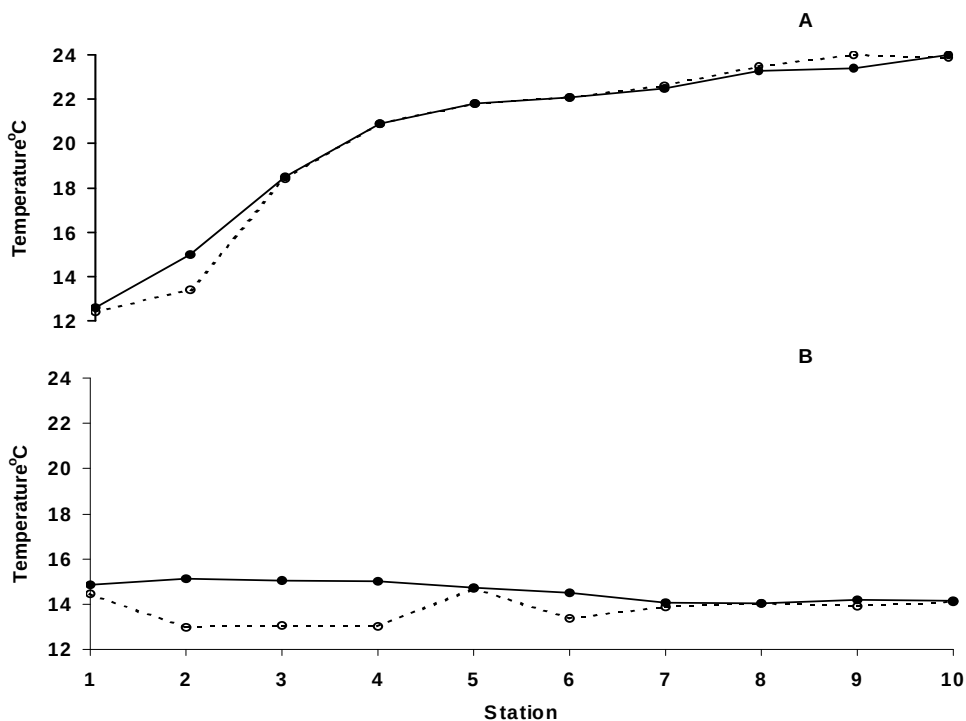


Fig 3. Temperature values recorded in near-surface (solid line) and bottom waters (dashed line) at 10 stations in March (A) and August 2004 (B).

rapid change occurred along the first 6 km of the estuary (up to Station 4) where temperature decreased by $>8^{\circ}\text{C}$. Salinity dropped by only 5.2 ppt along the same reach of the estuary.

During winter (August), the horizontal temperature gradient was absent, with temperatures at the mouth and upper reaches remaining at similar levels (Table 5, Fig. 3). Water temperature in the upper reaches of the estuary had therefore dropped by $>11^{\circ}\text{C}$, but water temperatures at the mouth had changed by $<1^{\circ}\text{C}$.

No consistent trend in the percentage distribution of mud ($<0.065\text{ mm}$) was apparent in the data. During summer mud was relatively important in the middle estuarine reaches, while in winter muddy sediment was more evenly distributed throughout the estuary. However, data suggest that mud constituted a relatively small proportion in the mouth (Station 1) and at Station 9 and 10 in the upper reaches. A similar pattern was evident during each trip for the distribution of organic matter along the estuary.

3.1.2 Biotic species composition and abundance

Zooplankton species composition and abundance recorded in during each of the two field trips is given in Annexure 1 and Annexure 2. Twenty and 18 taxa were present in March and August samples respectively, with copepods clearly dominating the zooplankton from a numerical viewpoint (over 99%, Fig 4).

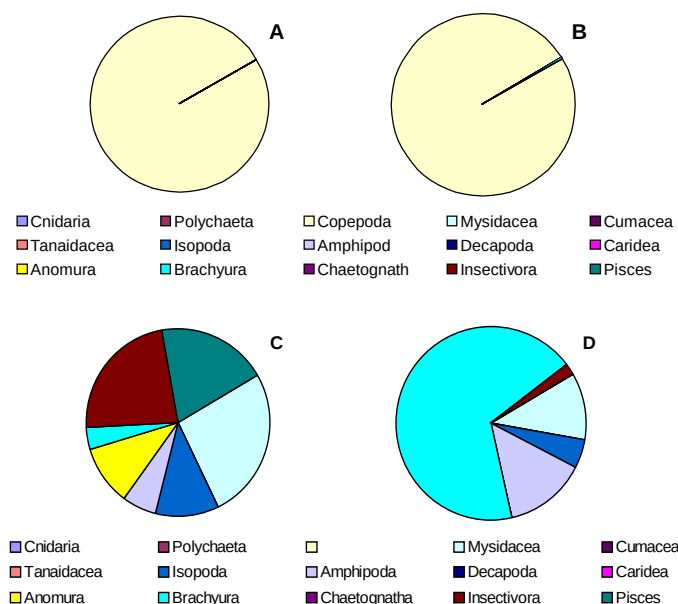


Fig 4. Pie-diagram showing the numerical dominance of copepods in March (A) and August (B) in the zooplankton of the Olifants estuary. After removal of copepods from the diagram, mysid shrimps, chironomid larvae and *Gilchristella aestuaria* eggs and larvae dominated the zooplankton in March (C), while brachyuran larvae (mainly *Hymenosoma orbiculare*), dominated in August (D).

Pseudodiaptomus hessei dominated the zooplankton during both sampling trips and was the only zooplankton recorded at all stations. Numbers increased progressively upstream, peaking at Stations 5 and 6 in summer, and 4 and 5 in winter (Fig. 5). Thereafter, numbers decreased sharply upstream. Other copepod species were relatively rare in the zooplankton

(Annexure 1 and 2). A species of *Saphiriella* was present in the lower estuary around high tide, presumably moving back to the marine environment on the ebb.

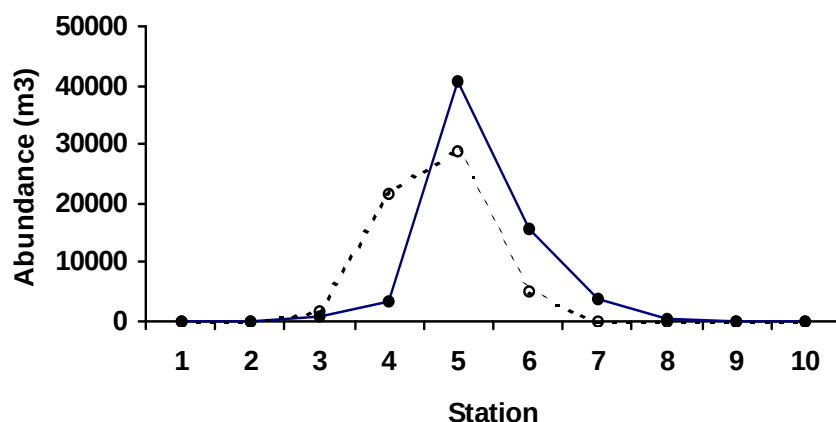


Fig 5. Distribution of the copepod *Pseudodiaptomus hessei* at 10 stations in the Olifants river estuary, March 2004 (solid line) and August 2004 (broken line). *P. hessei* was the most abundant species recorded in the zooplankton.

Acartia longipatella was the third most abundant copepod in the zooplankton in March (Fig.6), It August numbers were low (<50 m³).

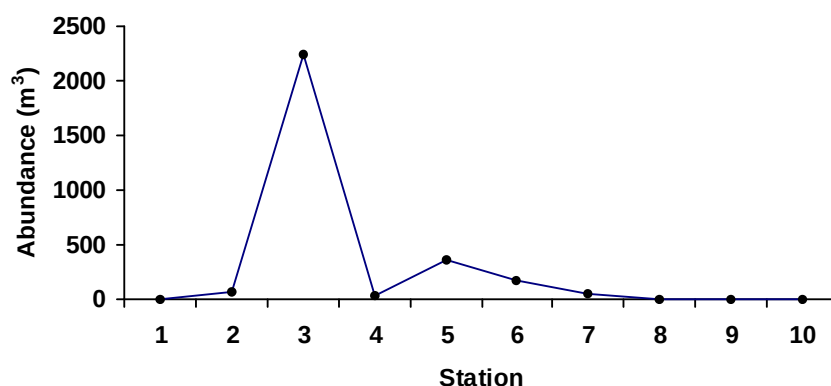


Fig 6. Distribution of the copepod *Acartia longipatella* at 10 stations in the Olifants river estuary, March 2004. In August *A. longipatella* was only present at Station 3 in low numbers (<50 m³).

Three species of mysid shrimps were present in the estuary, but numbers were very low, as were all other zooplankters (Annexure 1 & 2).

Hyperbenthic species composition and abundance recorded in March and August 2004 is given in Annexure 3 and 4 respectively. The number of taxa was low during both trips with only 12 and 10 species recorded. No species dominated the hyperbenthos and most occurred at abundance levels of $<1 \text{ m}^{-3}$. The amphipod *Melita zeylanica* was the most abundant (48 m^{-3}), occurring at the uppermost station in March. The crown-crab *Hymenosoma orbiculare* was the next most abundant at 4 m^{-3} at the same station.

Subtidal benthic species composition and abundance recorded in March and August 2004 is given in Appendices 5 and 6. Twenty-two and 23 taxa were identified respectively. Polychaete worms numerically dominated on both occasions, representing 61% and 58% on total abundance of all species. Amphipods were the second most important group, contributing 38% and 23% respectively. In August, chironomid larvae (11%) and a small anthurid isopod (8%) were also relatively important.

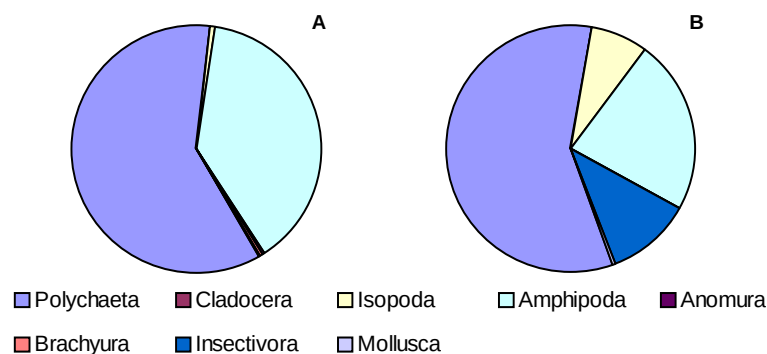


Fig 7. Pie-diagram showing the numerical dominance of polychaetes in March (A) and August (B) 2004 in the subtidal benthos of the Olifants estuary. Amphipods were the second most important group, while Chironomid larvae and a small anthurid isopod were also numerically important in August.

The most abundant polychaete in March was *Ceratonereis keiskamma*, attaining maximum abundance at the uppermost sampling site (Fig 8). The amphipod *Corophium triaenonyx* also attained extremely high numbers at the same station.

Three polychaete species were common in August, with their combined abundance levels peaking in the middle estuary (Fig. 9). The centre of distribution of each species (*Ceratonereis keiskamma*, *Desdemona ornata* and an Oligochaete species) was similar, shifting marginally between Stations 5 and 8). The amphipods *Grandidierella lutosa* and *Melita zeylanica* attained high numbers immediately downstream, peaking at Stations 3 and 4 respectively (Fig. 9).

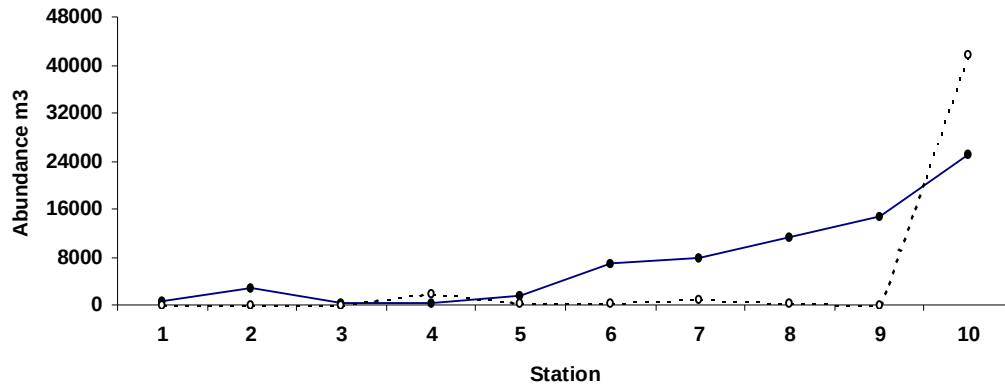


Fig 8. Distribution of polychaetes (solid line) and amphipods (hatched line) in March 2004 at 10 stations in the Olifants river estuary. Polychaete abundance was attributed to *Ceratonereis keiskama* at most sites, while *Corophium triaenonyx* was the most abundant amphipod.

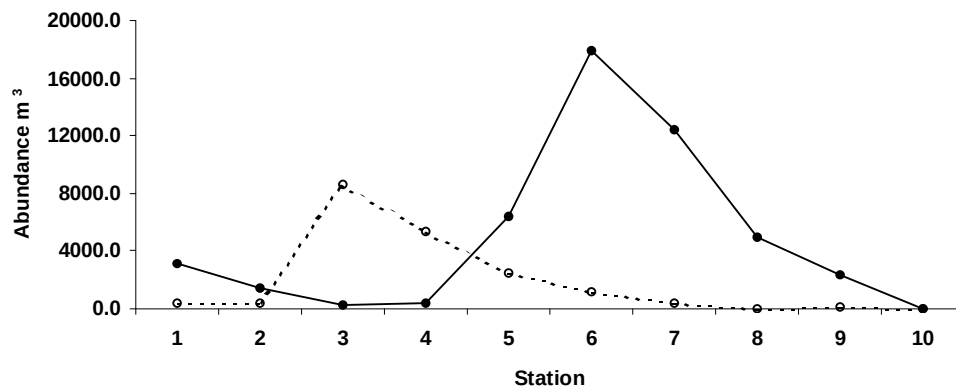


Fig 9. Distribution of polychaetes (solid line) and amphipods (hatched line) in August 2004 at 10 stations in the Olifants river estuary. *Ceratonereis keiskama* and *Desdemona ornata* were the most common polychaete worms, while *Grandidierella lutosa* and *Melita zeylanica* were the most abundant amphipods.

Note that in August, *Corophium triaenonyx* was relatively scarce compared to their abundance in March (<1600 m² compared to >42 000 m²), although the population attained maximum density at the uppermost station on both occasions.

3.1.3 Classification and ordination of biotic assemblages

Bray-Curtis similarity analysis using group average mode on square-root transformed zooplankton data (March 2004, Annexure 1) showed 3 main clusters around the 50% cut-off level (Fig 10). Composition of the community at Stations 1 and 2 (Group 1) showed very little similarity (<20%) compared to middle estuary sites (Group 2), while Stations 9 and 10 (Group 3) were also weakly linked to other stations. Group 1 and Group 3 represent marine and freshwater associated species respectively. Middle estuary sites (4 – 6) are typically estuarine, while Sites 3 and 8 represent transitional communities (mixed species assemblages) between the mouth and upper sites respectively. Analysis of similarity (ANOSIM) using the Primer package indicated a Global R value of 1; and the null hypothesis of no difference between selected groups (1, 2 and 3) is rejected at the 0.5% level.

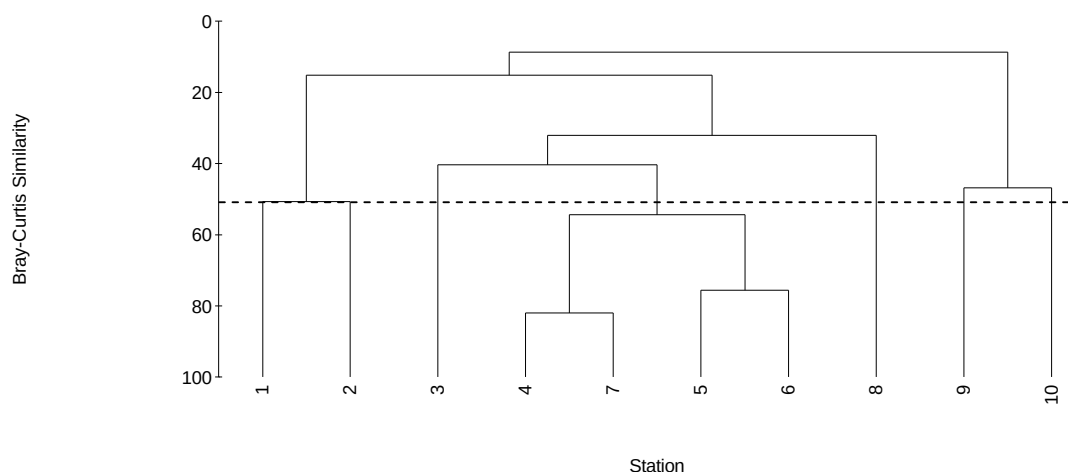


Fig. 10. Dendrogram for Bray-Curtis similarity clustering of sites based on zooplankton composition and abundance. Data for the Olifants estuary, March 2004. The dotted line represents the 50% cut-off line.

Three main groups using Bray-Curtis similarity analysis were again identified in August samples (Fig. 11, Annexure 2). Composition of the community at Stations 1 and 2 (Group 1) showed some similarity (ca 45%) compared to upper estuary sites (Stations 7-10, Group 3), but little similarity to middle estuary sites (Stations 3-6, Group 2). The closer affiliation between Groups 1 and 3 relative to middle estuarine sites is significant, but is probably a response to strong salinity stratification recorded in the middle estuary (Fig. 2b). Thus, the lower and upper estuary was similar in terms of salinity compared to deeper bottom waters in the middle estuary where a lens of high salinity water was present. Analysis of similarity (ANOSIM) using the Primer package indicated a Global R value of .933; and the null hypothesis of no difference between selected groups (1, 2 and 3) is rejected at the 0.2% level.

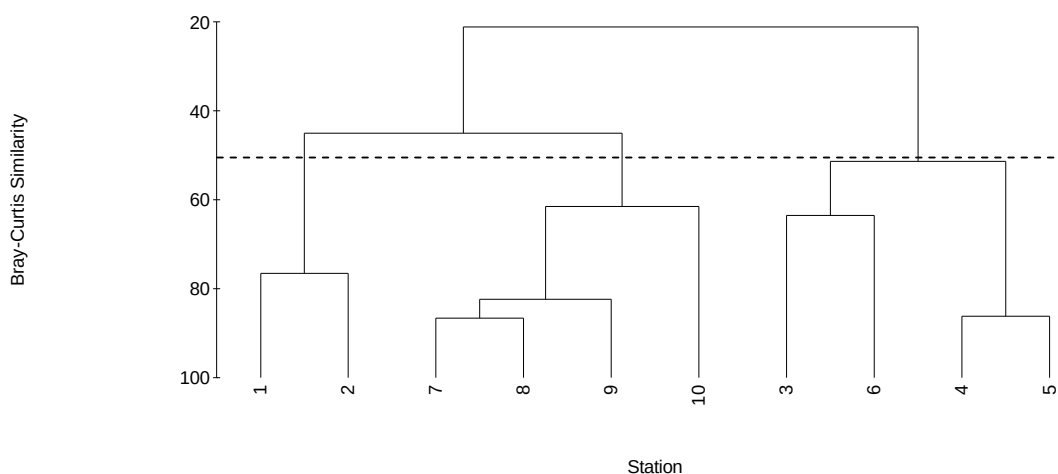


Fig. 11 Dendrogram for Bray-Curtis similarity clustering of sites based on zooplankton composition and abundance. Data for the Olifants estuary, August 2004. The dotted line represents the 50% cut-off line.

Group linkages shown by each Bray-Curtis similarity matrix (Figs. 10 and 11) is also closely reflected by the non-metric multi-dimensional scaling (MDS) plots (Figs. 12 and 13). The low stress levels (0.02) indicate a high degree of confidence in the accuracy of sample relationships (Clarke & Warwick 1994).

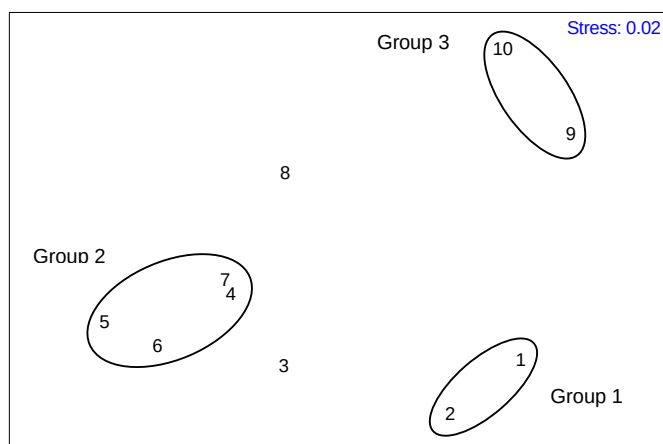


Fig. 12. 2-dimensional MDS configuration of zooplankton in the Olifants estuary, March 2004. Relative distances between sites is a reflection of the degree of similarity between them. The three groups are indicated (see Fig. 10).

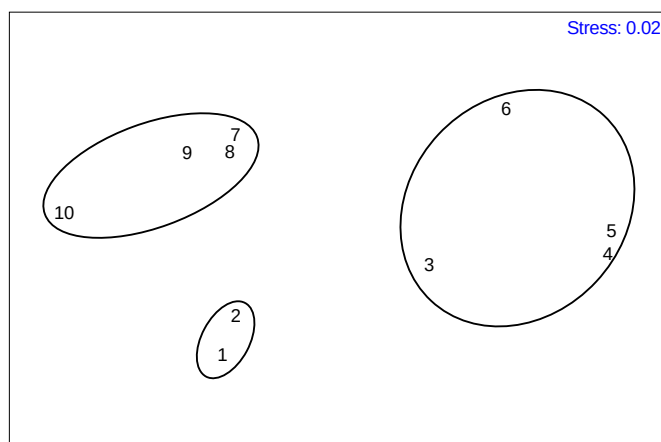


Fig. 13. 2-dimentional MDS configuration of zooplankton in the Olifants estuary, August 2004. Relative distances between sites is a reflection of the degree of similarity between them. The three groups are indicated (see Fig. 11).

Environmental variables (Tables 4 and 5) were then linked to the biotic assemblage data for March and August using the PRIMER package BIO-ENV in order to establish which of the physico-chemical parameters best explain linkages. A Draftsman Plot indicated that in March, integrated salinity, surface salinity and bottom salinity were highly correlated. Thus, surface and bottom salinity readings were excluded from further analysis. A similar exercise led to the exclusion of surface and bottom temperature from the environmental variables. Results are show in Table 6.

Table 6. Correlation between zooplankton structure and composition (March and August) and the environmental parameters (Tables 4 and 5 respectively). Three parameters explained the best correlation on each occasion, with salinity dominating on both occasions.

Zooplankton data	Correlation (%)	Selected variables	Comments
March	77	Integrated salinity, explained	Salinity
		Integrated oxygen, pH	68% of the correlation.
August	70	Integrated salinity, explained	Salinity
		Surface temperature, Integared pH	51% of the correlation.

SIMPER analysis on March zooplankton community structure shown in the three main clusters (Stations 1-2, 4-7 and 9-10, Fig. 10), rank the species in order of numerical dominance up to a cut-off cumulative contribution of 90% (Table 7). *Saphiriella* sp. and other marine associated copepod species dominated the mouth region. *Pseudodiaptomus hessei* and *Acartia longipatella* dominated the lower group of stations (Stations 4–7) and *P. hessei* dominated the upper stations (Stations 9-10). Six species account for 91.83% of the total zooplankton abundance at Stations 4 - 7, while only one taxa account for 94.88% of zooplankton abundance at Stations 9 -11.

Table 7. SIMPER analysis of the numerically dominant species (ranked) in the three main groups of species shown in Fig. 10. Columns represent average numerical abundance at each site in the cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (at the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 1 - 2					
<i>Saphiriella</i> sp.	1221.00	25.63	-	42.16	42.16
Copepod spp.	14.50	11.68	-	19.22	61.37
<i>Pseudodiaptomus hessei</i>	18.50	11.68	-	19.22	80.59
<i>Paramoera capensis</i>	1.50	6.28	-	10.32	90.91

Average similarity between stations in the group: 60.81%

Stations 4 – 7					
<i>Pseudodiaptomus hessei</i>	15936.25	33.01	8.04	48.79	48.79
<i>Acartia longipatella</i>	152.25	10.57	7.26	15.63	64.42
<i>Halicyclops</i> sp.	78.50	9.19	4.74	13.59	78.01
<i>Gastrosaccus brevifissura</i>	3.75	4.90	12.22	7.24	85.25
<i>Exosphaeroma hylocoetes</i>	2.25	2.30	0.91	3.41	88.66
<i>Mesopodopsis wooldridgei</i>	2.00	2.15	0.89	3.18	91.83

Average similarity between stations in the group: 67.65%

Stations 9 - 10					
<i>Pseudodiaptomus hessei</i>	5.00	45.70	-	100.00	100.00

Average similarity between stations in the group: 45.70%

Species represented at middle sites (Stations 4-7) may generally be described as typical estuarine species.

Bray-Curtis similarity analysis on the hyperbenthos collected in March 2004 using group average mode on square-root transformed data (Annexure 3) showed two main clusters at the 50% cut-off level (Fig. 14). Stations 1 and 10 reflect a marine and brackish water fauna respectively, but data should be treated with caution due to the low number of species and number of individuals per site (see Annexure 3). No Cluster Analysis was performed on August data, again because of low numbers and relatively few species in samples. Similarly, no MDS plots nor SIMPER Analysis was performed on the data.

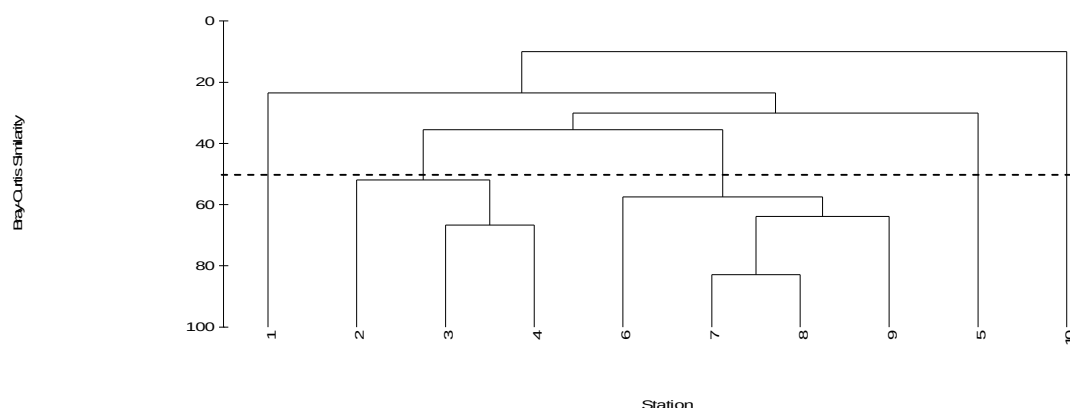


Fig. 14. Dendrogram for Bray-Curtis similarity clustering of sites based on hyperbenthic composition and abundance. Data for the Olifants estuary, March 2004. The dotted line represents the 50% cut-off line.

Bray-Curtis similarity analysis on the subtidal macrobenthic fauna collected March 2004 (Fig. 15) using group average mode on square-root transformed data (Annexure 5) shows two major clusters that separate lower sites (Sites 1-4) from the remainder of the estuary. At the 50% similarity level, only the two mouth sites group together, reflecting a relatively rapid change in community structure in an upstream direction. In the upper half of the estuary, sites 6 – 9 group together at the 50% level, with Station 10 having only about 30% similarity to any other site. These upper sites reflect a brackish water community compared to a marine associated fauna further downstream. A similar clustering of sites was reflected in the August data (Fig. 16, Annexure 6), with a lower estuarine community (Sites 1 - 4) separating at about the 22% level from a more brackish water community further upstream (Stations 5 - 9). Again, Station 10 clearly separated from any other site.

Analysis of similarity (ANOSIM) using the Primer package indicated a Global R value of 0.368; and the null hypothesis of no difference between selected groups (1-2, 3-4, 5-7, 8-9, 10-15) is rejected at the 0.1% level.

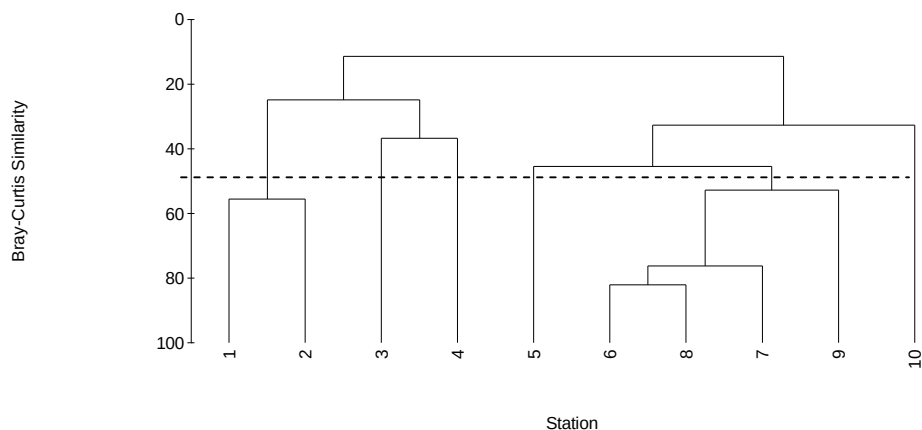


Fig. 15. Dendrogram for Bray-Curtis similarity clustering of sites based on composition and abundance of the subtidal macrobenthos. Data for the Olifants estuary, March 2004. The dotted line represents the 50% cut-off line.

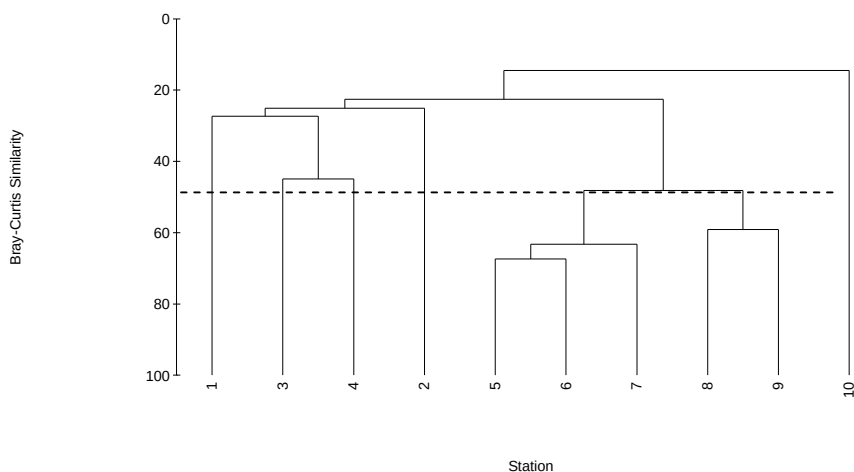


Fig. 16. Dendrogram for Bray-Curtis similarity clustering of sites based on composition and abundance of the subtidal macrobenthos. Data for the Olifants estuary, August 2004. The dotted line represents the 50% cut-off line.

Group linkages shown by the Bray-Curtis similarity matrix in March 2004 (Fig 15) is also closely reflected by the non-metric multi-dimensional scaling (MDS) plot (Fig. 17). The change in community structure from the lower estuary (Stations 1 – 2) to the upper estuary (Stations 5 – 9) is reflected in the plot, with Station 10 distinct from all other sites. The low stress level (0.03) indicates a high degree of confidence in the accuracy of sample relationships (Clarke & Warwick 1994).

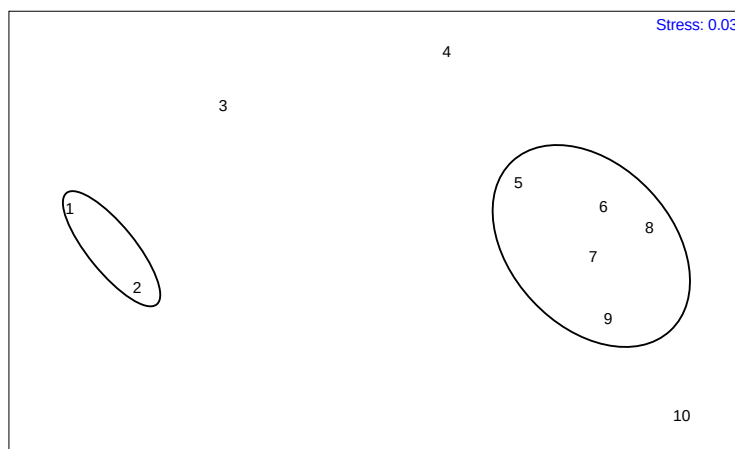


Fig. 17. 2-dimensional MDS configuration of the subtidal benthic community in the Olifants estuary, March 2004. Relative distances between points is a reflection of the degree of similarity between them. Circles include those sites that group at >50% similarity level (See Fig. 15).

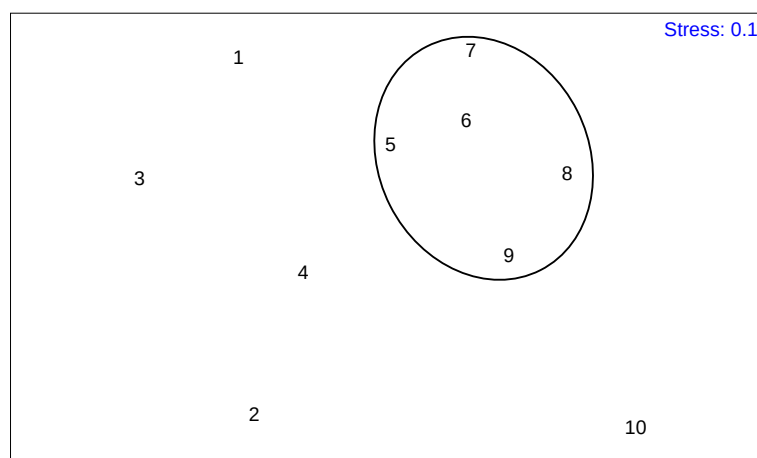


Fig. 18. 2-dimensional MDS configuration of the subtidal benthic community in the Olifants estuary, August 2004. Relative distances between points is a reflection of the degree of similarity between them. The circle includes those sites that group at >50% similarity level (See Fig. 16).

Fig. 18 reflects a similar pattern to that shown in Fig. 17, although the grouping of sites in the lower estuary is less clumped compared to the pattern shown in Fig. 16 for the same sites (compare similarity levels for these sites in Figs. 15 and 16).

Environmental variables (Table 8) were then linked to the subtidal benthic data using the PRIMER package BIO-ENV in order to establish which of the physico-chemical parameters best explain linkages. A Draftsman Plot indicated that in March, integrated salinity, surface salinity and bottom salinity were highly correlated. Thus, surface and bottom salinity readings were excluded from further analysis. A similar exercise led to the exclusion of surface and bottom temperature for analysis of the March data. In August, only bottom salinity was excluded from the analysis. Results show that salinity on its own accounts for most of the correlation between biotic and abiotic parameters.

Table 8. Correlation between subtidal benthic structure and composition (March and August) and the environmental parameters (Tables 4 and 5 respectively). Two parameters explained the best correlation on each occasion, with salinity dominating on both occasions.

Zooplankton data	Correlation (%)	Selected variables	Comments
March	92	Integrated salinity, explained	Salinity
		Integrated temperature	75% of the correlation.
August	80	surface salinity, surface oxygen, Integrated pH, percentage sand.	Surface salinity explained 71% of the correlation.

SIMPER analysis on community structure for the two cluster groups (>50% similarity) shown in Figs. 15 and 17 (March 2004, Stations 1-2 and 5-9) are shown in Table 9. Species are ranked in order of numerical dominance up to a cut-off cumulative contribution of 90%. Six species contributed >90% at the lower group of stations (Stations 1–2), while five species contributed to the analysis of the upstream group of stations (Stations 5 – 9). In both groups, polychaete worms were the most important contributors to overall abundance levels.

Table 9. SIMPER analysis of the numerically dominant species (ranked) in two major cluster groups shown in Figs. 15 and 17. Columns represent average numerical abundance at each site in the cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (at the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 1- 2					
<i>Nephtys capensis</i>	1402.78	16.35	-	27.06	27.06
Bivalve spat	172.22	9.60	-	15.89	42.95
<i>Orbinia angrapequensis</i>	63.89	8.67	-	14.36	57.31
<i>Glycera tridactyla</i>	66.67	7.71	-	12.77	70.08
<i>Hymenosoma orbiculare</i>	16.67	6.79	-	11.24	81.31
<i>Prionospio sexoculata</i>	161.11	6.13	-	10.15	91.46
Average similarity between the two stations in the group: 60.40%					
Stations 5 - 9					
<i>Ceratonereis keiskama</i>	5992.22	22.61	4.70	33.74	33.74
<i>Boccardia</i> sp.	1135.56	12.65	3.36	18.88	52.63
<i>Desdemonia ornata</i>	1285.56	10.92	2.06	16.30	68.93
<i>Corophium triaenonyx</i>	281.11	8.95	4.45	13.36	82.29
<i>Hymenosoma orbiculare</i>	22.22	5.21	6.51	7.78	90.07
Average similarity between stations in the group: 67.00%					

In August samples, only one cluster group was identified having more than 50% similarity with respect to community structure (Figs 16 and 18). Five species dominated this group, having three species that were also identified in March samples. Two other species (chironomid larvae and an unidentified oligochaete worm) reflected reduced salinity values recorded in this sector compared to March. A low similarity also characterized the

community structure and composition between stations in the cluster (36.71%), indicating a zone of relatively rapid change (particularly salinity – see Table 8) between the sites. Again, polychaete worms were the most important contributors to overall abundance levels.

Table 10. SIMPER analysis of the numerically dominant species (ranked) in the major cluster group shown in Figs. 16 and 18. Columns represent average numerical abundance at each site in the cluster, average similarity between sites, Similarity Standard deviation, Contribution of each species to total numerical abundance and the cumulative contribution (at the 90% cut-off value).

Species	Av. Abund.	Av. Sim.	Sim/SD	Contrib%	Cum %
Stations 5 - 9					
<i>Ceratonereis keiskama</i>	3847.78	17.21	1.41	46.88	46.88
<i>Desdemonia ornata</i>	2011.67	8.27	2.32	22.53	69.41
Chironomid larvae	1840.42	4.01	0.92	10.92	80.34
Oligochaete sp.	1967.78	3.05	0.53	8.32	88.65
<i>Boccardia</i> sp.	973.61	1.66	0.71	4.52	93.17

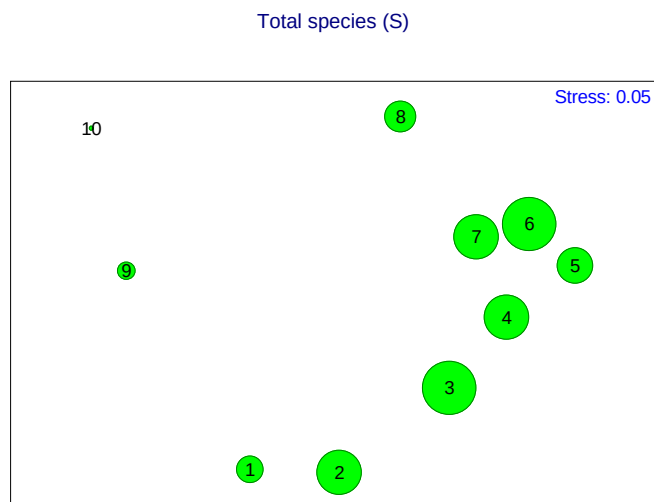
Average similarity between stations in the group: 36.71%

3.1.4 Diversity measures

Diversity measures for the zooplankton data collected in March is presented in Fig 19. The total number of species was highest at lower stations (Stations 2, 3 and 6, Fig 19A), but species dominance was maximal in the upper estuary. In August the total number of species was highest at the mouth (Fig. 20 A), presumably due to increased freshwater runoff effects on marine associated species. High species dominance again characterized the upper estuary (Fig. 20 B). The hyperbenthos in March followed a similar pattern to the zooplankton for the same month (Fig. 21), but numbers in August were too low to process the data.

The subtidal benthos showed a similar pattern on both sampling occasions. Total number of species was maximal at lower stations (Figs 22 A and 23 A), while dominance was highest at mid estuarine stations.

A



B

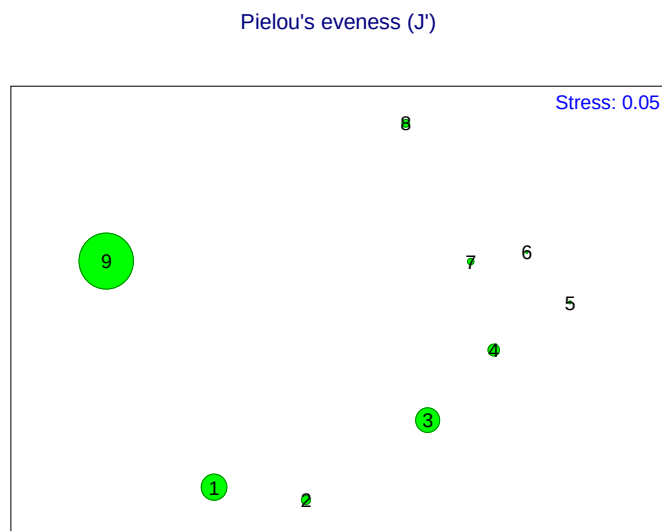


Fig. 19. Diversity measures of the zooplankton at 10 stations in the Olifants estuary, March 2004. A = Total number of species; B = Pielou's evenness index at each station. The size of circles provides a relative measure between sites.

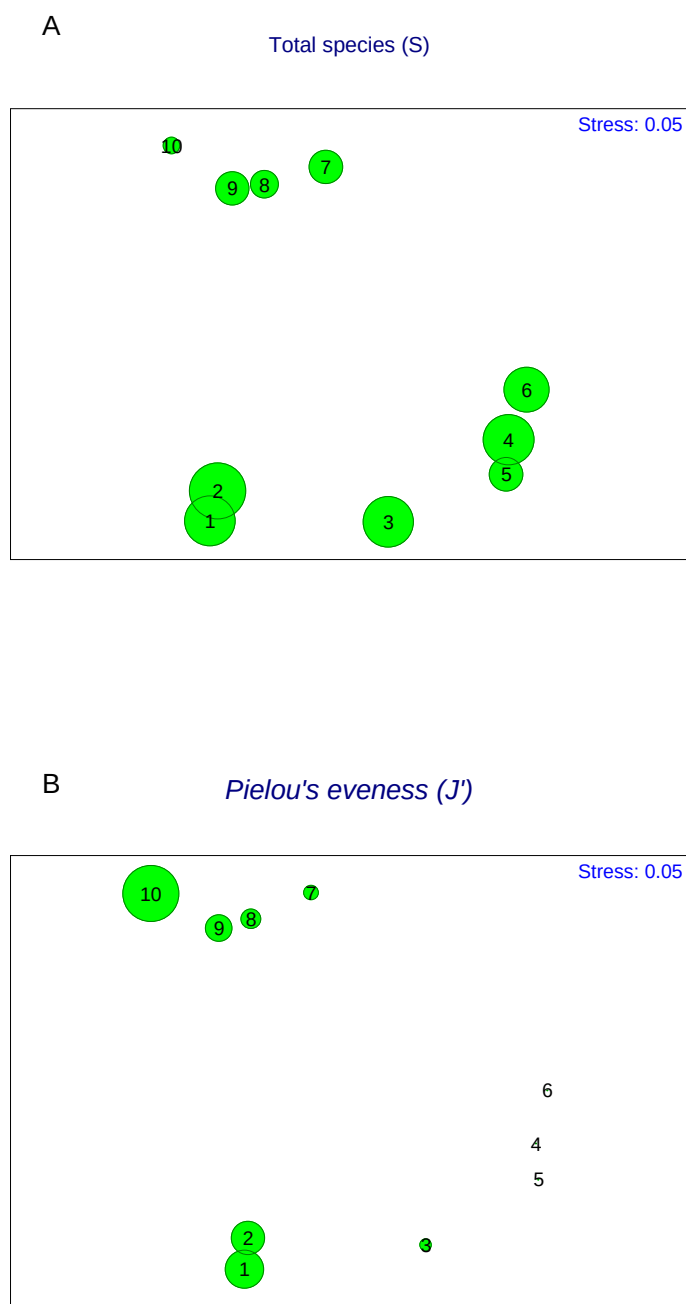


Fig. 20. Diversity measures of the zooplankton at 10 stations in the Olifants estuary, August 2004. A = Total number of species; B = Pielou's evenness index at each station. The size of circles provides a relative measure between sites.

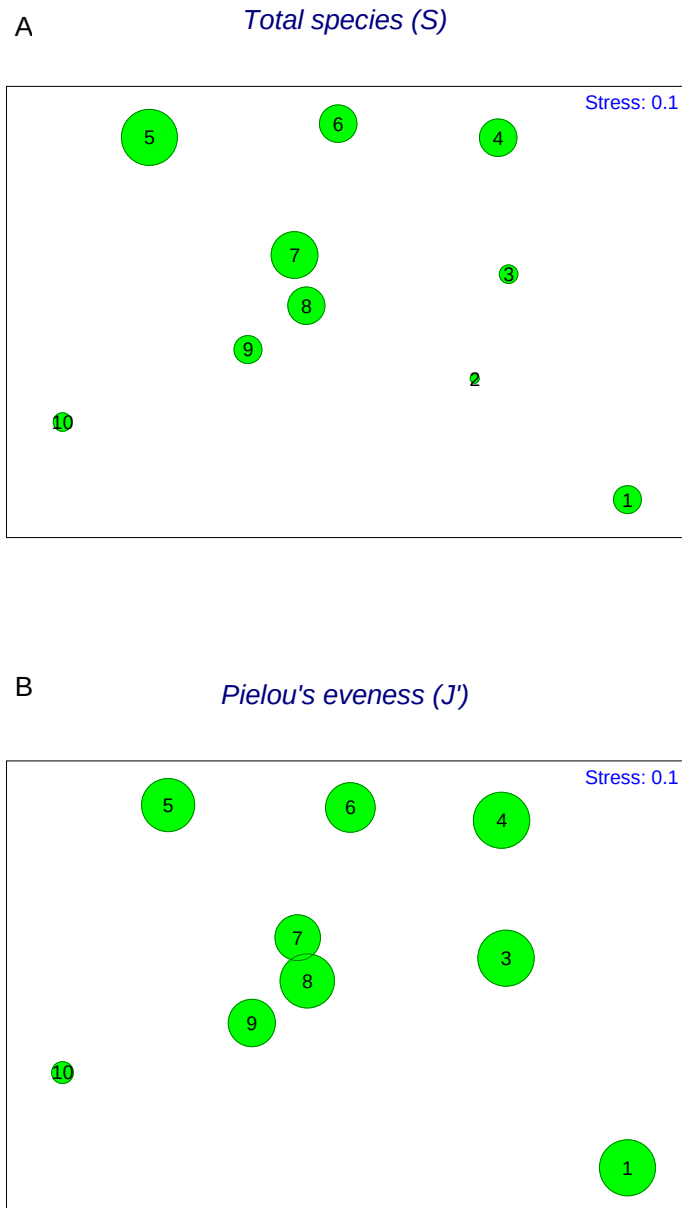


Fig. 21. Diversity measures of the hyperbenthos at 10 stations in the Olifants estuary, March 2004. A = Total number of species; B = Pielou's evenness index at each station. The size of circles provides a relative measure between sites.

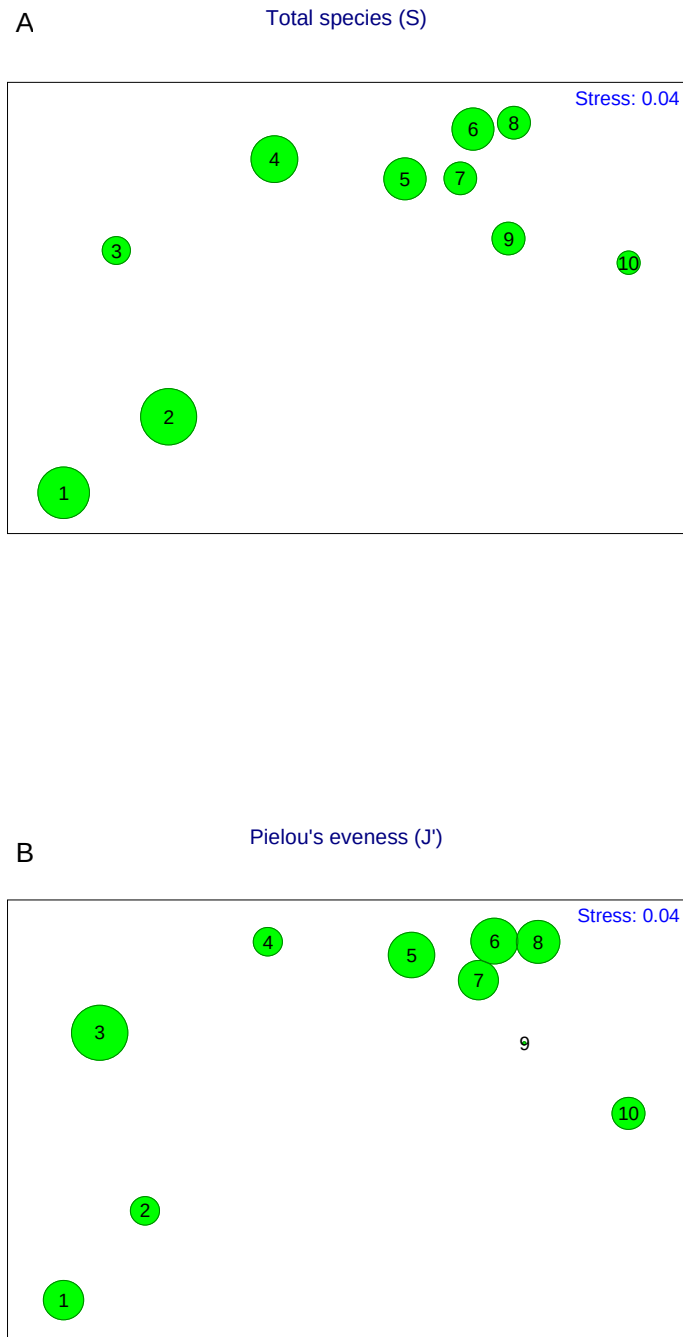


Fig. 22. Diversity measures of the subtidal benthos at 10 stations in the Olifants estuary, March 2004. A = Total number of species; B = Pielou's evenness index at each station. The size of circles provides a relative measure between sites.

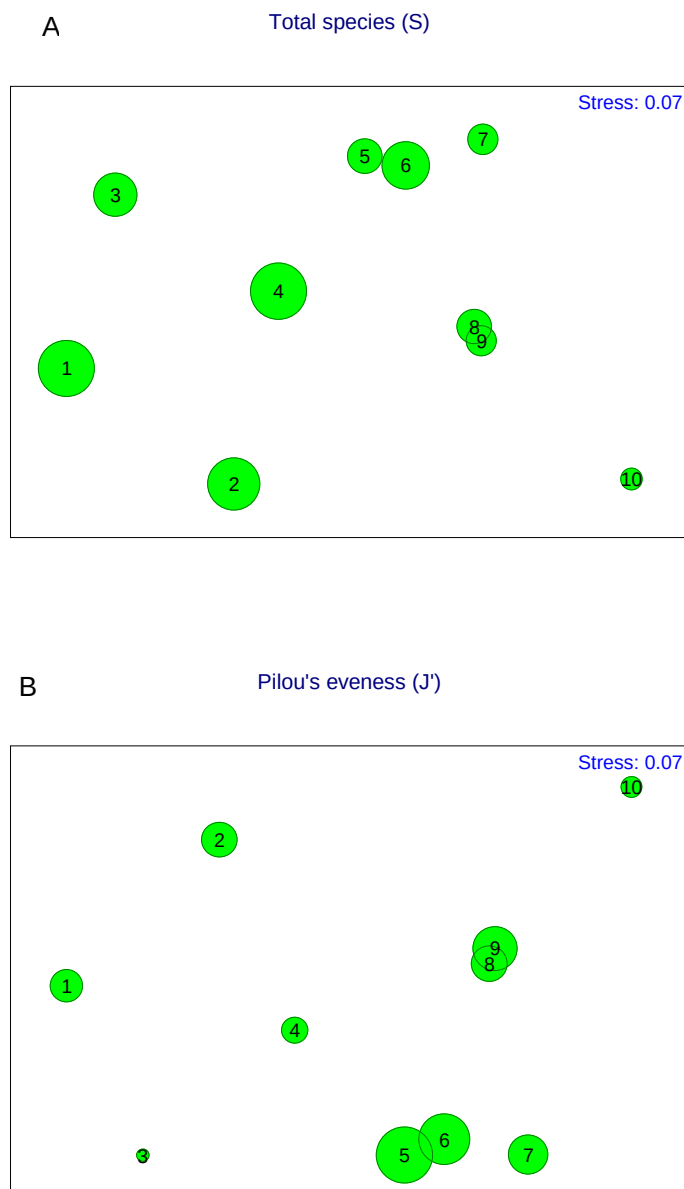


Fig. 23. Diversity measures of the subtidal benthos at 10 stations in the Olifants estuary, August 2004. A = Total number of species; B = Pielou's evenness index at each station. The size of circles provides a relative measure between sites.

4 SUMMARY NOTES

Invertebrates recorded over most of the Olifants estuary may generally be described as typical estuarine species that are of necessity tolerant of wide variation in the physico-chemical environment. This is borne out by BIO-ENV analysis that showed salinity best explained the correlation between the biological data (zooplankton and subtidal benthos) and the environmental variables measured. In addition, water temperature, pH and the percentage fine mud were also important parameters. Salinity is often described as the major

factor determining distribution patterns of estuarine benthic fauna (e.g. Day 1964, Carricker 1967, Hill 1981, Wolf 1983 among others), although sediment is also known to be a major factor in structuring communities (Day 1964, Holland, Shaughnessy & Hiegel 1987, Teske & Wooldridge 2003). Clearly, factors that structure invertebrate communities are inter-related in complex ways, with the relative importance of any particular factor linked to the magnitude of river domination, degree of sediment change and other drivers along the estuary.

Although salinity structured communities along the estuary, little change was observed between the summer and winter trip with respect to the number of invertebrate species recorded in the estuary (Table 11). Zooplankton species abundance was only slightly lower in winter presumably due to increased freshwater flow. Increased river flow would affect marine associated species to a greater degree compared to the euryhaline species. However, augmentation by marine species is also linked to the state of the tide at the time of sampling. In comparison to the Great Berg estuary, the Olifants clearly reflected fewer species in all groups investigated.

Table 11. The number of species recorded during summer and winter for the zooplankton, hyperbenthos and subtidal benthic communities in the Great Berg and Olifants estuaries. Unpublished data from Wooldridge (2004).

	Summer	Winter
Olifants estuary		
Zooplankton	20	17
Hyperbenthos	9	10
Subtidal benthos	22	23
Great Berg estuary		
Zooplankton	30	28
Hyperbenthos	22	16
Subtidal benthos	33	23

Although the number of species is relatively low in the Olifants estuary, total abundance of some estuarine species is very high. The composition of these estuarine species is also not unlike those found in estuaries on the south and east coasts of South Africa. Low temperature is usually linked to the cool temperate west coast, but in the river dominated Olifants estuary, colder water in summer is associated with the lower estuary and the degree marine intrusion. Water temperatures in the estuary ranged from 12.4°C to 23.9°C, with temperatures rising relatively steeply up to Station 5 at the time of sampling. Above Station 5, water temperature increased from ca 21.8°C to 23.9°C at the top of the estuary. Thus, summer water temperatures in the middle and upper reaches of the estuary are more influenced by the river flowing across the hot interior of the country and not the colder marine water. These data therefore support Day (1974) who concluded that summer temperatures

in the upper reaches of west coast estuaries are not much different from estuarine water temperatures on the east coast. However, water temperatures at least in the lower estuary fall sharply at times of upwelling (Day 1974). During winter, water temperatures in the estuary are probably reduced by colder inflowing river water and marine water, such that temperatures are maximal in the middle-lower estuarine reaches during the colder months.

Day (1974) noted that none of the benthic species recorded in Atlantic coast estuaries is restricted to the Atlantic coast. Polychaetes such as *Capitella capitata* and *Glycera tridactyla*, crustaceans and molluscs such as *Hymenosoma orbiculare*, *Palaemon perengueyi*, *Upogebia africana*, *Melita zeylanica* and *Nassaria kraussiana* even extend in to Mozambique. The present study on the estuarine zooplankton, hyperbenthos and subtidal benthos supports the notion that species are not unique to the west coast, although non-benthic marine species that temporarily move in to the lower estuary on flood tides may not all follow this pattern.

Many of the dominant zooplankton species in west coast estuaries also dominate in south and east coast estuaries. The copepod *Pseudodiaptomus hessei* is endemic to estuaries and is widespread around southern Africa (Wooldridge 1999). It attains high population densities, especially under conditions of relatively high freshwater inflow. In the Gamtoos estuary, maximum abundance was attained in regions of the estuary where salinity ranged between 10 and 25 ppt. In the Olifants, maximum abundance occurred at salinity values around 22 (summer) and 2.7 ppt (winter) in the middle estuary. However, It is interesting to note that maximum abundance of *P. hessei* correlates generally with that sector of the estuary where organic content and percent fine mud also reached maximum values.

The distribution of the estuarine copepod *Acartia longipatella* follows a predicted pattern, with the population centred nearer the mouth where salinity values are relatively high (Wooldridge & Melville-Smith 1979, Wooldridge 1999). The species was not present in winter samples, presumably because of river dominance that reduces salinity values below threshold tolerance levels. By contrast, *Pseudodiaptomus hessei* is described as a pioneer species (Wooldridge & Melville-Smith 1979), responding to flooding or strong freshwater discharges through marked increases in population density. Peak abundance levels are rapidly attained (weeks) after the discharge event. The relative abundance of *P. hessei* in different South African estuaries is shown in Table 12. Data reflect the population response (measured as numbers m³) to freshwater rich conditions and freshwater starved conditions.

Table 12. Maximum recorded abundance (number m³) of the copepod *Pseudodiaptomus hessei* from different estuaries around the coast of Southern Africa, relative to salinity range in the estuaries. Estuaries with strong inflow of freshwater have strong horizontal salinity gradients (Group 1 in the Table); estuaries with low or no freshwater inflow have weak or reverse horizontal salinity gradients (Group 2 in the table). The salinity range shown refers to salinity values recorded at all sampling stations along each estuary.

Estuary	Sal. range (ppt)	Max. abundance recorded to-date	Reference
Group 1			
Sundays (1982)	7 - 35	33500	Wooldridge & Bailey
Great Fish	0 - 35	91500	Unpublished records
Keiskamma	0 - 35	117000	Unpublished records
Great Berg	7 - 34	29600	Unpublished records
Olifants	0 – 34	41000	This study
Group 2			
Gqutywa	35 - 40	12250	Unpublished records
Kariega	25 - 36	4800	Unpublished records
Kromme	31 - 42	6000	Wooldridge 1999

5. CONCLUSIONS

- Euryhaline invertebrates identified from the Olifants estuary are not unique to the west coast of South Africa. However, the number of species present in the estuary may be low compared to communities on the south and east coasts. However, causal factors driving observed patterns are sometimes difficult to isolate. For example:
 - Because of river dominance, salinity values are reduced to relatively low levels most of the time. Consequently, a stenohaline benthic marine community does not establish itself in the lower estuary. However, an incursive marine zooplankton component enters the lower estuary on the flood tide. Species again leave the estuary on the ebb.
 - Although biogeographical patterns relating to intertidal organisms suggest that Atlantic coast estuaries have fewer species compared to south and east coast estuaries, the effects of river dominance on community composition may exacerbate this pattern. River dominated systems on the east and south coasts also have relatively few species (e.g Thukela and Breede estuaries). Only two other major estuaries occur on the west coast (Orange and Great Berg) and both are river dominated. The larger west coast estuaries are therefore characterized as river dominated systems and can be expected to have relatively low species richness.

- Sampling approach may lead to an underestimate of composition and abundance of species. For example, techniques used by different researchers have varied over time. The use of different types of sampling gear (corers, sleds, nets), or different mesh sizes to separate animals from water or sediment will provide different answers. Smaller animals are often more extremely abundant, but these may pass through a relatively coarse net or sieve.
- Water temperatures in the middle and upper estuary were relatively high in summer, due to warming of river water as it flowed across the landscape (the upper estuary was about 11°C warmer at the time of sampling in March 2004). It is possible that the similarity between estuarine invertebrate communities on the west coast and those in south and east coast estuaries are partly linked to these elevated summer estuarine water temperatures on the west coast.

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**Annexure 1. Composition and abundance (numbers m³) of zooplankton collected
March 2004 at 10 stations in the Olifants estuary.**

Station number	1	2	3	4	5	6	7	8	9	10
Crustacea										
Copepoda										
Acartia longipatella	0.0	73.0	2234.0	31.0	356.0	174.0	48.0	0.0	0.0	0.0
Copepod spp.	12.0	17.0	14.0	55.0	0.0	0.0	34.0	0.0	4.0	0.0
Daphnia sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Halicyclops sp.	0.0	0.0	0.0	148.0	120.0	32.0	14.0	0.0	0.0	0.0
Pseudodiaptomus hessei	12.0	25.0	858.0	3376.0	40836.0	15639.0	3894.0	404.0	3.0	7.0
Saphiriella sp.	278.0	2164.0	59.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mysidacea										
Gastrosaccus brevifissura	0.0	0.0	4.0	4.0	7.0	2.0	2.0	0.5	0.0	0.0
Mesopodopsis wooldridgei	0.0	0.0	2.0	0.0	4.0	1.0	3.0	0.5	0.0	0.0
Rhopalophthalmus terranatalis	0.0	0.0	0.0	0.0	2.0	1.0	1.0	0.5	0.0	0.0
Isopoda										
Eurydice longicornis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exosphaeroma hylocoetes	5.0	0.0	1.0	5.0	2.0	2.0	0.0	0.0	0.0	0.0
Amphipoda										
Corophium triaenonyx	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grandidierella lutosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melita zeylanica	0.0	0.5	2.0	1.0	0.0	0.5	0.0	0.5	0.0	0.0
Paramoera capensis	2.0	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caridea										
Palaemon peringueyi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anomura										
Upogebia africana stage 1	10.0	0.6	0.5	0.0	2.0	0.0	0.0	0.0	0.0	0.0
Upogebia africana postlarvae	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Brachyura										
Hymenosoma orbiculare larvae	0.0	2.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
Hymenosoma orbiculare	0.0	0.1	0.0	0.0	0.0	1.0	0.0	0.0	0.1	0.0
Insectivora										
Insect larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chironomid larvae	0.0	0.0	0.0	0.0	0.0	0.5	17.0	13.0	0.0	0.0
Pisces										
Gilchristella eggs	0.0	0.0	10.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0
Gilchristella larvae	0.0	0.0	0.0	0.0	0.0	1.0	2.0	1.0	0.5	0.0
Gobiid larvae	0.0	1.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Pipefish juv.	0.0	0.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Annexure 2. Composition and abundance (numbers m³) of zooplankton collected August 2004 at 10 stations in the Olifants estuary.

Station number	1	2	3	4	5	6	7	8	9	10
Crustacea										
Copepoda										
Acartia longipatella	0.0	0.0	42.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copepod spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Daphnia sp.	0.0	0.0	0.0	0.0	0.0	0.0	12.0	9.0	19.0	68.0
Halicyclops sp.	120.0	40.0	0.0	0.0	132.0	0.0	0.0	7.0	6.0	6.0
Pseudodiaptomus hessei	46.0	104.0	1613.0	21529.0	28657.0	5107.0	166.0	174.0	109.0	37.0
Saphiriella sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mysidacea										
Gastrosaccus brevifissura	2.0	2.0	2.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
Mesopodopsis wooldridgei	0.0	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhopalophthalmus terranatalis	0.0	0.0	2.0	5.0	5.0	8.0	0.0	0.0	0.0	0.0
Isopoda										
Eurydice longicornis	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exosphaeroma hylocoetes	2.0	1.0	2.0	1.0	4.0	1.0	1.0	0.0	0.0	0.0
Amphipoda										
Corophium triaenonyx	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
Grandidierella lutosa	5.0	2.0	2.0	1.0	4.0	1.0	0.0	0.0	0.0	0.0
Melita zeylanica	2.0	0.5	2.0	1.0	4.0	2.0	1.0	1.0	1.0	0.0
Paramoera capensis	4.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caridea										
Palaemon peringueyi	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anomura										
Upogebia africana stage 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upogebia africana postlarvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brachyura										
Hymenosoma orbiculare larvae	9.0	11.0	81.0	80.0	0.0	0.0	0.0	0.0	0.0	0.0
Hymenosoma orbiculare	0.0	0.0	0.0	1.0	0.0	0.0	0.5	0.0	0.0	0.0
Insectivora										
Insect larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Chironomid larvae	0.0	0.0	0.0	1.0	0.0	1.0	1.0	2.0	0.2	0.0
Pisces										
Gilchristella eggs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gilchristella larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gobiid larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipefish juv.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Annexure 3. Composition and abundance (numbers m³) of hyperbenthic species collected February 2004 at 10 stations in the Olifants estuary.

Station number	1	2	3	4	5	6	7	8	9	10
Mysidacea										
Gastrosaccus brevifissura	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mesopodopsis wooldridgei	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0
Rhopalophthalmus terranatalis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda										
Exosphaeroma hylocoetes	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Paridotea unguolata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda										
Corophium triaenonyx	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Cyathura estuaria	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grandidierella lutosa	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melita zeylanica	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.1	0.3	48.0
Caridea										
Palaemon capensis	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Brachyura										
Hymenosoma orbiculare	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	4.0
Pisces										
Gilchristella larvae	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.2	1.0	0.0
Gobiid larvae and juvs	0.0	0.0	0.0	0.1	0.3	0.2	0.0	0.0	0.0	0.0
Syngnathus temminkii	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Psammogobius knysnaensis	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0

Annexure 4. Composition and abundance (numbers m³) of hyperbenthic species collected August 2004 at 10 stations in the Olifants estuary.

Station number	1	2	3	4	5	6	7	8	9	10
Mysidacea										
<i>Gastrosaccus brevifissura</i>	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
<i>Mesopodopsis wooldridgei</i>	0.0	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0
<i>Rhopalophthalmus terranatalis</i>	0.0	0.0	0.0	0.0	0.1	1.0	0.0	0.0	0.0	0.0
Isopoda										
<i>Exosphaeroma hylocoetes</i>	0.0	0.0	3.0	0.4	0.5	1.0	0.0	0.0	0.0	0.0
<i>Paridotea unguolata</i>	0.0	0.1	3.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Amphipoda										
<i>Corophium triaenonyx</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cyathura estuaria</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Grandidierella lutosa</i>	0.0	0.1	0.0	0.0	0.3	0.5	0.0	0.0	0.0	0.0
<i>Melita zeylanica</i>	0.0	0.0	2.0	1.0	0.1	1.0	0.1	0.1	0.1	0.2
Caridea										
<i>Palaemon capensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brachyura										
<i>Hymenosoma orbiculare</i>	0.0	0.0	1.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0
Pisces										
<i>Gilchristella</i> larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gobiid larvae and juvs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Syngnathus temminkii</i>	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Psammogobius knysnaensis</i>	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Annexure 5. Composition and abundance (numbers m⁻²) of benthic organisms collected March 2004 at 10 stations in the Olifants estuary.

Station	1	2	3	4	5	6	7	8	9	10
Sipunculoidea										
<i>Siphonostoma</i> sp?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polychaeta										
<i>Boccardia</i> sp.	5.6	5.6	0.0	5.6	555.6	2344.4	438.9	2300.0	38.9	0.0
<i>Capitella capitata</i>	0.0	0.0	81.3	105.6	0.0	61.1	0.0	61.1	0.0	0.0
<i>Ceratonereis erythraeensis</i>	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ceratonereis keiskama</i>	0.0	0.0	25.0	255.6	1005.6	2800.0	5500.0	5922.2	14733.3	25166.7
<i>Chaetopterid</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Desdemona ornata</i>	0.0	5.6	0.0	0.0	16.7	1588.9	1766.7	3005.6	50.0	0.0
<i>Glycera tridactyla</i>	105.6	27.8	37.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Nephtys capensis</i>	561.1	2244.4	231.3	11.1	0.0	0.0	0.0	0.0	0.0	0.0
<i>Oligochaete</i> sp.	0.0	38.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Orbinia angrapequensis</i>	44.4	83.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Prionospio sexoculata</i>	11.1	311.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
Cladocera										
<i>Cladoceran</i> sp.	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda										
<i>Anthurid</i> sp.	0.0	0.0	0.0	5.6	650.0	11.1	0.0	0.0	0.0	0.0
<i>Eurydice longicornis</i>	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Exosphaeroma hylocoetes</i>	38.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Sphaeromid</i> sp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda										
<i>Corophium triaenonyx</i>	0.0	0.0	0.0	0.0	38.9	272.2	788.9	283.3	22.2	40933.3
<i>Grandidierella lutosa</i>	0.0	11.1	62.5	1988.9	161.1	0.0	61.1	0.0	0.0	0.0
<i>Melita zeylanica</i>	0.0	5.6	0.0	11.1	5.6	55.6	5.6	0.0	88.9	733.3
<i>Paramoera capensis</i>	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anomura										
<i>Callianassa kraussi</i>	0.0	11.1	0.0	205.6	5.6	183.3	0.0	0.0	0.0	0.0
Brachyura										
<i>Hymenosoma orbiculare</i>	16.7	16.7	6.3	22.2	5.6	38.9	55.6	5.6	5.6	5.6
Insectivora										
<i>Chironomid larvae</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.8	5.6	0.0
Mollusca										
<i>Bivalve spat</i>	66.7	277.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Tellina rousi</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Annexure 6. Composition and abundance (numbers m⁻²) of benthic organisms collected August 2004 at 10 stations in the Olifants estuary.

Station	1	2	3	4	5	6	7	8	9	10
Sipunculoidea										
<i>Siphonostoma</i> sp?	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polychaeta										
<i>Boccardia</i> sp.	16.7	6.3	12.5	5.6	762.5	3294.4	744.4	55.6	11.1	0.0
<i>Capitella capitata</i>	0.0	1125.0	31.3	77.8	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ceratonereis erythraeensis</i>	0.0	0.0	0.0	22.2	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ceratonereis keiskama</i>	0.0	0.0	0.0	261.1	4400.0	5811.1	6755.6	566.7	1705.6	5.6
<i>Chaetopterid</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Desdemona ornata</i>	2388.9	6.3	162.5	61.1	1275.0	2911.1	4233.3	1166.7	472.2	0.0
<i>Glycera tridactyla</i>	72.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Nephtys capensis</i>	461.1	143.8	12.5	5.6	0.0	0.0	0.0	0.0	0.0	0.0
<i>Oligochaete</i> sp.	11.1	125.0	0.0	0.0	0.0	5894.4	627.8	3216.7	100.0	22.2
<i>Orbinia angrapequensis</i>	55.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Prionospio sexoculata</i>	72.2	0.0	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cladocera										
<i>Cladoceran</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda										
<i>Anthurid</i> sp.	0.0	0.0	787.5	772.2	1987.5	2677.8	61.1	0.0	0.0	0.0
<i>Eurydice longicornis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Exosphaeroma hylocoetes</i>	38.9	6.3	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0
<i>Sphaeromid</i> sp	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda										
<i>Corophium triaenonyx</i>	0.0	6.3	0.0	11.1	125.0	933.3	350.0	27.8	133.3	5.6
<i>Grandidierella lutosa</i>	394.4	18.8	8662.5	594.4	918.8	55.6	0.0	0.0	0.0	0.0
<i>Melita zeylanica</i>	0.0	281.3	6.3	4750.0	1400.0	222.2	0.0	33.3	44.4	5.6
<i>Paramoera capensis</i>	0.0	118.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anomura										
<i>Callianassa kraussi</i>	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0
Brachyura										
<i>Hymenosoma orbiculare</i>	11.1	6.3	6.3	5.6	0.0	5.6	0.0	5.6	0.0	0.0
Insectivora										
<i>Chironomid larvae</i>	0.0	0.0	0.0	22.2	468.8	1027.8	5.6	6694.4	1005.6	288.9
Mollusca										
<i>Bivalve spat</i>	11.1	0.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Tellina rousi</i>	105.6	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX G

SPECIALIST REPORT: FISH

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INTRODUCTION & BACKGROUND

The Olifants / Doring catchment drains an almost entirely arid area. Despite this, existing and future agricultural and other developments have led to an increasing demand for water. A number of alternatives have been proposed to meet this demand, ranging from the raising of the Clanwilliam Dam to the building of a new dam at Melkboom on the Doring just upstream of its confluence with the Olifants. The feasibility of these developments and their impacts on flows and ultimately the river and estuarine ecosystems are being investigated under various components of the Olifants / Doring Catchment Study. This report forms the fish component of a Comprehensive RDM study on the Olifants River Estuary co-ordinated by the CSIR.

The RDM methodology is driven by a scenario based approach. Runoff scenarios for the natural and present day conditions are used to define the present ecological status of the estuary and to determine the ecological management class (EMC). These runoff scenarios, together with a series of future runoff scenarios are then evaluated to derive the Reserve and Resource Quality Objectives for the estuary under consideration.

For the Olifants River Estuary, the following future runoff scenarios were to be evaluated in addition to the natural (reference) and present runoff scenarios:

- Scenario 2: Present inflow plus Ecological Flow Requirement (EFR) releases, (75 % of natural MAR)
- Scenario 7: Raising Clanwilliam Dam by 15 m plus EFR releases, (69% of natural MAR)
- Scenario 5: Raising Clanwilliam Dam by 15 m (57 % of natural MAR)
- Scenario 17: Brandewyn Dam, a tributary of the Doring (50 % of natural MAR)
- Scenario 10: Melkbosrug Dam on the Doring (40 % of natural MAR)

Terms of reference for the fish study were:

- To synthesize new and existing information on, and to provide a description of, the species composition, abundance and distribution of the fish fauna of the Olifants River Estuary. In doing so, key fish species important in terms of the estuary, were to be identified
- To define the present status of the fish community and establish the relative importance of the estuary to different species or groups of species and to discuss the value of the estuary relative to other South African estuaries.
- To predict the reference condition of the fish community using the above information and that available for the other biotic and abiotic components.
- To predict the response of the fish community to the reduction in freshwater inflows presented by each of the four future scenarios in terms of the biotic and abiotic changes that may occur.

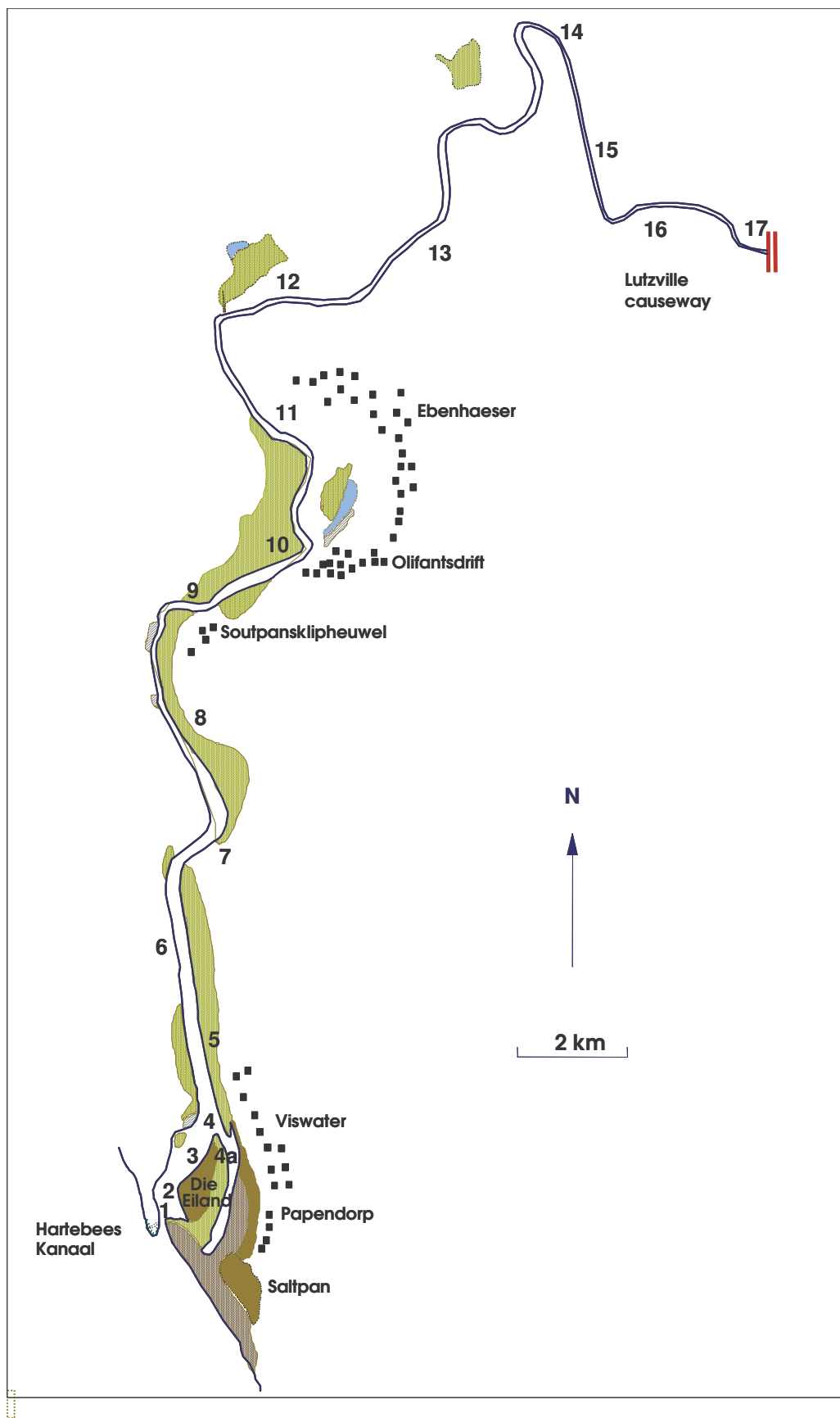


Figure 1. Map of the Olifants River Estuary showing seine and gillnet sampling sites

STUDY AREA

The Olifants / Doring system, at 49 000 km² is the second largest catchment in South Africa but contributes only 2 % of the country's MAR. The Olifants River is approximately 250 km long, falls in a winter rainfall area and is impounded by two of South Africa's oldest large dams, the Clanwilliam and Bulshoek. The Doring River runs out of the Ceres Karoo and joins the Olifants below the Bulshoek Dam above Klawer.

The Olifants Estuary flows into the Atlantic Ocean and is approximately 36 km long from the mouth below Papendorp to the Lutzville causeway, the latter which inhibits tidal influence from extending any further upstream. The surface area of the estuary is approximately 720 ha. The upper reaches 15-36 km from the mouth are narrow, 20-50 m in width with water depths averaging 1-3 m. Agriculture is intensive on both banks and fields and debris are often bulldozed to the edge, and into, the stream. The lower 15 km of the estuary widens to approximately 400 m with extensive saltmarsh on either side. Two kilometres from the mouth there is an approximately 2 km long backwater that originally was a second channel that became blocked with marine sand after a severe storm in 1925 (Morant 1984). The estuary enters the sea between a rocky headland to the north and a large sandy spit to the south. The spit and beach extending 5 km to Strandfontein Village are diamond-mining concessions but have yet to be mined. The Hartebees Kanaal, a shallow rocky channel bisects the northern headland. The rocky shores, beaches and subtidal areas to the north are mined.

The lower 15 km of the estuary supports a gillnet fishery comprised of fishers from the Ebenhaeser / Olifantsdrift and Papendorp / Viswater communities. There are currently 45 operators although there have been up to 120 in the past. Consequently, the fish fauna and assemblages are likely to have been impacted over and above any changes arising from altered habitat or freshwater flows.

METHODS AND STUDY APPROACH

Quantitative data on the fish of the Olifants River Estuary was obtained from a summer and winter seine and gillnet survey in February and August 2004, from a bimonthly seine and gillnet fishery simulation survey during 1997 – 1999, from a gillnet survey in March and August 1995 and from monthly catch returns from the commercial gillnet fishery 2003 – 2005 (MCM, Netfish System). The 2004 survey entailed sampling every 1-2 km from the mouth to the Lutzville Causeway, approximately 36 km upstream, whereas the 1997 – 1999 sampling was confined to the lower 8 km of the estuary (Figure 1 – also refer to Annexure 1). The 1995 survey was confined to gillnets but sampling, 1 km apart, extended all the way to the Lutzville Causeway. Additional information was obtained through observations during the various surveys and the published literature.

Gillnets used were 30 m in length with mesh sizes of 44, 48, 51, 54, 75, 100 and 145 mm respectively. During the 2004 survey they were deployed for approximately one hour at each site whereas during the 1997-1999 sampling they were set and checked on an hourly basis until sufficient fish were caught. Most of the fish caught were cut from the net to prevent injury, identified, measured and released. Night sampling was avoided due to boat traffic, the possibility of net theft and the difficulty in preventing high mortalities through large catches.

The seine net used was 30 m long, 2m deep with a mesh size of 10 mm and hauling ropes of 50 m. Depending on the size of the catch, all fish or a sub-sample, were identified, measured and, if alive, released. Temperature, Salinity (portable refractometer) and water clarity (sechii disc) were measured at each site.

THE FISH OF THE OLIFANTS RIVER ESTUARY

Importance of the estuary to fish

Estuaries provide numerous benefits to fish. These include high productivity, low predation, low salinities and refuge from adverse conditions in the marine environment such as low temperature or oxygen levels, all factors which contribute to more rapid growth and/or reduced mortalities (Potter *et al.* 1990, Whitfield 1998). As a result, many South African fish species are either partially or entirely dependent on estuaries to complete all or part of their lifecycle (Wallace *et al.* 1984, Whitfield 1994). The life history characteristics of most of South Africa's estuarine fish are known. This allows the fish recorded from the Olifants Estuary to be classified into the five major categories of estuarine-dependence suggested by Whitfield (1994) (Table 1).

A total of 38 fish species from 30 families have been recorded from the Olifants River Estuary (Day 1981, Morant 1984, Harrison *et al.* 1994, Hutchings & Lamberth 1999, Lamberth unpublished data and this study) (Table 2). Six (16 %) of these are entirely dependent on estuaries to complete their lifecycle. Eight of these breed in estuaries and include the estuarine round-herring *Gilchristella aestuaria*, Cape silverside *Atherina breviceps*, prison goby *Caffrogobius gilchristi*, commafin goby *Caffrogobius saldhana* and longsnout pipefish *Syngnathus temminckii*. Four, white steenbras *Lithognathus lithognathus*, leervis *Lichia amia*, freshwater mullet *Myxus capensis* and flathead mullet *Mugil cephalus* are entirely dependent on estuaries as nursery areas for at least their first year of life.

Another 7 (18 %) species e.g. harder *Liza richardsonii*, elf *Pomatomus saltatrix*, blackhand sole *Soleo bleekeri* and white stumpnose *Rhabdosargus globiceps* are at least partially dependent on estuaries. In all, 50 % of the fish species recorded from the Olifants Estuary can be regarded as either partially or completely dependent on estuaries for their survival. Most, (32 %) of the remaining species were marine species e.g. Silver kob *Argyrosomus inodorus*, pilchard *Sardinops sagax*, bluntnose guitarfish

Table 1. The five major categories of fishes which utilize South African estuaries (After Whitfield 1994)

Categories	Description of categories
I	Estuarine species which breed in southern African estuaries. Further divided into: Ia. Resident species which have not been recorded spawning in the marine or freshwater environment Ib. Resident species which also 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. Further divided into: Ila. Juveniles dependent on estuaries as nursery areas. Ilb. Juveniles occur mainly in estuaries but are also found at sea. Ilc. Juveniles occur in estuaries but are usually more abundant at sea
III	Marine species which occur in estuaries in small numbers but are not dependent on these systems
IV	Euryhaline freshwater species, whose penetration into estuaries is determined by salinity tolerance. Includes some species which may breed in both freshwater and estuarine systems.
V	Catadromous species which use estuaries as transit routes between the marine and freshwater environments. Further divided into: Va. Obligate catadromous species which require a freshwater phase in their development Vb. Facultative catadromous species which do not require a freshwater phase in their development

Rhinobatos blochi and eagle ray *Myliobatis aquila*, which occur in, but are not dependent on estuaries. Finally, seven euryhaline freshwater species, whose penetration into estuaries is determined by salinity tolerance, have been recorded from the Olifants Estuary. These are the endemic, red data Clanwilliam yellowfish *Labeobarbus capensis*, sawfin *Barbus serra*, and Cape galaxias *Galaxias zebratus* as well as the introduced smallmouth bass *Micropterus dolomieu*, bluegill sunfish *Lepomis macrochirus*, banded tilapia *Tilapia sparrmanii* and Mozambique tilapia *Oreochromis mossambicus*. No catadromous species have been recorded from the Olifants.

Species that breed in estuaries and / or estuarine residents comprise 21 % of the Olifants Estuary fish fauna as compared to 22 - 26 % for the Orange and Berg and between 4-18 % for estuaries on the south (e.g. Breede), east and KwaZulu-Natal coasts (Bennett 1994, Harrison 1999)). Including all estuarine breeders, entirely estuarine dependent species comprise 32 % of the Olifants Estuary fish fauna comparing well with the Orange (24-33%), Berg (26 %) and 25-54, 22 and 9 % recorded for the south, east and KwaZulu-Natal coasts respectively (Bennett 1994, Harrison 1997, 1999, Lamberth 2001, Lamberth 2003). Partially estuarine dependent species comprise 16 % of the Olifants fish fauna, which is lower than the 29 % for the Berg, 7- 22 % of the Orange and 18-27 % for estuaries from Cape Point to KwaZulu-Natal (Bennett 1994, Lamberth 2003).

Bennett (1994) points out that the high degree of estuarine-dependence of the Berg River fish fauna suggests that estuaries on the west coast are more important than those on the east coast of South Africa. Bennett (1994) further argues that the high reliance of the local fish on the Berg Estuary means

Table.2. A list of all species recorded in the Olifants Estuary during the 1995 gill-net study (a), by Morant 1984 (b), by Day *et al.* 1981 (c), by Harrison *et al.* 1994 (d), during a 1997-1998 seine & gillnet survey (Hutchings & Lamberth (2000) (e), by 2003-2004 commercial gillnet catch returns (MCM) (f), during this study (g) and Lamberth unpublished (h). The species are classified into five major categories of estuarine-dependence as suggested by Whitfield 1994, table 1.

Family name	Species name	Common name	Dependence category	Recorded by
Ariidae	<i>Galeichthys feliceps</i>	Barbel	IIb	a,d,e,f,g
Atherinidae	<i>Atherina breviceps</i>	Cape silverside	Ib	a,b,c,d,e,g
Carangidae	<i>Lichia amia</i>	Leervis	Ia	a,c,e,f
	<i>Trachurus trachurus</i>	Maasbanker	III	a,f
Centrarchidae	<i>Lepomis macrochirus</i>	Bluegill sunfish	IV	g
	<i>Micropterus dolomieu</i>	Smallmouth bass	IV	a,f,g
Cichlidae	<i>Oreochromis mossambicus</i>	Mozambique tilapia	IV	a,f
	<i>Tilapia sparrmanii</i>	Banded tilapia	IV	g
Clinidae	<i>Clinus superciliosus</i>	Super klipvis	Ib	a,e,f,g
Clupeidae	<i>Gilchristella aestuaria</i>	Estuarine roundherring	Ia	a,b,c,d,e,g
	<i>Sardinops sagax</i>	Pilchard	III	a,e,f
Cyprinidae	<i>Barbus serra</i>	Sawfin	IV	b,c,g
	<i>Labeobarbus capensis</i>	Clanwilliam yellowfish	IV	g,h
Dasyatidae	<i>Dasyatis chrysonota</i>	Blue stingray	III	a
Galaxiidae	<i>Galaxias zebratus</i>	Cape galaxias	IV	a
Gobiidae	<i>Caffrogobius gilchristi</i>	Prison goby	Ib	a,e,g
	<i>Caffrogobius nudiceps</i>	Barehead goby	Ib	b,e,g
	<i>Caffrogobius saldanha</i>	Commafin goby	Ib	g
	<i>Psammogobius knysnaensis</i>	Knysna sand-goby	Ia / Ib	a,d,e,g
Myliobatidae	<i>Myliobatis aquila</i>	Eagle ray	III	e
Mugilidae	<i>Liza richardsonii</i>	Harder	IIc	a,b,c,d,e,f,g
	<i>Mugil cephalus</i>	Springer mullet	IIa	a,b,d,e,f,g
	<i>Myxus capensis</i>	Freshwater mullet	IIa	a
Ophichthidae	<i>Ophisurus serpens</i>	Sand snake-eel	IIc	a
Pomatomidae	<i>Pomatomus saltatrix</i>	Elf	IIc	a,d,e,f,g
Rhinobatidae	<i>Rhinobatos blochi</i>	Bluntnose guitarfish	III	a,e,g
	<i>Rhinobatos annulatus</i>	Lesser guitarfish	III	a,e
Sciaenidae	<i>Argyrosomus coronus</i>	West coast kob	III	h
	<i>Argyrosomus inodorus</i>	Silver kob	III	d,f
Scyliorhinidae	<i>Haploblepharus pictus</i>	Dark shyshark	III	a,e,g
Soleidae	<i>Austroglossus microlepis</i>	West coast sole	III	b,f
	<i>Heteromycteris capensis</i>	Cape sole	IIb	a
	<i>Solea bleekeri</i>	Blackhand sole	IIb	a,f,g
Sparidae	<i>Lithognathus aureti</i>	Westcoast steenbras	III	h
	<i>Lithognathus lithognathus</i>	White steenbras	IIa	a,b,c,e,f
	<i>Rhabdosargus globiceps</i>	White stumpnose	IIc	a,e,f
Syngnathidae	<i>Syngnathus temminckii</i>	Pipefish	Ib	b,d,e,g
Triglidae	<i>Chelidonichthys capensis</i>	Gurnard	III	a,b,f,g

that any degradation of the estuarine habitat will have worse consequences for fish on the west coast than elsewhere in South Africa. A similar argument can be made for the Olifants Estuary where 48 % of the species caught show some degree of estuarine dependency compared to 54 % and 39 % in the Berg and Orange respectively. The Olifants Estuary is thus of equal importance to the Berg and Orange estuaries as an estuarine habitat for fish.

Non estuarine dependent marine (category III) species comprise 32 % of the species recorded but similar to the Orange Estuary, at least two of these, *A. inodorus* and *L. aureti*, occur predictably according to season and weather conditions as opposed to being vagrants that occur randomly. Although the proportion (and occurrence) of non estuarine dependent marine species is high, it can be expected given that the Olifants Estuary is permanently open and one of the few available warm water refuges during the summer upwelling season on the west coast.

Based on their distributional ranges given by Smith and Heemstra (1986), 21 (55 %) of the fish recorded in the Olifants River Estuary are southern African endemics. Twelve of these are South African endemics. In terms of the fish importance score outlined in the RDM methodology, the Olifants Estuary has a biodiversity and overall importance score of 99 % which places it within the top quintile of all estuaries in South Africa (refer to Appendix C – Abiotic Specialist Report). In turn, the Olifants Estuary is one of only three permanently open estuaries on the west coast of South Africa situated between the Berg River Estuary 125 km southwards and the Orange River Estuary *circa* 380 km to the north. The loss or degradation of the Olifants as an estuarine habitat could, in a bad case scenario, see a reduction in the range of the estuarine-dependent species by 125 km or more. This would be more likely to occur with those species to which the Olifants represents the western extremities of their distribution. For those fish whose range extends to the Orange River, the loss of the Olifants estuarine habitat could result in stock separation. The probability of occurrence and / or magnitude of these two scenarios will ultimately depend on the movement patterns of the species concerned.

Distribution and abundance

Gillnet sampling is usually targeted at the adults and sub-adults of the larger fish species whereas seine-nets are aimed at catching juveniles and the smaller fish species. A total of 247 048 fish representing 21 species from 14 families were caught in 64 seine hauls during 1997 – 1998 and February and August 2004 (Table 3). A further 567 630 fish representing 13 species from 10 families were recorded in gillnet catches during the 1997 – 1998 and 2004 sampling period and from 2 700 net-days reported in the 2003 – 2004 catch returns from the commercial gillnet fishery.

Sixty-four seine hauls yielded 247 048 fish or 3 860 fish.haul⁻¹ (Table 3). *Liza richardsonii* (55 %) and *Gilchristella aestuaria* (42 %) dominated numerically, providing 97 % of the total catch. Only two other species, *Caffrogobius* spp. (1.3 %) and *Atherina breviceps* (1 %), each provided 1 % to the total catch. *Liza richardsonii* occurred in 92 % of hauls whereas *G. aestuaria* (68 %), *Caffrogobius* spp. (57 %), (*Syngnathus temminckii* (53%) and *Psammogobius knysnaensis* (43 %) occurred in more than 40 % of the hauls. *Caffrogobius* spp. were not identified to species level in the field but through otolith

Table 3. Species composition and abundance (catch per haul) in 64 seine net samples from the Olifants Estuary during 1997 / 1998 and 2004. Shading indicates months in which new recruits were recorded.

	Number per haul												Total catch	% Occurrence
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
<i>Liza richardsonii</i>	-	753.1	-	-	2282.5	42	-	90.6	-	4445.0	9046.4	-	135 854	92
<i>Gilchristella aetuararia</i>	-	3757.8	-	-	230.0	1.0	-	456.9	-	1970.0	678.7	-	103 224	68
<i>Caffrogobius spp.</i>	-	43.3	-	-	77.5	0.3	-	4.9	-	205.0	122.4	-	3 109	57
<i>Atherina breviceps</i>	-	60.7	-	-	6.3	-	-	8.7	-	157.5	35.3	-	2 221	36
<i>Psammogobius knysnaensis</i>	-	22.3	-	-	10	7.7	-	3.7	-	-	-	-	620	43
<i>Lepomis macrochirus</i>	-	23.3	-	-	-	-	-	2.2	-	-	-	-	552	15
<i>Syngnathus temminckii</i>	-	10.1	-	-	0.5	10.0	-	2.8	-	0.5	7.7	-	391	53
<i>Clinus superciliosus</i>	-	1.4	-	-	0.3	-	-	0.8	-	105.0	11.7	-	385	23
<i>Micropterus dolomieu</i>	-	14.9	-	-	-	-	-	-	-	-	-	-	328	7
<i>Tilapia sparrmanii</i>	-	7.1	-	-	-	-	-	0.2	-	-	-	-	159	10
<i>Mugil cephalus</i>	-	7.0	-	-	-	-	-	-	-	-	-	-	155	3
<i>Pomatomus saltatrix</i>	-	1.4	-	-	-	-	-	-	-	-	-	-	30	13
<i>Rhinobatos blochi</i>	-	0.4	-	-	-	-	-	-	-	-	-	-	9	5
<i>Haploblepharus pictus</i>	-	0.1	-	-	-	-	-	-	-	0.5	-	-	3	5
<i>Chelidonichthys capensis</i>	-	0.1	-	-	-	-	-	-	-	-	-	-	2	2
<i>Solea bleekeri</i>	-	0.1	-	-	-	-	-	0.1	-	-	-	-	2	3
<i>Rhabdosargus globiceps</i>	-	-	-	-	-	-	-	-	-	-	0.2	-	2	2
<i>Oreochromis mossambicus</i>	-	0.1	-	-	-	-	-	-	-	-	-	-	1	2
<i>Lithognathus lithognathus</i>	-	-	-	-	-	-	-	-	-	-	0.1	-	1	2
Total per haul	-	4703	-	-	2607	61	-	571	-	6884	9902	-	247 048	
Number of species	-	17	-	-	7	5	-	10	-	7	6	-	19	

characteristics of a selected subsample. They comprised 90, 7 and 3 % *C. nudiceps* *C. saldhana* and *C.gilchristii* respectively.

Gillnet sampling caught a total of 105 fish at an average catch rate of 14 and 5 fish.set-hour⁻¹ in summer and winter respectively (Table 4). Sampling was limited, catches low and not considered representative of the larger or adult fish in the system. Consequently, it was decided to use the commercial catch return data as it was continuous and comprised 2 700 net-days over a two-year period. Commercial gillnet catches were dominated by *Liza richardsonii* which provided over 98 % of the total catch. Elf *P.saltatrix* provided 1 % whereas all other species (e.g. *M. cephalus* & *L. amia*) provided < 1 % of the catch. *Liza richardsonii* appeared in 97 % whereas *P. saltatrix*, *M. cephalus*, *S. sagax*, *A. inodorus* and *L. lithognathus* occurred in 1-10 % of the catches. Catch size and occurrence of species other than *L. richardsonii* are likely to be higher than reported, largely due to the fishery targeting *L. richardsonii* and the landing of species such as *P. saltatrix*, being prohibited.

Seasonality

Catches were strongly seasonal (Tables 3 & 4). The highest (9 902 fish.haul⁻¹) and lowest (61 fish.haul⁻¹) seine catches were in spring / early summer (October) and winter (June) respectively (Table 3). The greatest number of species caught was in February (17) and the lowest in June (5). *Liza richardsonii*,

Table 4. Species composition and abundance (catch per net-day) in the Olifants Estuary during 2003 - 2004. The data represents the reported catch of 2 700 net-days from the commercial gillnet fishery.

	Number per net-day												Total catch	% Occurrence
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
<i>Liza richardsonii</i>	203.68	183.51	189.73	249.42	235.98	177.84	227.50	195.73	226.90	214.46	144.17	259.78	563 162	97.0
<i>Pomatomus saltatrix</i>	6.57	2.53	2.06	0.67	0.31	0.20	0.184	0.39	1.41	0.64	1.22	2.90	3 557	10.6
<i>Mugil cephalus</i>	0.17	0.17	0.04	0.04	0.02	0.02	0.01	0.39	0.24	0.04	0.33	0.27	410	1.9
<i>Sardinops sagax</i>	0.08	0.06	0.09	0.17		0.01	0.02	0.01	0.09	0.03	0.16	0.06	177	1.5
<i>Argyrosomus inodorus</i>	0.06	0.04	0.05	0.03				0.01	0.04	0.02	0.12	0.05	95	0.7
<i>Rhabdosargus globiceps</i>			0.11	0.12	0.01			0.01			0.04	0.04	68	0.3
<i>Galeichthys feliceps</i>	0.10								0.03	0.07	0.01	0.03	52	0.4
<i>Chelidonichthys capensis</i>	0.06		0.07	0.07	0.02								40	0.2
<i>Lithognathus lithognathus</i>		0.01		0.02	0.01	0.02	0.01	0.02	0.04	0.01			36	0.5
<i>Micropterus dolomieu</i>	0.01		0.01	0.02		0.01	0.01		0.01	0.01	0.01	0.02	22	0.4
<i>Trachurus trachurus</i>				0.01	0.01					0.01			5	0.1
Sole spp.												0.02	4	0.1
<i>Lichia amia</i>				0.01									2	0.1
Total per net-day	207	186	192	251	236	178	228	197	229	215	146	263	567 630	
Number of species	8	6	8	11	7	6	6	7	8	9	8	9	13	
Number of net-days	115	183	172	233	214	215	190	249	311	327	296	199	2 700	

appears to recruit throughout year with the highest number of new recruits recorded in the spring months August and October. Overall, in terms of species, the highest number of new recruits was recorded in summer (February, 8 species) and the lowest in winter (June, 1 species) (Table 3). However, no seine data exist for the summer months December, January and March nor for July and September. Consequently, no conclusions can be made regards juvenile recruitment during those months or the overall pattern throughout the year.

Commercial gillnet catches were moderately to strongly seasonal, the highest *cpue* values, 229 - 263 fish.net-day⁻¹ and 236 - 251 fish.net-day⁻¹ being recorded in spring / early summer and autumn respectively (Table 4). In turn, the number of species caught was highest in autumn (April, 11) and lowest in winter (June / July 6). The reasons for the high spring and autumn *cpue* values are due to a number of factors. False Bay commercial beach-seine catches, showed a similar pattern that was attributed to the shoaling of *Liza richardsonii* and other species prior to migration into or out of the surf-zone during the spring and autumn months and not to an overall change in abundance (Lamberth *et al.* (1994). However, even though many species may leave the Olifants Estuary during the winter months its unlikely that pre-migration shoaling is entirely the cause of the higher *cpue* values. What may be true is that the higher *cpue* reflects a small change in the total number of fish in the estuary as well as a distributional change in response to flow or other variables that concentrate fish in certain areas and increase catchability. During autumn and spring, increased flows move fish downstream whereas cool marine waters force fish upstream with the nett result that they become more concentrated 4 – 8 km from the mouth. The higher number of species at this time can be attributed to marine species that have entered from the sea and freshwater species that have moved from upstream.

On the whole, it is likely that seasonal fluctuations in catches in the Olifants Estuary are not as pronounced as they were historically. Reduced flows and the prolonged summer low flow period as well as the dams on the

mainstream will have blurred a once abrupt switch between summer and winter. This would have been due to changes in abundance, long stream distribution and catchability of each species.

Along stream distribution

With the exception of the mouth region there was a marked difference in surface salinities at each sampling site between the summer and winter 2004 surveys (Figure 2). During summer, salinity from the mouth to 4 km upstream ranged from 30 – 35 ppt. whereas in winter it ranged from 20 – 25 ppt. In summer the 10 – 20 ppt salinity zone ranged from 5 – 15 km upstream whereas in winter it was confined to 3 – 4 km from the mouth. In summer the REI zone (0 – 10 ppt) extended from 15 km upstream all the way to the Lutzville Causeway where salinity was 2.6 ppt. In winter the REI started at 4 km from the mouth and salinities dropped to zero approximately 10 km upstream. In all, both 2004 surveys fell within a low flow drought period corresponding to States 3 & 4 and Scenario 17 of the future scenarios (refer to Appendix C – Abiotic Specialist Report).

Water clarity at the mouth, ranged from > 200 cm in summer to approximately 100 cm in winter. In both seasons, water clarity dropped to below 20 cm at approximately 3 km from the mouth, largely due to wind-mixing in the shallow old channel backwater. In summer, water clarity remained fairly constant (80 cm) until 15 km upstream, thereafter it fluctuated according to the presence or absence of dense *Potamogeton* beds that occurred at the time. During winter, water clarity remained at 40 cm from 5 – 30 km upstream. Water temperature in summer ranged from 15 °C at the mouth to 26 °C at the Lutzville Causeway. In winter temperature ranged from 12 °C at the mouth to 14 °C upstream, the exception being the shallow blind arm where it reached 16 °C (Figure 3).

Upstream distribution of the species caught by the gillnet fishery and during the summer and winter survey, was largely a reflection of the estuarine-dependence category to which they belong. *Gilchristella aestuaria*, a category Ia, estuarine breeding species (also freshwater populations), with a preference for the REI zone showed a slight downstream shift in distribution during the winter months (Figure 3 a). This corresponded with the REI zone starting at 4-5 km from the mouth during winter as opposed to 15 km during summer. In summer, species that have marine and estuarine breeding populations i.e. *Caffrogobius* spp., *Atherina breviceps*, *Syngnathus temminckii*, *Psammogobius knysnaensis*, and *Clinus superciliosus* were largely confined to the lower 12 km of the estuary in salinities of 5-35 ppt. During winter there was a distinct downstream shift and drop in abundance of nearly all these species (Figure 3a).

Category IIa species which are entirely dependent on estuaries as a juvenile habitat showed various responses between summer and winter. *Lithognathus lithognathus* showed a slight downstream shift but doubled in abundance during the winter months (Figure 3 b). *Lichia amia* was found up to 20 km from the mouth in summer but only 10 km upstream in winter. *Mugil cephalus* was distributed

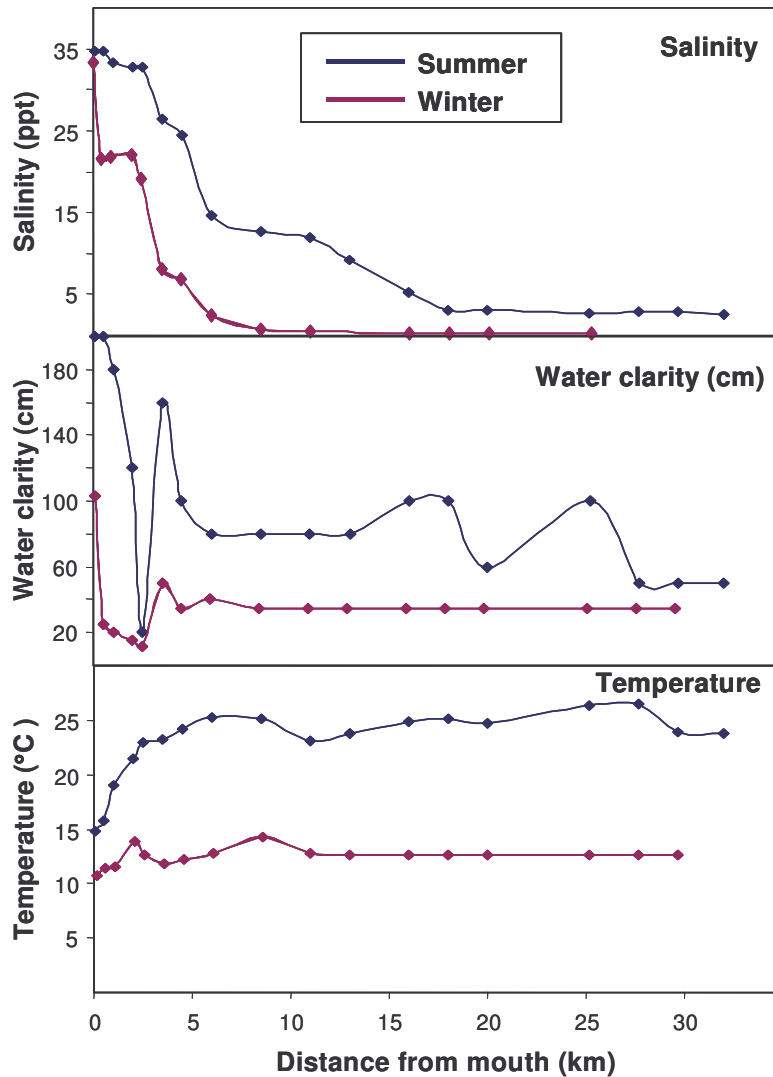


Fig. 2. Salinity, water clarity and temperature measured at each sampling site during summer (February) and winter (August) 2004 on the Olifants River Estuary.

throughout the estuary in summer with the highest densities 20 – 35 km upstream as opposed to winter when juveniles were completely absent and the entire population was confined to the lower 20 km (Figure 3 a & b).

Partially estuarine dependent species (II b & IIc), *Solea bleekeri*, *Rhabdosargus globiceps* and *Galeichthys feliceps* were distributed in the lower 15 km during summer and winter but in much lower numbers in the latter season. *Liza richardsonii* (IIc) were spread throughout the estuary during summer but concentrated in the lower 20 km during winter (Figures 4 b & c). *Liza richardsonii* was interesting in that, similar to the Breede Estuary, it had two peaks of abundance during summer, one in the lower 5 - 10 km and one 30-35 km upstream, the latter which disappeared in the winter months (Lamberth 2001). *Pomatomus saltatrix* occurred throughout the estuary from the mouth to 30 km upstream in both winter and summer. It was more abundant in summer with densities gradually increasing from the mouth to 25 - 30 km upstream (Figure 3b).

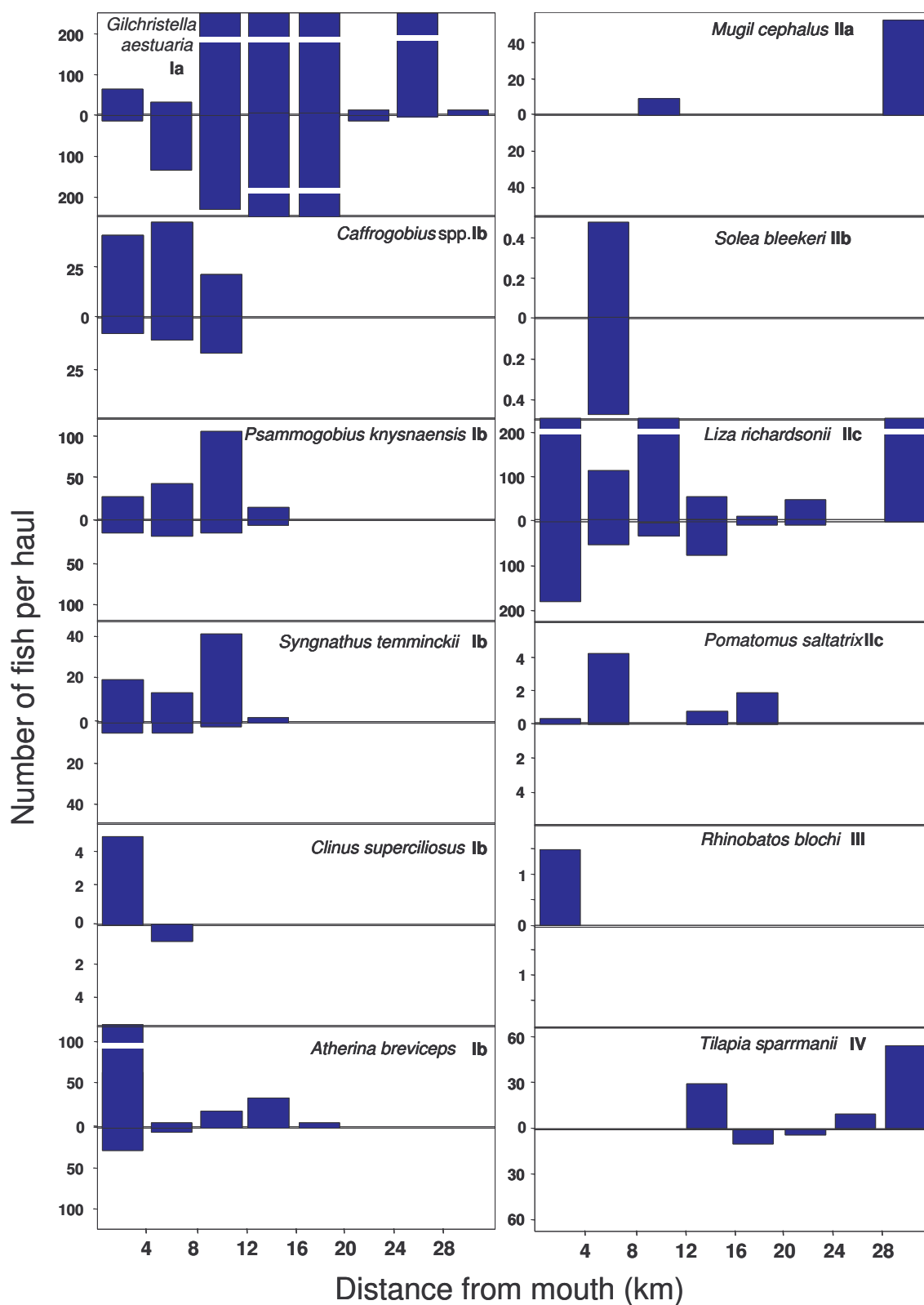


Fig. 3a. Catch per seine haul from the mouth of the Olifants Estuary to 36 km upstream during summer (Feb) and winter (Aug) 2004. Summer catches are shown above, and winter catches below, each axis. Species arranged in order of their estuarine dependence category (Table 1)

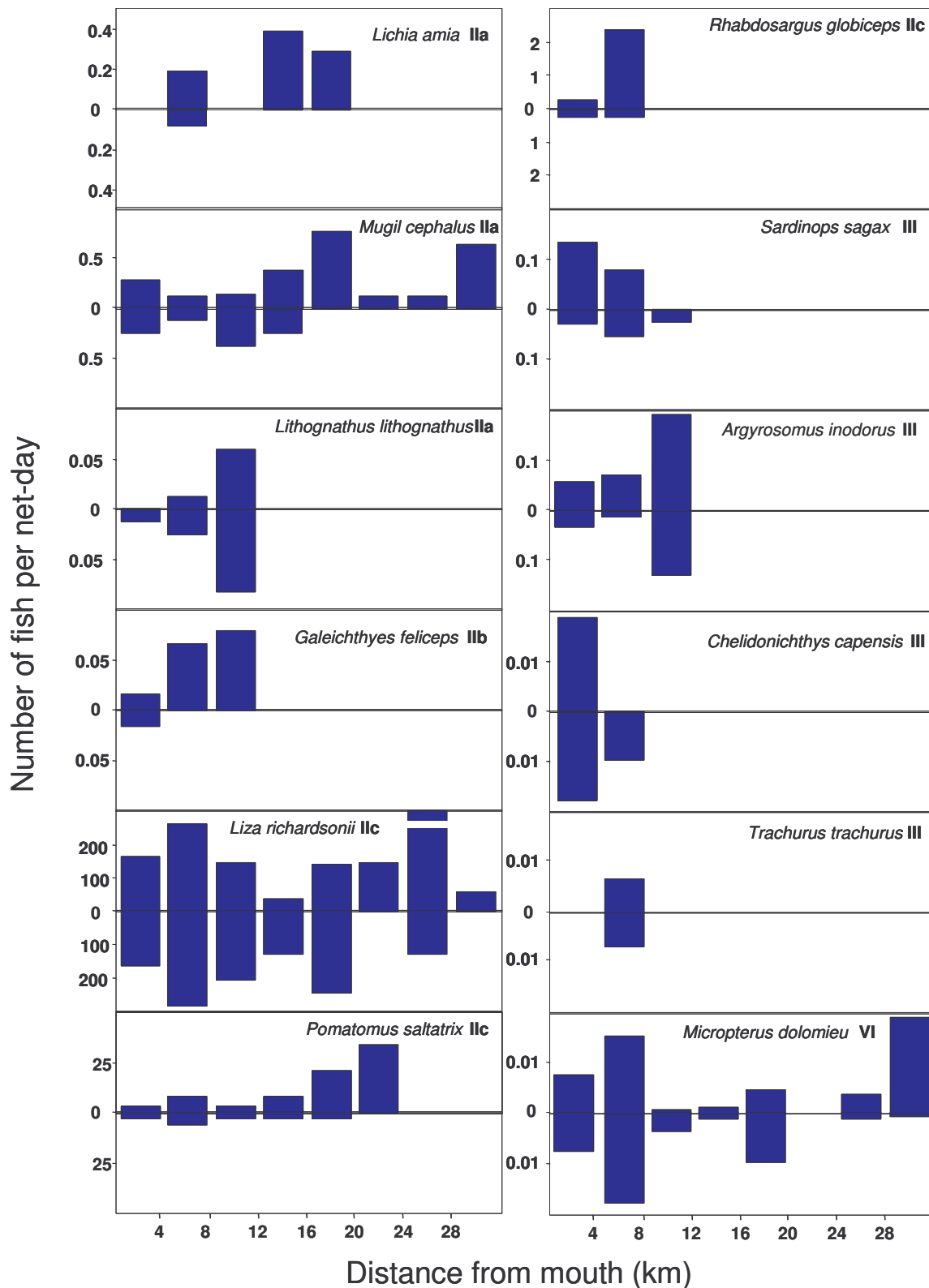


Fig. 3b. Commercial gillnet catch per net-day from the mouth of the Olifants Estuary to 36 km upstream during 2003 - 2004. Summer catches are shown above, and winter catches below, each axis. Species arranged in order of their estuarine dependence category (Table 1)

Non estuarine dependent marine species *Rhinobatos blochi*, *Sardinops sagax*, *Chelidonichthys capensis* and *Argyrosomus inodorus* were confined to the lower 15 km in winter and summer. With the exception of *A. inodorus* which peaked at 10 –15 km in winter and summer, they all decreased in abundance from the mouth upstream.

On the whole, the majority of completely and partially estuarine dependent species were most abundant from 5-20 km from the mouth in salinities ranging from 0-20 ppt and water clarity less than 100 cm. With the exception of *A. inodorus*, non estuarine dependent marine species were most often in the lower 5 km at salinities higher than 20 ppt whereas most freshwater tolerant species were further than 15 km from the mouth in salinities of 0-10 ppt.

Two species of kob, silver kob *Argyrosomus inodorus* and Angolan kob *A. coronus* are known from the Berg, Olifants and Orange Estuaries, the latter only been caught by anglers in the mouth regions. Interestingly, on the east coast of South Africa dusky kob (*A. japonicus*) are dependent on estuarine nursery areas whereas *A. inodorus* seldom if ever ventures into estuaries. On the west coast however, *A. inodorus* frequently (& predictably) occurs in the Berg, Olifants and Orange Estuaries whereas *A. coronus* is predominantly caught on the beaches immediately adjacent to their mouths only having been recorded in estuaries during low oxygen conditions in the sea (Lamberth 2003, unpublished data). Therefore, *A. inodorus* may show some degree of estuarine dependence on the west coast of South Africa. All three of the kob species mentioned prefer turbid waters such as that in the lower 5 – 15 km of the Olifants. Further, towards the edge of the range of *A. inodorus*, *A. coronus* becomes the dominant kob species in the Kunene River Estuary over 1 800 km to the north.

Recruitment

Seine sampling indicated that the abundance of the juvenile / sub-adult component of most species in the Olifants Estuary was low compared to other systems on the west coast. This suggests that recruitment may be low and / or mortality high for most species in the estuary. The nature of events in the gillnet fishery for *L. richardsonii* adds credence to this argument. There are four possibilities surrounding recruitment and fishing mortality of *L. richardsonii* in the Olifants Estuary. These are:

1. recruitment high, fishing mortality low
2. recruitment high, fishing mortality high
3. recruitment low, fishing mortality high
4. recruitment low, fishing mortality low

In 1990/1991 fishers complained of a drastic decline in catch rates - blaming diamond mining activities on the adjacent coastline, blockage of the Hartebees Kanaal and the mooring of diamond boats within the estuary mouth (Sowman *et al.* 1997). However, the reduction of catches coincided with the raising of the minimum mesh size from 51-54 mm and an almost doubling of the number of net permits issued to 65. Although the decline in catches can be attributed to both these factors it is unlikely that it would have happened to such an extent unless recruitment was low relative to fishing mortality and more fishers were sharing the same pool of fish. Further, 2004 catch return data suggest a direct negative correlation between fishing effort (number of net-days) and catch per unit effort in the Olifants Estuary.

In the absence of the gillnet fishery, measured recruitment of larger bodied species (e.g. *P. saltatrix*, *L. lithognathus*) into the Olifants may be within the same orders of magnitude as other west coast estuaries. However, most of them are caught within their first year of life once they reach approximately 50 mm in body depth and can no longer swim through the 48 – 51 mm mesh nets used by the gillnet fishery.

Migration and links between adjacent estuaries and the sea

There are only nine functional estuaries on the west coast. Of these, only the Berg and Olifants are permanently open, the Orange intermittently closed. The Olifants lies between the Orange, 380 km to the north and the Berg, 125 km to the south. Consequently, each of these estuaries is crucial in maintaining the range and stock integrity of estuarine and estuarine dependent species along the entire west coast. In turn, the Olifants is an important nursery area for exploited marine and estuarine species before they recruit into the marine fisheries. This is illustrated by the decline in the *L. richardsonii* stock and marine gillnet fishery catches on the west coast, being directly attributable to recruitment over-fishing in the Berg and Olifants estuary gillnet fisheries (Hutchings & Lamberth 2003). The Berg Estuary fishery has since been closed.

In the long-term, migration of marine and estuarine species up and down the west coast may be facilitated by the Orange, Olifants and Berg Estuaries. Throughout the year, but especially during the summer upwelling months, species such as *P. saltatrix*, *A. inodorus*, *L. lithognathus* and *L. aureti* tend to be distributed within the warmer water areas along the west coast. These warm areas are limited and tend to be in shallow bays, estuaries or within the warm water plumes in the vicinity of estuary mouths. The southward distribution of Angolan dusky kob (*Argyrosomus coronus*) and west coast steenbras (*L. aureti*), both non-estuarine marine species, to Langebaan may only be possible due to the availability of the warm water refuge offered by estuary mouths and plumes. Southward movement appears to be during Benguela Niño years, a reduction in upwelling and warmer coastal waters. Once upwelling resumes these species are confined to the limited warm water areas provided by estuaries and shallow bays. Consequently, a reduction in flow may have an influence on the distribution of these species by reducing the extent and availability of these refugia. A similar process is likely to facilitate exchange (including genetic) between South African, Namibian and Angolan stocks of *A. inodorus* and *P. saltatrix*. All four of the above species are important commercial and recreational fish in the region.

IMPORTANCE OF THE ESTUARY TO FISHERS

The value of estuarine fisheries and estuary contribution to marine fisheries on the west coast is in the region of R 18 million per annum of which R 2 million (11 %) can be attributed to the Olifants Estuary (Lamberth & Turpie 2003). Prior to the closure of the Berg Estuary gillnet fishery, an estimated 640 t of fish were caught annually from estuaries on the west coast, 121 t from the Olifants Estuary (Lamberth & Turpie 2003, Hutchings & Lamberth 2003). The bulk of this catch can be attributed to the gillnet fishery.

Gillnet fishery

The Olifants gill-net fishery is targeted on *L. richardsonii*. Mean annual landings of *L. richardsonii* by the fishery are in the region of 100 t with a further 5 - 20 t of bycatch species such as elf *P. saltatrix* and silver kob *A.*

inodorus (Lamberth & Hutchings 2003, MCM Netfish System). In contrast, the annual tonnage from the Olifants Estuary, comprises 1 – 2 % of the national catch by the inshore beach-seine and gillnet fisheries (Lamberth *et al.* 1997). There are 45 licensed individuals and an estimated 10 - 30 illegal fishers operating in the estuary (Sowman *et al.* 1997, MCM Netfish System). The nets used are restricted to 45 m in length and a minimum mesh size of 48 mm. All the fishers use rowing boats, the use of motors being frowned upon either because the fishers cannot afford them or due to the perception that they scare the fish. Fishing is seasonal, being confined mostly to summer (October - April) during low flows. Although abundance and / or catchability of *L. richardsonii* may be lower in the winter months, making fishing un-worthwhile, any attempt at setting nets is usually impeded by water borne debris. Sixty percent of the fisher households rely on fishing for 25 %-50 % of their summer income, whereas for the remaining 40 %, fishing comprises 75 % of household income (Sowman *et al.* 1997). A large part of the catch is consumed with more than 50 % of households eating fish very day.

The low flow experienced during 2004 saw the fishery active throughout the winter months. However, despite the overall increase in effort throughout the year, total catch was 100 – 120 t, similar to the annual average. This suggests that catches were spread out over a longer period and that *cpue* declined with the increase in effort. Consequently, it appears that recruitment is low, fishing mortality high and the 45 operators are above the effort maximum, most fish entering the system being caught. In turn, prolonged high flows or floods in winter may result in extreme hardship for the families reliant on fishing for a livelihood.

Recreational linefishery

The estuarine line-fishery comprises recreational shore-angling and limited recreational boat fishing. The boats used range from small dinghies to ski-boats of 6 m in length. On the Olifants, the bulk of the effort is from shore angling and boat use minimal. Based on angler densities on the adjacent shorelines and angler and boat counts in the Berg and Olifants estuaries, there may be up to 0.12 anglers per km of estuary or a maximum of 4 400 angler-days per year expended in west coast estuaries from the Berg River northwards (Lamberth & Turpie 2003). The gear used ranges from handlines to fishing rods of various shapes and sizes including fly-fishing. All the effort is currently recreational although approximately 14 % of these anglers admit to selling part of their catch (Lamberth 1996).

Recreational anglers catch an estimated 14 – 20 t of marine line-fish in estuaries on the west coast annually, 1 - 2 ton (8 %) from the Olifants Estuary. Recreational anglers catch a further 0.1 t of harders (*Liza richardsonii*) using cast-nets as well as a small but unknown quantity of freshwater fish, mostly the introduced species such as Mozambique tilapia (*O. mossambicus*) and smallmouth bass (*M. dolomieu*). The bulk of the Olifants Estuary linefish catch is made within 500 m of the mouth and comprises silver kob (*A. inodorus*), Angolan kob (*A. coronus*), white steenbras (*L. lithognathus*), west coast steenbras (*L. aureti*) and elf (*P.saltatrix*). Of these, the stocks of *A. inodorus* and *L. lithognathus* are collapsed and those of *P.saltatrix* and *L. aureti* overexploited. Estuarine fish stocks cannot be considered as discrete and in isolation from the marine environment. The current status of estuarine stocks is largely a reflection of the nationwide decline that has occurred for most line-fish species. In all, the associated yields are not sustainable with the current levels of effort.

POSSIBLE EFFECTS OF ALTERED FRESHWATER FLOWS

In order to predict the response of the fish community to future changes in flow, samples were grouped into five salinity ranges. Fish densities (fish.m⁻²), were then multiplied by the total area covered by each salinity range. In addition, exploited fish densities (Category II & III species) were corrected for fishing effects using catch ratios of fished to non-fished estuaries obtained from Hutchings and Lamberth (2003). For each scenario, “absolute abundance” was the sum of the total number of fish within each salinity range. The predicted changes are based on the assumption that all being equal, overall fish abundance will correspond with the shrinking or expansion of their preferred salinities under present day conditions. In reality, many of the species are tolerant of a wide range of salinities and will also respond to changes in, amongst others, habitat availability, prey availability, turbidity and temperature.

Under reference conditions the estuary was more river dominated than present during which State 1 never occurred and State 4 conditions with average flows greater than 20 m³s⁻¹, persisted for at least four months (June - September) every year (Table 5 a & b). Under these conditions the REI zone of 0 - 10 ppt begins 0 – 5.4 km from the mouth during a spring tidal cycle and extends 36 km upstream (refer to Appendix C – Abiotic Specialist Report). State 2 conditions (2 - 5 m³s⁻¹) would have dominated during the summer months of December - March and State 3 would have occurred during autumn (April - May) and spring (November – December). Under drought conditions the REI zone would have persisted from 9 km upstream and been approximately 140 ha or 34 % of the water surface area in extent.

The extensive REI zone suggests that turbidity would have been higher over a greater stretch of the estuary. This would have favoured species such as *Argyrosomus inodorus* and *Galeichthys feliceps*, which prefer turbid waters, and *Gilchristella aestuaria*, which adapts easily to either turbid or clear conditions. High turbidity would have excluded *Atherina breviceps*, which is a visual feeder that prefers clear water. Low salinity conditions throughout much of the estuary would have favoured freshwater tolerant species such as *Mugil. cephalus* and *Myxus. capensis*, although the latter species, similar to the present day, is likely to have been a rare vagrant.

Lower phytoplankton, benthic diatom and zooplankton production would have suited *G. aestuaria*, which can switch feeding behaviour from filter to selective feeding over a short time period. However, an

Table 5 a. Summary of the four possible abiotic states of the Olifants Estuary (from Appendix C: Abiotic Specialist Report).

	State 1	State 2	State 3	State 4
General description	Marine dominated	Saline penetration extended to middle reaches	Saline penetration limited to lower reaches	Freshwater dominated
Typical flow	< 2 m ³ s ⁻¹ , usually in summer (Zero occurrence under reference)	2-5 m ³ s ⁻¹ , (Summer under reference)	5-20 m ³ s ⁻¹ , (Autumn & spring under reference)	> 20 m ³ s ⁻¹ , (Winter under reference)
Mouth condition	Open, slightly constricted	Open	Open	Wide open
Tidal amplitude	0.3 - 1.3 m	0.3 - 1.3 m	0.3 - 1.3 m	0.3 - 1.3 m
REI zone begins (spring tides)	13 - 20 km	9 km	1 - 6 km	0 – 5.4 km
REI area (maximum)	64 – 110 ha	141 ha	201 ha	252 – 417 ha
REI area as % total surface area	15 – 26 %	34 %	48 %	60 – 100 %

Table 5 b. Monthly occurrence of the abiotic states under the different flow scenarios.

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
<i>Reference</i>	17.21	9.06	4.36	2.27	2.41	2.76	5.51	19.34	57.95	63.32	50.62	34.87
<i>Present</i>	6.49	0.76	0.74	0.75	0.70	0.57	0.51	2.19	21.22	40.66	43.61	24.82
2	10.11	2.93	1.50	1.51	1.34	1.42	2.84	6.19	37.99	51.82	47.54	22.18
7	9.33	3.29	1.90	1.91	1.71	1.77	2.86	5.48	38.23	51.94	47.57	16.21
5	4.36	1.42	1.52	1.53	1.41	1.32	1.23	2.33	14.39	22.60	27.35	13.96
17	1.75	1.87	1.52	1.53	1.41	1.32	1.15	0.78	12.54	20.11	21.10	10.19
10	1.24	1.36	1.52	1.53	1.41	1.32	1.15	0.67	2.20	4.53	13.11	6.36

abundant supply of detritus from the *Phragmites* beds would have been ideal for partial detritivores such as the mullet species *M. cephalus* and *L. richardsonii*. Benthic burrowers *Upogebia* and *Callianassa* would have been restricted to the lower reaches if there was suitable habitat present but densities and productivity would have been lower due to the lower salinities. Consequently, adult benthic feeders such as *L. lithognathus* and *Rhabdosargus globiceps* would probably have occurred further downstream and in lower densities. *Zostera* beds in the lower reaches, similar in size to the present day, would, in the absence of anthropogenic disturbance, have facilitated a much higher abundance of fish such as pipefish *Syngnathus temminckii* and gobies *Caffrogobius* spp.

In all, the fish community would have been dominated by estuarine resident (37 % numerically) or dependent species that are tolerant of, or prefer, lower salinities (Table 6). These would have been the estuarine resident *G. aestuaria*, and the detritivorous *M. cephalus* and *L. richardsonii*. These small species would have been preyed on by adults and juveniles of the large picivorous *A.inodorus*, *L. amia* and *P.saltatrix* which are likely to have been abundant, and the dominant predators in the system. Juveniles of most estuarine dependent benthic feeders such as *L. lithognathus* and *R. globiceps* are likely to have been abundant but the adults are likely to have had a shorter residence time within the system. Indigenous freshwater species such as *B. serra* and *L. capensis* are likely to have been

Table 6. Estuarine dependence categories in terms of “absolute” abundance in each salinity range during reference and present day conditions and for each of the five future scenarios. Percentage reference is abundance expressed as a percentage of that under reference conditions

Dependence category	Salinity ppt					Total	%	%
	30-35	20-30	10-20	0-10	0		composition	Reference
Reference: 100 % MAR								
la	3382305	312917	7209379	8392371	19238236	38535208	36.637	
lb	1787915	122340	79514	98955	29635	2118358	2.014	
lia	0	0	8665	79900	537547	626112	0.595	
lib	0	0	578	567	0	1144	0.001	
llc	38837056	17565647	4556763	2043396	583622	63586484	60.455	
III	27176	0	0	0	0	27176	0.026	
IV	0	0	0	181872	103723	285596	0.272	
V	0	0	0	0	0	0	0.000	
						105180079		
Present: 66.8 % MAR								
la	5991709	810491	6797331	9428540	8005666	31033737	41.916	81
lb	3167267	316874	74969	111172	12332	3682615	4.974	174
lia	0	0	2627	28868	71938	103433	0.140	17
lib	0	0	175	205	0	380	0.001	33
llc	22125529	14631623	1381677	738281	78104	38955214	52.615	61
III	15482	0	0	0	0	15482	0.021	57
IV	0	0	0	204327	43163	247490	0.334	87
V	0	0	0	0	0	0	0.000	0
						74038351		70
Scenario 2: 74.8 % MAR								
la	5134833	731249	6783169	8785984	11659561	33094797	46.589	86
lb	2714316	285893	74813	103596	17961	3196579	4.500	151
lia	0	0	2622	26901	104771	134294	0.189	21
lib	0	0	175	191	0	366	0.001	32
llc	18961353	13201085	1378798	687967	113752	34342955	48.346	54
III	13268	0	0	0	0	13268	0.019	49
IV	0	0	0	190402	62863	253265	0.357	89
V	0	0	0	0	0	0	0.000	0
						71035524		68
Scenario 7:69.3 % MAR								
la	5162523	713352	7639710	8385041	11506196	33406821	46.875	87
lb	2728953	278896	84260	98868	17725	3208702	4.502	151
lia	0	0	2953	25673	103393	132019	0.185	21
lib	0	0	197	182	0	379	0.001	33
llc	19063602	12877993	1552905	656572	112256	34263328	48.077	54
III	13340	0	0	0	0	13340	0.019	49
IV	0	0	0	181714	62036	243749	0.342	85
V	0	0	0	0	0	0	0.000	0
						71268338		68
Scenario 5: 56.6 % MAR								
la	5721598	803590	6819802	7836793	9975177	31156960	42.818	81
lb	3024484	314176	75217	92404	15366	3521648	4.840	166
lia	0	0	2636	23994	89636	116266	0.160	19
lib	0	0	176	170	0	346	0.001	30
llc	21128094	14507037	1386244	613643	97319	37732337	51.854	59
III	14784	0	0	0	0	14784	0.020	54
IV	0	0	0	169832	53781	223614	0.307	78
V	0	0	0	0	0	0	0.000	0
						72765955		69
Scenario 17: 49.5 % MAR								
la	4903898	651653	5891645	6530230	4432937	22410363	39.130	58
lb	2592241	254774	64980	76998	6829	2995822	5.231	141
lia	0	0	2277	19994	39834	62105	0.108	10
lib	0	0	152	142	0	294	0.001	26
llc	18108581	11764144	1197580	511335	43248	31624888	55.219	50
III	12672	0	0	0	0	12672	0.022	47
IV	0	0	0	141518	23900	165418	0.289	58
V	0	0	0	0	0	0	0.000	0
						57271561		54
Scenario 10: 39.6 % MAR								
la	5279421	634551	6145896	6009057	3419780	21488705	37.314	56
lb	2790746	248088	67784	70853	5268	3182739	5.527	150
lia	0	0	2376	18398	30730	51504	0.089	8
lib	0	0	158	130	0	289	0.001	25
llc	19495271	11455417	1249261	470526	33364	32703839	56.788	51
III	13642	0	0	0	0	13642	0.024	50
IV	0	0	0	130223	18438	148661	0.258	52
V	0	0	0	0	0	0	0.000	0
						57589379		55

abundant in the lower reaches during the winter months and frequently throughout the year. Non estuarine-dependent marine species, similar to the present day, are likely to have occurred according to the frequency of upwelling events in the sea. However, they would have been rare, confined almost entirely to the lower reaches of the estuary. Overall, the estuarine fish community would have been characterised by “low” diversity and “high” abundance typical of a freshwater dominated system.

Present day conditions and future scenarios

Under present day conditions the estuary has switched from a river to a marine dominated system for most of the year. State 1 conditions, which never occurred under reference conditions, with average flows $< 2 \text{ m}^3\text{s}^{-1}$, persist for six months of the year (November – April). High flow State 4 conditions ($> 20 \text{ m}^3\text{s}^{-1}$) still occur for four months during the winter (June – September) but State 3 conditions ($5 - 20 \text{ m}^3\text{s}^{-1}$), once characteristic of spring and autumn, now only occur for one month during spring. Under these conditions the winter REI zone of 0 - 10 ppt still begins at 0 – 5.4 km from the mouth. However, under a spring tidal cycle, the summer REI begins at 13 – 20 km as opposed to a maximum of 9 km under reference conditions. (refer to Appendix C – Abiotic components). In all, the summer REI may be 55 % smaller in extent than it was under reference conditions.

Present day conditions represent a 34 % reduction in MAR. The future scenarios represent a slight increase in MAR reaching the estuary under Scenarios 2 & 7 (25 – 31 % < reference), but thereafter a further reduction from 43 % under Scenario 5 to 60 % under Scenario 10 and the construction of the Melbosrug Dam. The reductions in MAR result in the Olifants Estuary gradually changing from a river to a marine dominated system. The REI zone shrinks and may become close to non-existent under drought conditions. In turn, depending on their salinity preferences, the ranges of different species of fish may either shrink or expand. Depending on the persistence of the different states and the life-history characteristics and movement patterns of the species concerned, changes in species composition and abundance may be either short-term or permanent.

Species that breed only in estuaries (Ia) have undergone a 20 % reduction in numbers from the reference to present day condition whereas those that have estuarine and marine breeding populations (Ib) have increased by 74 % (Table 6). Estuarine breeders increase slightly to 86 – 87 % of reference under Scenarios 2 & 7 but thereafter continue to decline to 81 % and 56 % of reference abundance from Scenarios 5, 17 & 10. Their decline corresponds with the shrinking of the REI zone and their preferred salinity range of 0-10 ppt. Category Ib species increase due to their being equally at home in the estuarine or marine environment, mostly confined to the middle and lower reaches of the estuary and preference or tolerance of low turbidity. The response of category Ia species to lower flows is largely due to the decline in estuarine round-herring *Gilchristella aestuaria* whereas the increase in category Ib species is due to Cape silverside *Atherina breviceps*, *Caffrogobius* spp. and *Clinus superciliosus* (Table 7). *G. aestuaria* is responding to a loss of habitat or preferred salinity in the upper reaches of the estuary whereas *A. breviceps*, a visual feeder, is responding to a decrease in turbidity and increase in area covered by their preferred salinity range in the middle and lower reaches.

Table 7. Species change in abundance from reference to present day conditions and the five scenarios

	Dependence category	Percentage of abundance under reference conditions					
		Present day	Scenario 2	Scenario 7	Scenario 5	Scenario 17	Scenario 10
<i>Gilchristella aestuaria</i>	1a	60	64	65	60	58	55
<i>Psammogobius knysnaensis</i>	1a	106	96	98	103	115	122
<i>Clinus superciliosus</i>	1b	135	117	117	130	148	158
<i>Caffrogobius spp.</i>	1b	133	116	116	128	144	153
<i>Atherina breviceps</i>	1b	129	111	112	122	140	149
<i>Syngnathus temminckii</i>	1b	99	93	98	97	109	110
<i>Mugil cephalus</i>	2a	9	12	12	10	7	6
<i>Lithognathus lithognathus</i>	2a	20	19	18	17	19	17
<i>Soleo bleekeri</i>	2b	19	18	19	17	19	19
<i>Liza richardsonii</i>	2c	34	30	30	33	37	39
<i>Pomatomus saltatrix</i>	2c	21	20	21	20	23	24
<i>Rhabdosargus globiceps</i>	2c	47	42	41	46	50	49
<i>Haploblepharus pictus</i>	3	32	27	28	31	35	38
<i>Rhinobatos blochi</i>	3	32	27	28	31	35	38
<i>Chelidonichthys capensis</i>	3	32	27	28	31	35	38
<i>Tilapia sparrmanii</i>	4	73	72	69	64	66	60
<i>Oreochromis mossambicus</i>	4	84	79	75	70	78	72
<i>Micropterus dolomieu</i>	4	84	79	75	70	78	72
<i>Lepomis macrochirus</i>	4	57	62	60	54	50	44

Category IIa obligate estuarine dependent species such as flathead mullet *Mugil cephalus* and white steenbras *Lithognathus lithognathus* have declined by 83 % since reference conditions and are likely to decline to 8 % of reference under Scenario 10. *Lithognathus lithognathus* shows an 80 % decrease from reference to present day and thereafter a gradual decline to 17 % of reference by Scenario 10. In the absence of fishing and its current overexploited state, *L. lithognathus* would have actually show a small increase from reference to present day. This would have been due to it being a benthic feeder and responding positively to an upstream expansion of the mudflats and an increase in the burrowing mudprawn *Upogebia africana* and sandprawn *Callinassa krausii*.

The 80 % decline of *P. saltatrix* and *L. lithognathus* in Scenarios 17 & 10 is a point of concern as the stocks of these two species are already overexploited and / or collapsed at 34 % and 6 % of pristine respectively. Partially estuarine dependent category II fish, mostly *Liza richardsonii* are 40 % less abundant under present day as opposed to reference conditions (Table 6). However, this is largely due to fishing effects, in the absence of which they would have been more than twice as abundant as under reference conditions. Under the future scenarios, they continue to decline to 50 % of their reference abundance. In turn, *L. richardsonii* are the mainstay of the inshore beach-seine and gillnet fisheries including the Olifants gillnet fishery. Although lower flows may, to some extent, have compensated for the decline due to fishing, they are regarded as overexploited and the local fishers are already struggling to maintain a viable catch. Should this species decline in numbers under the future scenarios, it may see many of the current fishers being forced out of the fishery, prior to its' phasing out within the next ten years.

Non estuarine-dependent marine species (category III) undergo a 43 % decrease in abundance from reference to present day (Table 6). They decline a further 7-10 % from present day to Scenario 10. Again, in the absence of fishing, they would have been 77 % more abundant under the present day. The most likely reason for this to

occur would be a decline in flow resulting in a reduction in the warm water plume entering the sea with a corresponding decline in the number of marine fish encountering it. Similarly, the shrinking of the plume and reduction in the magnitude of olfactory and temperature cues reaching the marine environment is likely to be the main cause of juvenile obligate estuarine dependent species not recruiting to the estuary.

Category IV freshwater species are likely to decline by 48 % by Scenario 10 but as they are solely represented by introduced fish such as smallmouth bass *Micropterus dolomieu*, this can be regarded as a positive consequence of reduced flows. However, reduced flows will prevent the success of any future initiatives to re-introduce indigenous species to the upper reaches of the estuary.

In summary, reduced freshwater flows are likely to see an overall reduction in abundance of species that breed only in estuaries, those that are entirely estuarine dependent and freshwater species. With the addition of fishing effects, numbers may decline to such an extent that some of these species may completely disappear from the Olifants Estuary. In the absence of fishing, partially estuarine dependent and marine species would have increased from reference to the present day with the encroachment of higher salinity further upstream and expansion of available habitat. However, they will decrease under future scenarios and shrinking of the warm water plume entering the sea. Overall, in the absence of fishing, the fish community has experienced a gradual change from a high biomass, low diversity, freshwater dominated system under reference conditions, to a high biomass, medium diversity, marine dominated system under the present day. Overall abundance has decreased by 20 % from reference to present day and thereafter will gradually decline to 55 % of reference from Scenario 2 through to Scenario 10. Consequently, future reductions in flow are likely to see the Olifants Estuary progressing towards a medium to low biomass, low diversity, marine dominated system.

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Annexure 1. Olifants River Estuary fish sampling sites



Site 1: 0.1 km



Site 2: 0.5 km



Site 3: 1 km



Site 4: 2 km



Site 4a: 2.5 km



Site 5: 3.5 km



Site 6: 4.5 km



Site 7: 6 km



Site 8: 8.5 km



Site 9: 11 km



Site 10: 13 km



Site 11: 16 km



Site 12: 18 km



Site 13: 20 km



Site 14: 25 km



Site 15: 28 km



Site 16: 30 km



Site 17: 36 km

APPENDIX H

SPECIALIST REPORT: BIRDS

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1. INTRODUCTION

This study forms part of the estuarine freshwater reserve determination for the Olifants River Estuary, which in turn forms part of the Olifants / Doring catchment ecological water requirements study. The overall study aims to describe the present state of the estuary in terms of health, and the probable state of the estuary under a number of possible future scenarios. The study follows Resource Directed Measures (RDM) methodology, and will ultimately be used to set the Management Class of the estuary, which determines its future health state and the quantity and quality of water that is allocated to the environment versus alternative uses.

In the case of the Olifants estuary, the RDM process is being carried out at a comprehensive level, the methods for which are described in detail in DWAF (2004). Runoff scenarios for the natural and present situation are used to evaluate the present ecological status of the estuary and to determine the recommended ecological reserve category (ERC). These runoff scenarios, together with a series of five possible future run-off scenarios are then evaluated to derive the Reserve and Resource Quality Objectives for the estuary.

Four different states of the Olifants estuary have been described (Table 1). Their prevalence under the five different runoff scenarios is summarised in Table 2.

Table 1. Summary of four possible states of the Olifants estuary (refer to Appendix C – Abiotic Report)

	State 1	State 2	State 3	State 4
General description	Marine dominated	Saline to middle reaches	Saline to lower reaches	Freshwater dominated
Typical season	Summer	Summer	Winter	Winter
Typical flow	< 2 m ³ /s	2-5 m ³ /s	5 - 20 m ³ /s	> 20 m ³ /s
Mouth	Open	Open	Open	Open
Tidal amplitude	Neap: 0.3 (neap) Spring, mouth: 1.3, Spring, top: 1.0	Neap: 0.3 (neap) Spring, mouth: 1.3, Spring, top: 1.0	Neap: 0.3 (neap) Spring, mouth: 1.3, Spring, top: 1.0	Neap: 0.3 (neap) Spring, mouth: 1.3, Spring, top: 0
Water retention time	Lower: 1-10 days Mid-upper: > 6 weeks	Lower: 1-5 days Mid-upper: 1-4 weeks	Lower: 1-3 days Mid-upper: 1-2 weeks	<1-4 days throughout
Salinity distribution	10 – 20‰ range is 10 – 14 km upstream	10 – 20‰ range is 7-9 km upstream	10 – 20‰ range is 5-6 km upstream	10 – 20‰ range is 4.5-5.5 km upstream
Temperature	Quite a steep gradient ~12 to 25	Similar to State 1	Generally cold 12-15	Generally cold 12-15
Turbidity	Low – secchi >1	Low – secchi >1	Higher turbidity in upper reaches	Higher turbidity in mid-upper reaches
Dissolved Inorganic Nitrogen (DIN)	Lower 8km: ~200µg/l 8- 25km: negligible, Above 25km: ~100µg/l*	Lower 8km: ~200µg/l 8- 25km: negligible, Above 25km: ~100µg/l*	Lower 3km: ~200µg/l 3- 9km: gradient, Above 9km: >300µg/l*	Lower 3km: ~200µg/l 3- 9km: gradient, Above 9km: >300µg/l*
Dissolved Reactive Phosphate-P (PO₄-P)	Lower 8km: ~50µg/l 8- 25km: negligible, Above 25km: ~100µg/l*	Lower 8km: ~50µg/l 8- 25km: negligible, Above 25km: ~100µg/l*	~50µg/l throughout	~50µg/l throughout
Dissolved Reactive Silicate (SiO₄-Si)	Lower 8km: ~500µg/l 8- 25km: negligible, Above 25km: ~2000*	Lower 8km: ~500µg/l 8- 25km: negligible, Above 25km: ~2000*	Lower 3km: ~500µg/l 3- 9km: gradient, Above 9km: >2000µg/l*	Lower 3km: ~500µg/l 3- 9km: gradient, Above 9km: >2000µg/l*

* this will increase in future scenarios with greater agricultural runoff; in the reference condition, DIN in upper reaches probably lower than present

Table 2. Summary of the average flows (m³/s) and predominant states (state 1 = blue, state 2 = green, state 3 = orange, state 4 = white) in each month for the reference condition, present condition and five possible future scenarios (refer to Appendix C – Abiotic Specialist Report)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Reference	17.21	9.06	4.36	2.27	2.41	2.76	5.51	19.34	57.95	63.32	50.62	34.87
Present	6.49	0.76	0.74	0.75	0.70	0.57	0.51	2.19	21.22	40.66	43.61	24.82
Scenario 2	10.11	2.93	1.50	1.51	1.34	1.42	2.84	6.19	37.99	51.82	47.54	22.18
Scenario 7	9.33	3.29	1.90	1.91	1.71	1.77	2.86	5.48	38.23	51.94	47.57	16.21
Scenario 5	4.36	1.42	1.52	1.53	1.41	1.32	1.23	2.33	14.39	22.60	27.35	13.96
Scenario 17	1.75	1.87	1.52	1.53	1.41	1.32	1.15	0.78	12.54	20.11	21.10	10.19
Scenario 10	1.24	1.36	1.52	1.53	1.41	1.32	1.15	0.67	2.20	4.53	13.11	6.36

The terms of reference for the specialist bird study were as follows:

1. Describe the avifaunal community based on one winter and one summer site visit as well as existing information;
2. Determine the importance of the estuary for birds;
3. Identify the key abiotic or biotic parameters which influence the avifauna;
4. Define the present status of the avifaunal community;
5. Predict the reference condition for birds, using the above information, as well as the reference conditions estimated by other specialists for the abiotic and other biotic components; and
6. Predict the effect of each of the five future scenarios on birds.

The approach and method follows that provided in the updated version of Water Resource Protection Policy Implementation. Methodology for the Determination of the Preliminary Ecological Reserve for Estuaries (Version 2) (DWAf 2004). The results of this study are also summarised in the accompanying RDM specialist templates.

2. STUDY AREA AND METHODS

This study is based on existing count data as well as counts conducted during two site visits in 2004. Summer count exist for 1975 and 1980, and regular summer Co-ordinated Waterbird Counts (CWAC) counts began in 1996 (Table 3). However, these studies only concentrated on the lower 3km of the estuary. In this study, a summer count was conducted in March 2004, when bird numbers are usually maximal, and a winter count was conducted in July. The summer count extended about 25km up the estuary, and the winter count extended 31km up the estuary. Birds were counted from the estuary mouth to the top of the estuary during spring low tide. In this study, the estuary was divided into counting sections in order to determine the distribution of birds along the estuary (Figure 1).

Table 3. Summary of existing bird count data for the Olifants estuary

Year	Season	Area	Source
1975	Summer	Waders only	Summers <i>et al.</i> 1976
1980	Summer	Lower estuary only	Underhill & Cooper 1984
1996-04	Summer, Winter	Lower estuary only	CWAC
2004	Summer, Winter	Whole estuary	This study

Habitats along the Olifants estuary are described in Adams *et al.* (2005). In summary, the estuary is dominated by a channel area of 228ha, it has 235ha of saltmarsh (excluding the 700ha of floodplain paleo-saltmarsh), there are 55ha of intertidal mudflats, 23ha of sand flats, 48ha of *Zostera* beds and 60ha of reedmarsh. In addition, there is a saltpan in the mouth area which is 57ha in extent. The microphytes, invertebrates and fish of the estuary and under different flow scenarios are described in Appendix D, Appendix F and Appendix G, respectively.

1 CWAC data were purchased from the Avian Demography Unit, University of Cape Town.

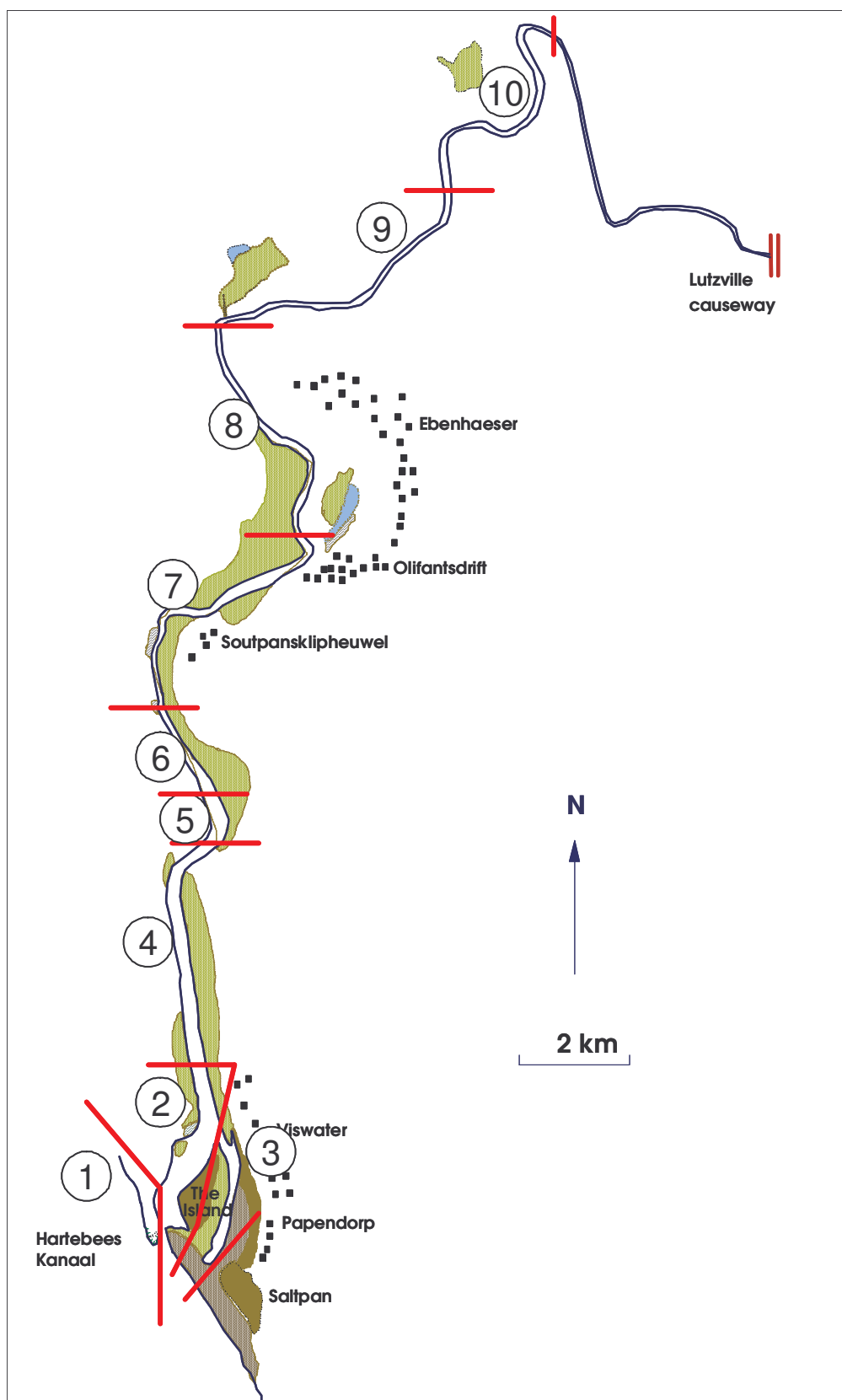


Figure 1. Map of the Olifants estuary showing the divisions between main counting areas (red lines).

3. IMPORTANCE OF THE OLIFANTS ESTUARY FOR BIRDS

The Olifants is one of four perennial estuaries in the Cold Temperate zone (West Coast). Covering 700 ha (or double that if the paleo-saltmarsh, a remnant of the time when the orange river flowed out via the present day Olifants estuary, is included), the estuary is one of the largest 10% in the country. It is also one of the most important in terms of the amount and diversity of habitat it contains, including more saltmarsh than any other estuary. Not surprisingly, the estuary is one of the most important in the country in terms of its conservation value. Based on an index which takes size, estuary type rarity and biodiversity (plants, invertebrates, fish, birds) into account, the estuary is ranked second overall (Turpie *et al.* 2004). It has been identified as an Important Bird Area (Barnes 1998) and a desired protected area (Turpie *et al.* 2002, Turpie 2004).

The estuary is ranked among the top 10 estuaries in South Africa in terms of its avifauna (Turpie 2004, which updates Turpie *et al.* 2002). This score is calculated using the 1979/80 summer bird counts for 178 estuaries (Underhill & Cooper 1984), as well as subsequent counts for the remaining estuaries.

The estuary has a fairly typical composition of birds compared with other permanently open South African estuaries. In addition to having high diversity and numbers of birds (see below), it regularly supports important and/or red data species, including African Black Oystercatcher, Caspian Tern, Chestnut-banded Plover, Lesser Flamingo and African Marsh Harrier.

4. PRESENT STATUS OF AVIFAUNA

4.1 Taxonomic composition

Nine orders are represented on the estuary, with Charadriiformes, making up 41% of the waterbird species recorded on the estuary (Table 4). Other groups are relatively evenly represented. A total of 21 species are long-distance migrants. The taxonomic make up is highly representative of estuarine avifauna in South Africa (see Hockey & Turpie 1999), with a large proportion of species being recorded here.

Table 4. Numbers of species of different groups that have been recorded on the estuary (Non-passerine waterbirds, excluding vagrants).

Order	Common names	Total	Migratory
Podicipediformes	Grebes	3	
Pelecaniformes	Cormorants, darters	5	
Ciconiiformes	Herons, egrets, ibis, spoonbill...	8	
Phoenicopteriformes	Flamingos	2	
Anseriformes	Ducks	12	
Falconiformes	Birds of prey	2	1
Gruiformes	Rails, crakes, coots..	3	
Charadriiformes	Waders	24	15
	Gulls	3	
	Terns	7	5
Alcediniformes	Kingfishers	3	
		72	22

4.2 Species richness and abundance

The Olifants estuary is a particularly rich estuary in terms of avifauna, this being largely ascribed to its size, diversity of habitat types (including a full range of freshwater to marine) and productivity. A total of 72 non-passerine waterbird species (excluding vagrants) have been recorded on the estuary, with about 52 species recorded in single summer and winter counts of the whole estuary (Table 5).

Table 5. Species and maximum numbers recorded on the Olifants estuary during this study and previous counts.

Species	Summer	Winter	Species	Summer	Winter
Grebes			Moorhen	3	6
Great Crested Grebe	2	0	Red-knobbed Coot	992	654
Black-Necked Grebe	0	1			
Little Grebe	13	39	Waders		
Pelicans, cormorants, darters			African Black Oystercatcher	37	16
Great White Pelican	430	9	Common Ringed Plover	205	3
White-breasted Cormorant	183	120	White-fronted Plover	68	143
Cape Cormorant	1671	266	Chestnut-banded Plover	14	71
Bank Cormorant	0	1	Kittlitz's Plover	75	68
Reed Cormorant	104	155	Three-banded Plover	16	2
African Darter	37	98	Grey Plover	330	29
Hérons, egrets etc			Blacksmith Lapwing	21	18
Grey Heron	23	22	Turnstone	35	0
Goliath Heron	0	1	Terek Sandpiper	5	0
Purple Heron	2	1	Common Sandpiper	5	0
Great Egret	8	0	Green Sandpiper	11	0
Little Egret	33	25	Marsh Sandpiper	29	0
Yellow-billed Egret	1	0	Common Greenshank	183	192
Black-crowned Night-Heron	8	10	Knot	182	0
Yellow-billed Stork	3	0	Curlew Sandpiper	5362	0
African Sacred Ibis	22	29	Little Stint	395	1
Glossy Ibis	19	38	Sanderling	246	0
African Spoonbill	35	31	Ruff	48	0
Flamingos			Bartailed Godwit	22	0
Greater Flamingo	321	157	Eurasian Curlew	96	10
Lesser Flamingo	2728	177	Common Whimbrel	66	1
Ducks			Pied Avocet	487	59
Egyptian Goose	20	54	Black-winged Stilt	16	42
South African Shelduck	103	83	Gulls		
Yellow-billed Duck	44	109	Kelp Gull	109	174
African Black Duck	0	4	Grey-headed Gull	2	1
Cape Teal	14	18	Hartlaub's Gull	184	129
Hottentot Teal	0	3	Terns		
Redbilled Teal	3	3	Caspian Tern	25	4
Cape Shoveller	58	35	Swift Tern	533	68
Spur-winged Goose	0	43	Sandwich Tern	39	0
Maccoa Duck	0	2	Common Tern	12013	0
Whitebacked Duck	1	0	Antarctic Tern	0	435
Whitefaced Duck	0	2	Little Tern	3	0
Bird of prey			Whitewinged Tern	62	0
African Marsh Harrier	1	1	Kingfishers		
Osprey	1	0	Pied Kingfisher	26	39
Rails			Giant Kingfisher	2	0
Purple Gallinule	2	1	Malachite Kingfisher	0	3

Most estuarine waterbird species occur in this system, thus the full range of taxonomic groups is found. Species are dominated by waders (25), and there is also a high diversity of ducks (12), terns (7), ciconiiformes (8) and pelicaniformes (5). The latter group includes two marine cormorant species that are largely confined to the rocky point at the mouth, and which are excluded from later analyses.

No monthly counts have been carried out at the Olifants estuary, but based on trends at other estuaries such as the Berg, bird numbers are expected to be maximal in December - March and minimal in mid-winter. However, numbers of certain groups may be maximal during spring, as at the Berg estuary, and this is not captured in this study. A total of about 5900 birds were counted in this study in late summer and 3200 in mid-winter. Numbers in summer have reached much higher levels in past counts, with numbers of around 16000 birds being recorded in both January and December 1980 (Underhill & Cooper 1984). These high counts were due to high numbers of terns (up to 12 000) and high numbers of waders (up to 7500, compared with 1500 in this study).

4.3 Community composition

While species richness is similar in summer and winter, there are marked changes in community composition and numbers. The following is based primarily on the counts conducted during this study, and excludes the large number of marine cormorants that roost on the rocky point at the mouth and occasionally spill over into the lowest part of the estuary.

The avifauna in summer was numerically dominated by waders (about 36%) and terns (about 45%), the majority of which are long-distance migrants. It must be noted, though, that the numbers of waders and terns vary considerably between years, as do numbers of flamingos. Terns are dominated by Common Tern, with up to 12 000 of these having been recorded in the estuary. Apart from terns, the avifauna in summer is consistently dominated by waders (plovers, sandpipers, etc), particularly the smaller species such as Curlew Sandpiper (Figure 2). Just over 90% of the waders using the estuary in summer are Palearctic migrants (from sub-Arctic and Arctic breeding grounds). The remaining waders are resident species: about 144 resident waders (e.g. Whitefronted Plovers, Kittlitz's Plover, Water Dikkop) were recorded on the estuary during this study, but up to over 650 have been recorded in the past (1980). Much of the difference is due to high numbers of Avocets having been recorded in 1980.

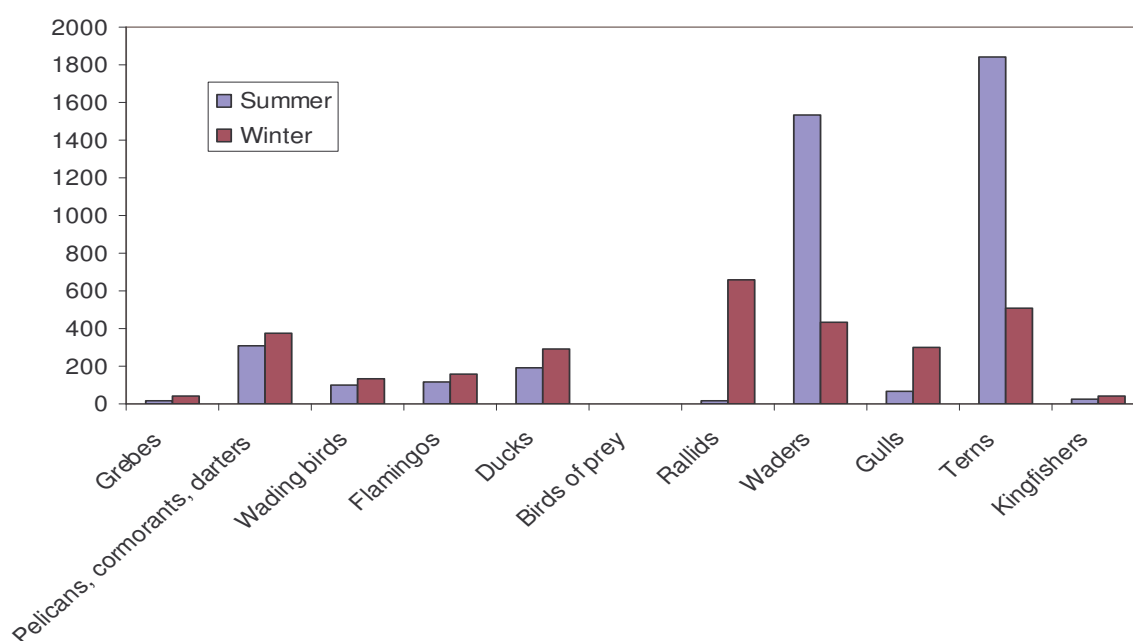


Figure 2. Avifaunal community composition in summer and winter in terms of broad taxonomic groupings.

In winter, avifauna is dominated by resident species and there is a far more even spread in terms of community composition (Figure 2). While waders and terns made up about 32% of birds, waterfowl (ducks, rails and grebes) making up about 35% of birds, pelicaniformes (pelicans, cormorants and darters) and ciconiiformes (herons, egrets etc) make up about 4% of birds. Kingfishers and birds of prey are present in small numbers.

About 28% of the Palearctic waders remain on the estuary during winter (the first-year birds of the longest-distance migrants), whereas numbers of resident waders increase by about 50%. Nevertheless, Palearctic waders continue to dominate, making up about two-thirds (67%) of waders. Migratory terns from the northern hemisphere are replaced by migratory terns from the Antarctic, though in much smaller numbers. Numbers of the other groups tend to increase in winter.

4.4 Spatial patterns in distribution

Bird numbers are highest in the northern arm and blind arm of the estuary (Figure 3). About 80% of birds are found in this area, with bird densities decreasing progressively upstream. 91% of summer numbers and 74% of winter numbers are found within the first 9km of the estuary (sections 1-5). The density gradient is much steeper in summer than in winter, since most migratory waders and terns occur in the lower estuary. Very low densities of waders occur in the saltpan and supratidal marshes.

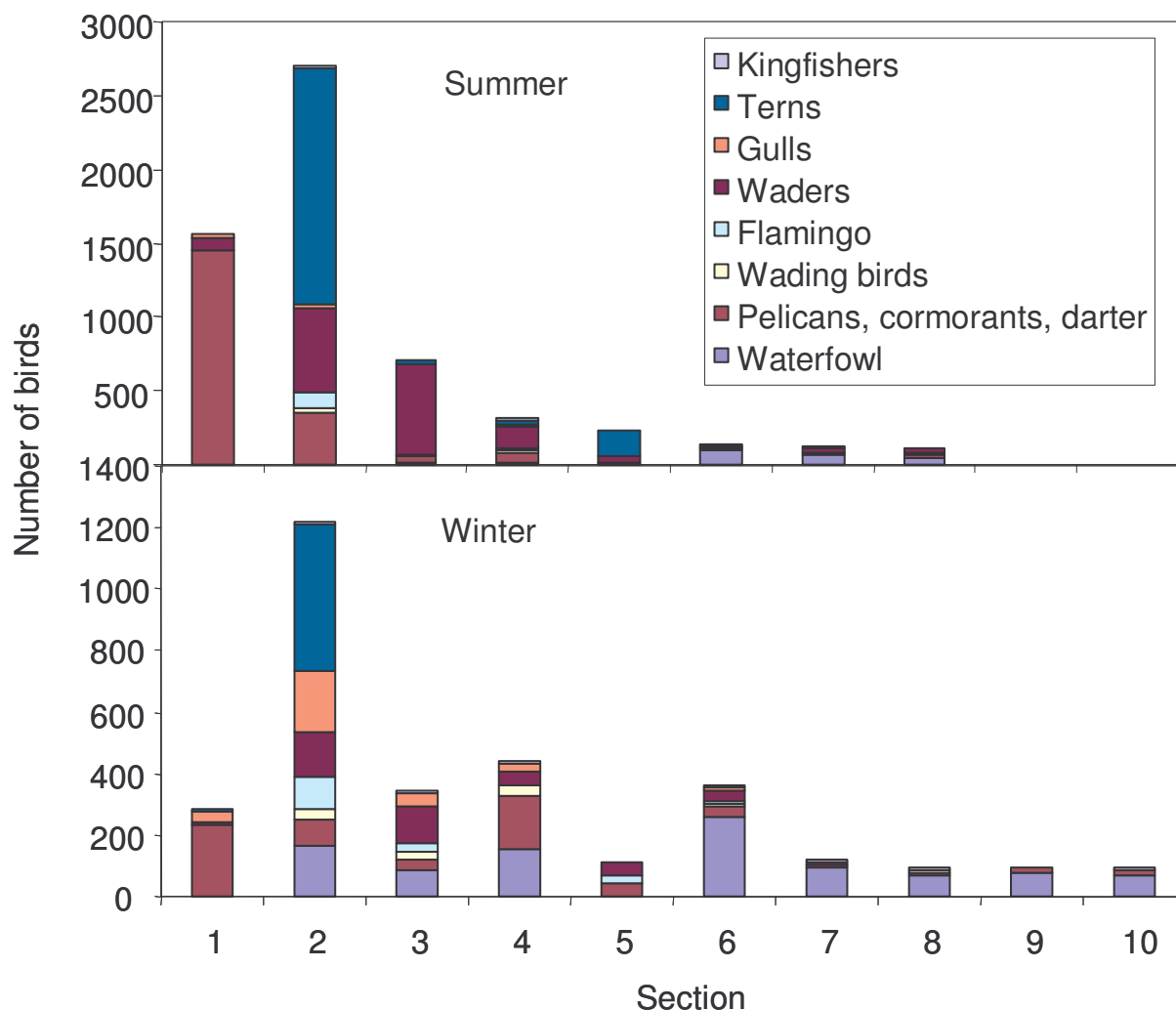


Figure 3. Detailed distribution of different groups of species along the estuary. Note differences in scale, and that sections 9 and 10 were not included in the summer count.

Whereas numbers of birds in the lower estuary are dramatically reduced in winter, numbers increase slightly in the middle to upper reaches (Figure 3).

Spatial variation in community composition along the estuary is linked to habitat differences.

The lower estuary is characterised by large areas of intertidal sand- and mudflats and channels fringed with rocky (shale) banks, and a large saltmarsh with creeks. The intertidal areas are dominated by waders, terns and gulls, with the latter two groups being mainly restricted to the sandier banks, and waders making more use of muddy areas. The saltmarshes in the lower estuary also support wading birds such as egrets and herons. Coots also occur in the lower estuary in winter.

Above 3km up the estuary, mudflats are narrow, apart from a small mid-channel sandflat and a large mudflat on the first main bend in the river. Above this bend, reedmarsh occurs and the marginal banks change in nature. Relatively dry banks with little or no vegetation occur in the middle reaches and are particularly attractive to waterfowl and resident waders. In the upper reaches, the river becomes narrow with heavily vegetated banks (mainly reedmarsh *Phragmites australis*). These reaches tend to feature wading birds, cormorants, kingfishers and more freshwater-loving waterfowl.

Multidimensional scaling analysis of the change in community structure along the estuary suggests that there are three main communities: the rocky headland at the mouth, the lower 9km of the estuary and the upper estuary above 9km. The 9km break corresponds to the appearance of reedbeds, or where a predominantly marine habitat becomes more brackish.

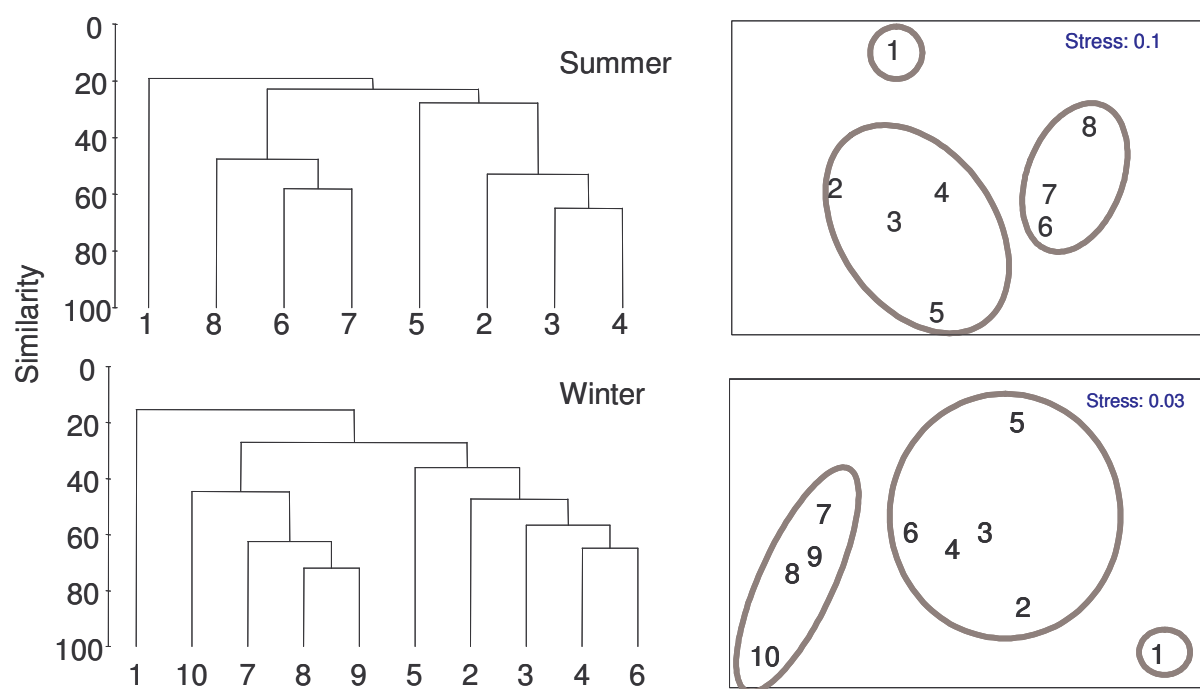


Figure 4 Similarity dendrogram and MDS plot of community composition along the estuary.

Figures 5 – 9 show the distribution along the estuary of most of the commonly –occurring species. Whereas Cape and Bank Cormorants are marine cormorants that are largely confined to the mouth, Whitebreasted and Reed Cormorants range throughout the estuary, though predominating in the lower estuary (Figure 5). Darter are spread throughout the estuary, and pelicans found mainly in the lower estuary.

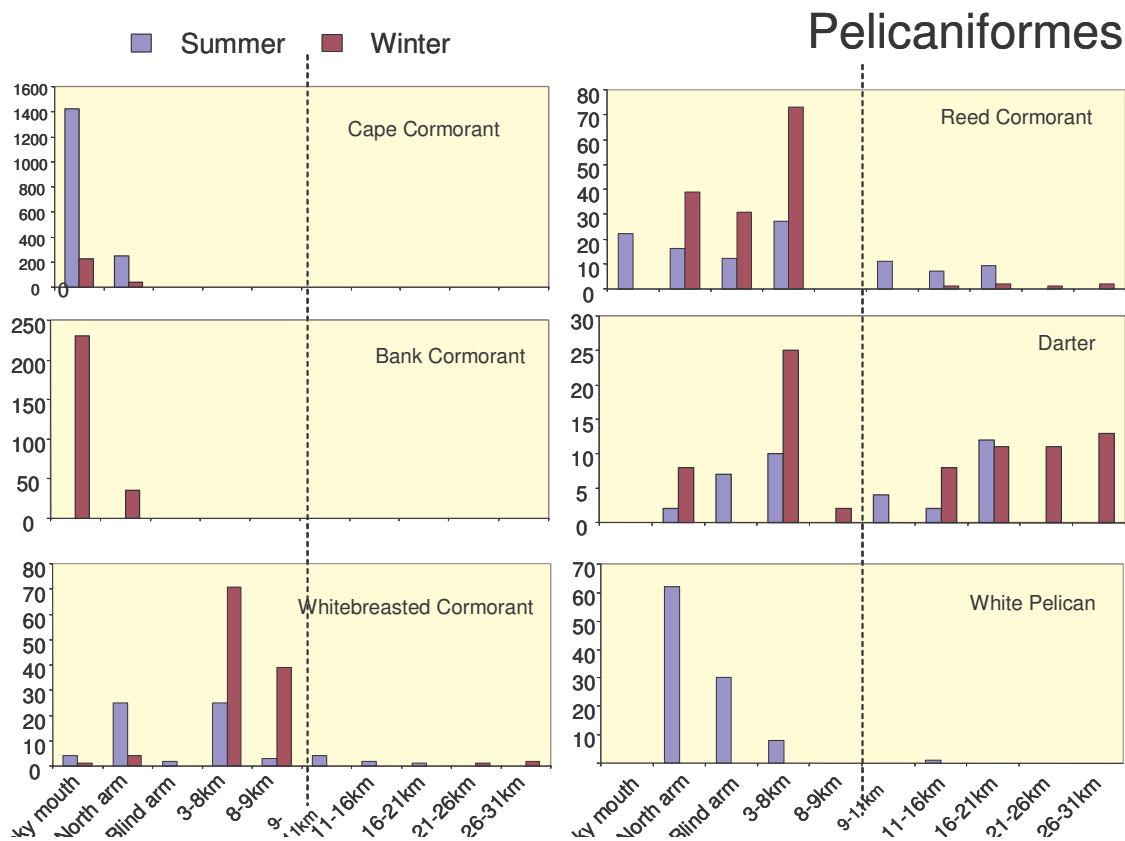


Figure 5. Distribution of pelican, cormorants and darter along the estuary during summer and winter.

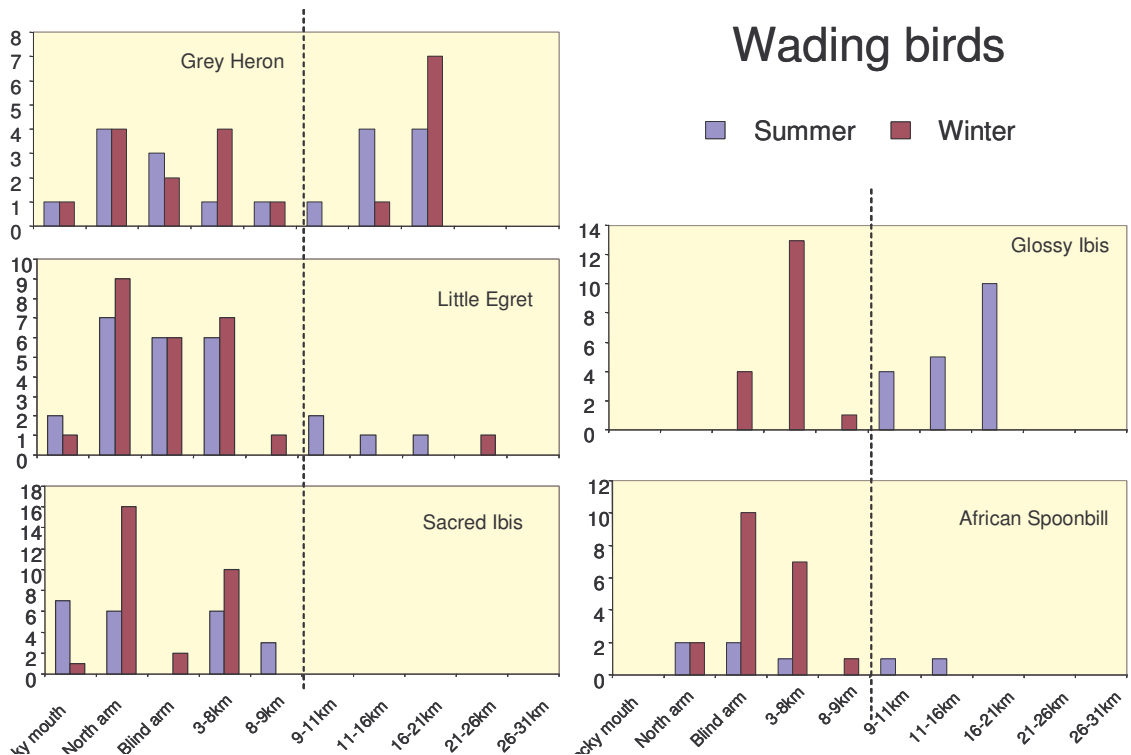


Figure 6. Distribution of wading birds along the estuary during summer and winter.

Apart from Sacred Ibis, which were confined to the lower reaches, wading birds were found throughout the estuary. Little Egret and African Spoonbill had a strong preference for the lower reaches, especially in winter. Glossy Ibis also occurred lower in the estuary during winter (Figure 6).

Two groups of waterfowl could be identified: those that tended to occur mainly at lower salinities, and those that were found over a broader salinity range (Figure 7).

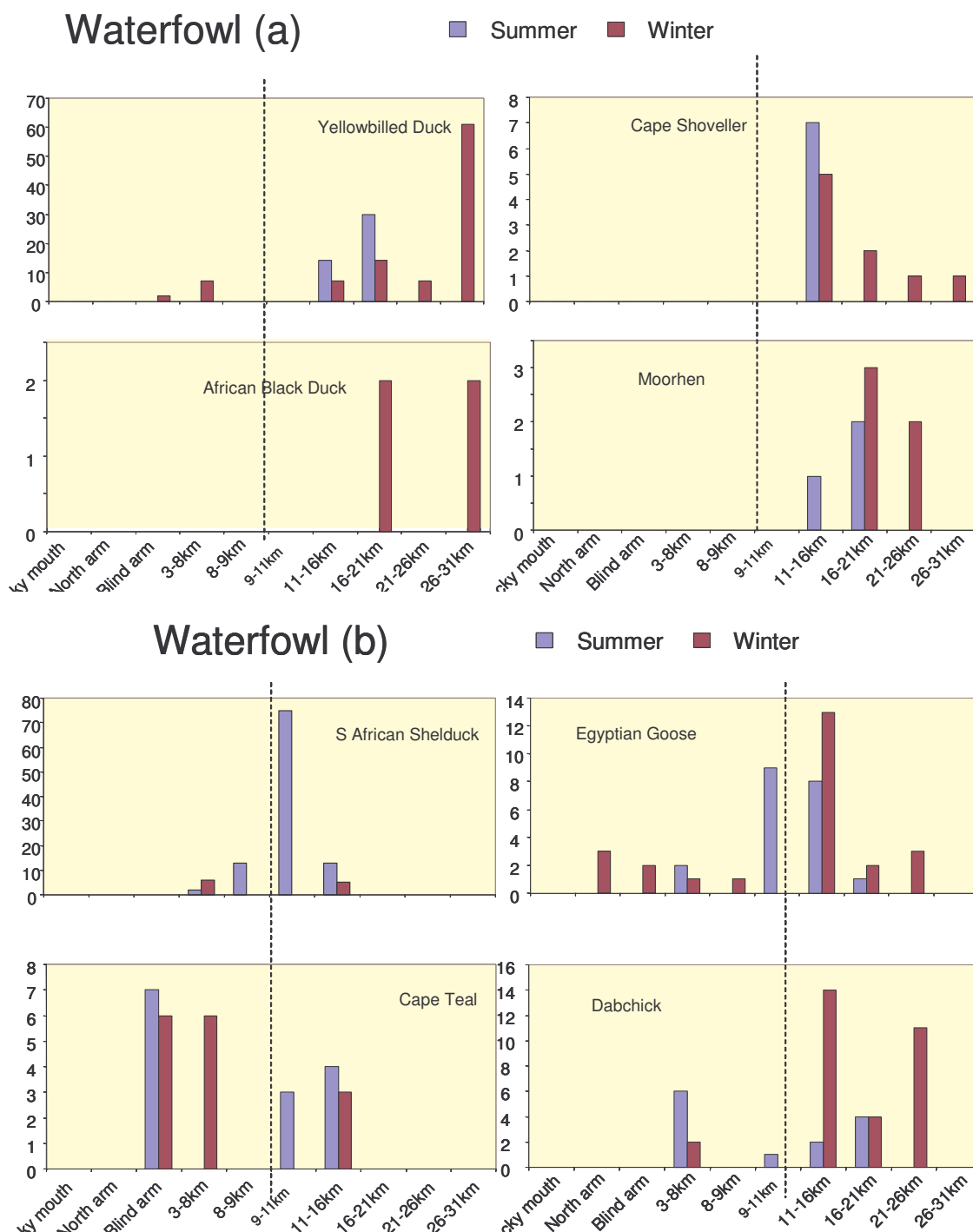


Figure 7. Distribution of waterfowl typical of the lower salinity reaches (a), and waterfowl species that ranged over a greater proportion of the estuary (b).

The waders occur predominantly in the lower estuary (Figure 8). A few species, such as Threebanded Plover, Blacksmith Plover, Blackwinged Stilt and Ruff (all but the latter being resident species) were mainly found in the upper estuary, however. These species spread down the estuary during winter, when the numbers of waders in the lower estuary was reduced.

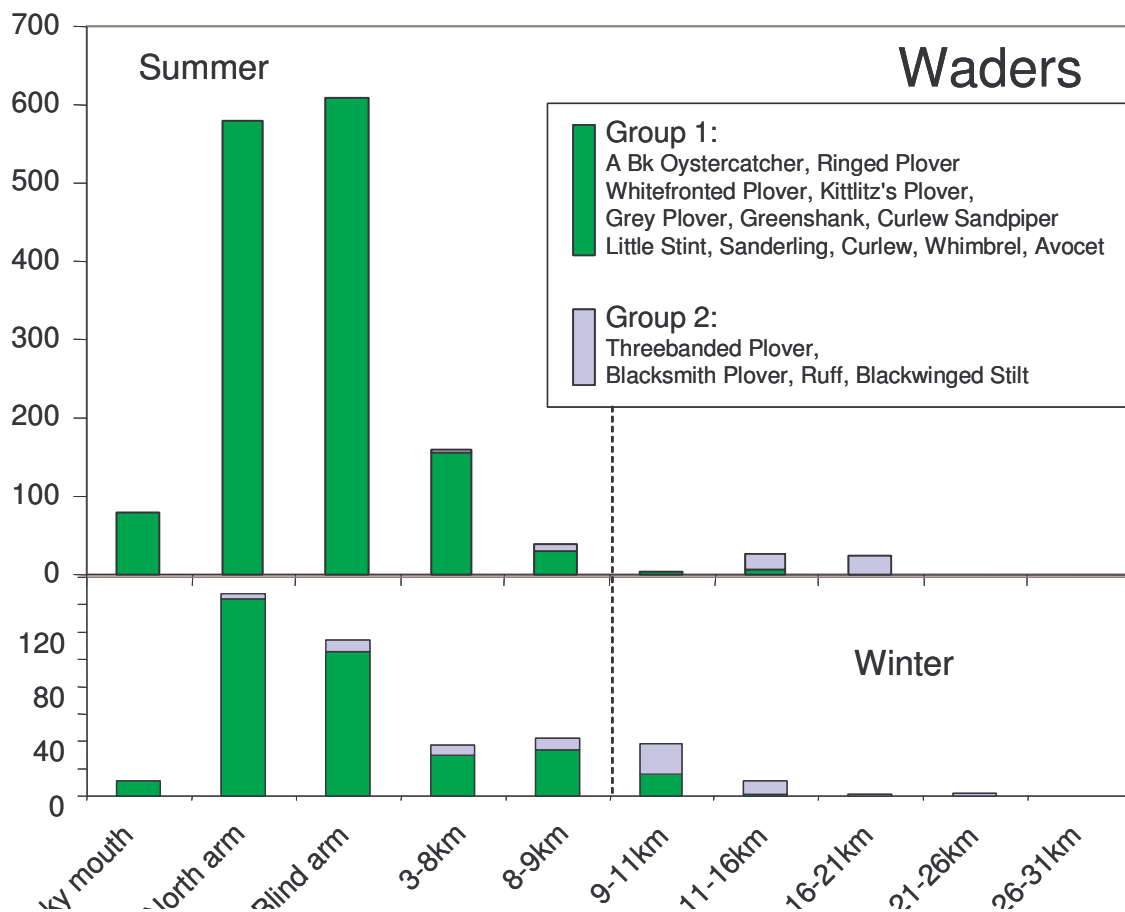


Figure 8. Distribution of waders along the estuary during summer and winter

Gulls were almost entirely confined to the lower reaches (Figure 9). While most terns occurred in the lower estuary, Caspian and Sandwich Terns tended to be more common in the middle reaches (Figure 10). Kingfishers were common throughout the estuary (Figure 11).

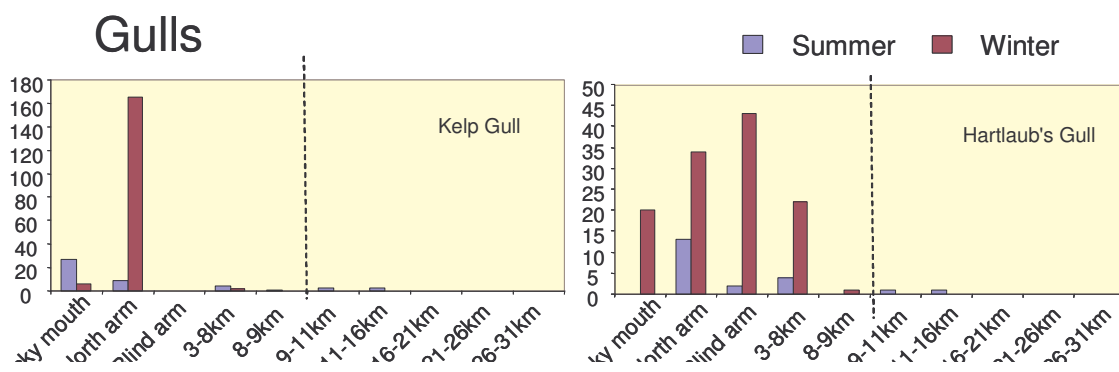


Figure 9. Distribution of gulls along the estuary during summer and winter

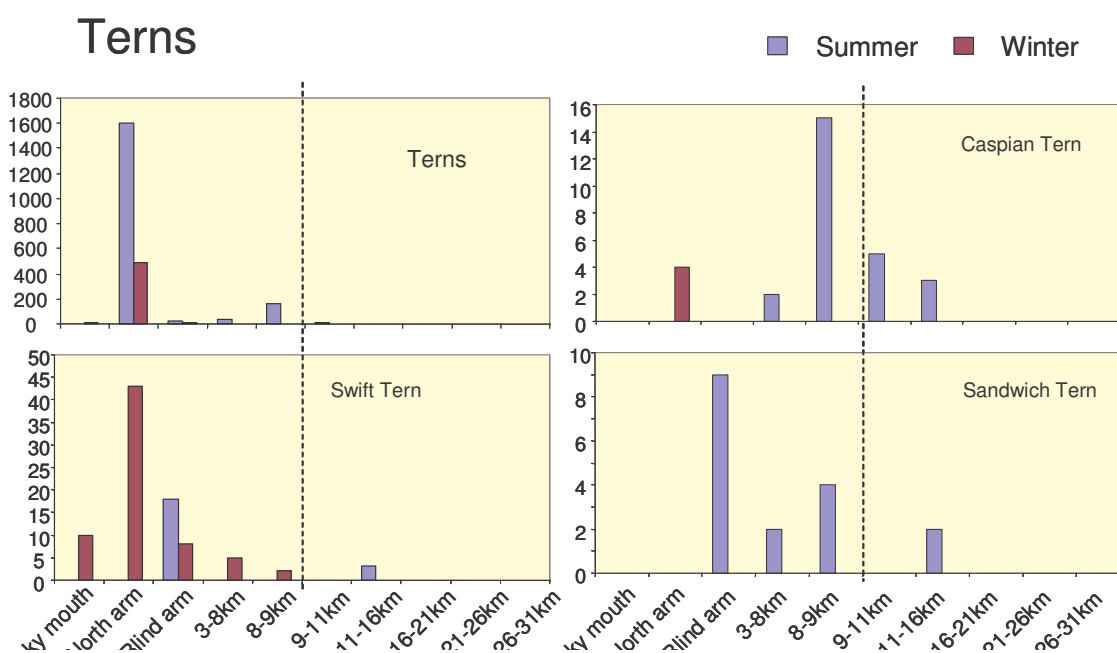


Figure 10. Distribution of terns along the estuary during summer and winter

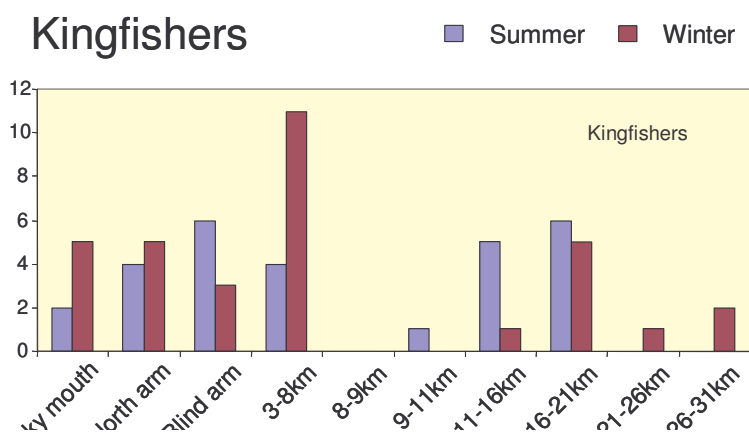


Figure 11. Distribution of kingfishers along the estuary during summer and winter

4.5 Dietary guilds and use of habitats

While most species feed in the estuary, some of the more abundant species do not use the estuary as their main feeding area, or feed there at all. These include most of the terns, and probably some gulls. The sandbanks in the lower estuary are important roosting areas for terns and gulls. These areas are thought to be attractive to the birds in that they provide relatively safe roost sites. 'The Island' would probably have been a popular roosting area for gulls when it was an island. Egyptian Geese use the estuary for resting and breeding, but not as a feeding habitat.

Excluding the Cape and Bank Cormorants, the avifauna is dominated by invertebrate feeders (mostly waders) and piscivores (mostly terns) in summer (Figure 12). There is a more even distribution of trophic groups in winter.

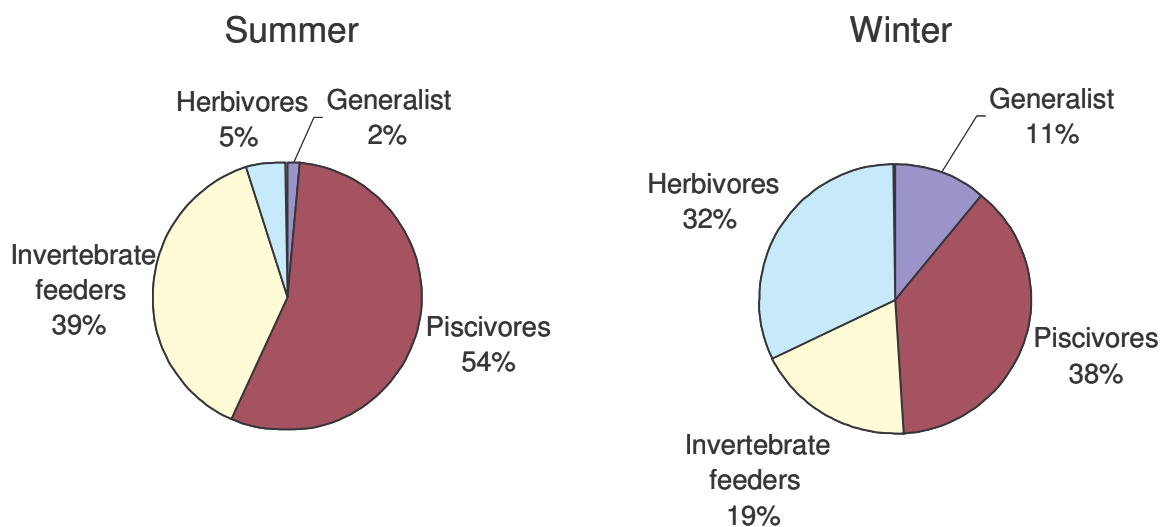


Figure 12. Guild composition of birds on the estuary in summer and winter

Intertidal mudflats support most of the waders in the lower estuary, though the saltmarshes are important, particularly during high tide. The large number of invertebrate feeders is due to the relatively large intertidal area of the estuary, although the areas where estuarine muds predominate (including areas covered with *Zostera*) are most important, not the extensive sandy areas near the mouth. Waders are opportunistic foragers whose diets reflect the macroinvertebrate fauna, and are typically dominated by prawns (*Upogebia*), crabs (e.g. *Hymenosoma*), polychaets (e.g. *Ceratonereis*), and amphipods.

Saltmarshes tend to be less favourable as feeding habitats for waders, except for the muddy creeks within them that are highly productive. The relatively moist saltmarshes around the blind arm were fairly extensively used by waders, however.

Reed marshes support a characteristic suite of species from a range of dietary guilds that use the reeds for food or shelter. Reedmarsh habitat is abundant on the Olifants, and supports species such as Purple Heron, Purple Gallinule and Moorhen, as well as passerine reedbed species such as Red Bishop.

The river channel is dominated by piscivorous waterbirds (e.g. pelicans, cormorants, darters and kingfishers) and waterfowl. Fish Eagles have not been recorded on the estuary during any of the counts.

4.6 Inter-annual variation in abundance

Ten years of CWAC data exist for the south bank of the lower estuary, corresponding mainly to area 3 and part of area 2 of this study. These counts do not include the main mudflat area of the northern arm. Numbers of birds in this area have remained relatively constant over most years, fluctuating around 1400 in summer and slightly fewer in winter. However, there are substantial differences in community composition over this period.

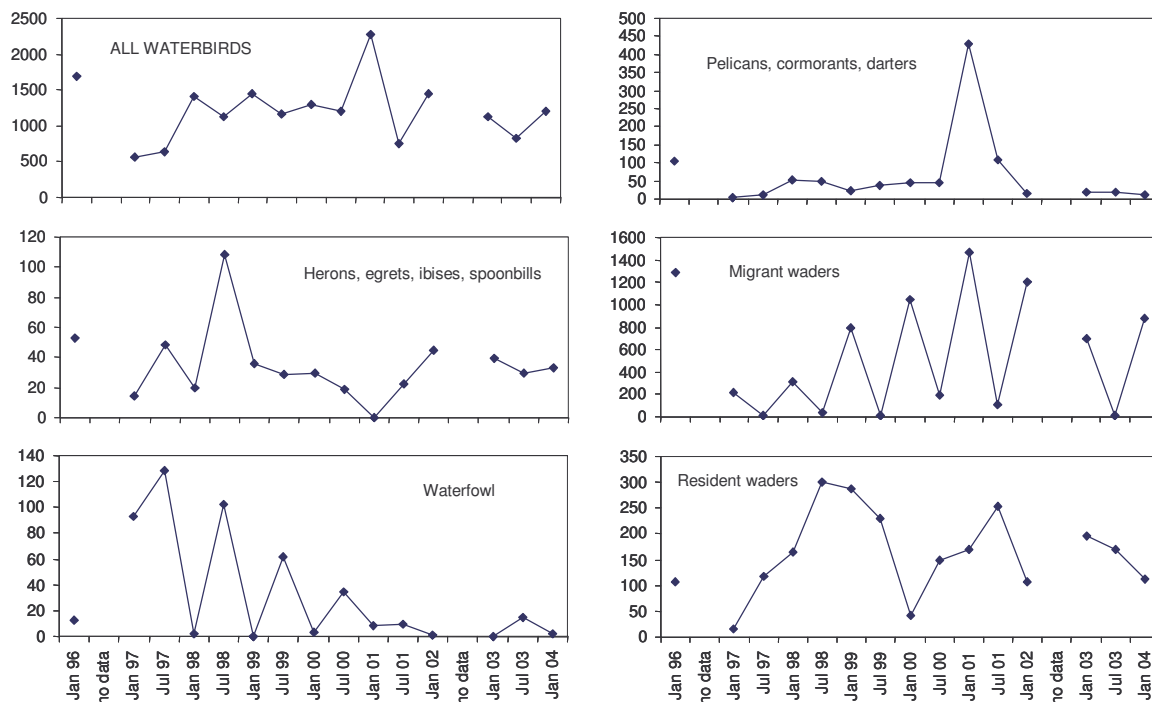


Figure 13. Variation in the numbers of waterbirds on the south bank of the lower Olifants estuary (based on CWAC data).

1997 and 2001 stand out as anomalous years in terms of total bird numbers. The high numbers in summer 2001 are largely due to particularly high numbers of Curlew Sandpiper and Great White Pelicans. In 1997 there were higher-than-usual numbers of Blackwinged Stilt, Ruff, Spurwinged Geese, Cape Shoveller and South African Shelduck, suggesting the existence of shallow, relatively fresh, standing water in both the summer and winter count. Higher than usual numbers of Lesser Flamingo were also recorded, which is usually associated with hyper-saline conditions. These were possibly recorded in the saltpan. Several species became more common in 1998 and 1989, with those years providing the highest counts for Yellowbilled Duck, Greater Flamingo and Kelp Gull. Whereas some species decline in abundance over the period (such as the freshwater-associated waterfowl and African Spoonbill), others tend to increase, including several migrant waders species and Reed Cormorant. This suggests that the nature of the habitat has shifted somewhat from somewhat fresher 'wetland' characteristics to a shallower, habitat that attracts species that use exposed shorelines. In other words, it could reflect a gradual change from wetter years to drier years. This needs to be verified, but flow data were not available for the corresponding period (Van Niekerk, pers. comm.). The increase in numbers of reed cormorants is probably unrelated to habitat change in the lower estuary but indicative of a general increase in population in the area.

5. FACTORS INFLUENCING AVIFAUNAL COMMUNITY STRUCTURE & ABUNDANCE

The main factors influencing the presence or absence of different species, and hence community structure, relate to food and habitat availability, the latter including feeding, roosting and breeding habitat. Turpie (2000) described the major relationships that are considered in assessing the influence of changes in freshwater inflows on estuarine avifaunal communities (Figure 14). It is difficult to accurately predict the impact of changes in estuarine characteristics on bird assemblages (Hockey & Turpie 1999a,b), and predictions often have to be made on the basis of qualitative (“gut-feel”) assessments of the relationships between the main variables that influence bird community structure and abundance in estuaries. 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. Difficulties in prediction are also compounded by variability due to external factors such as breeding success on distant breeding grounds.

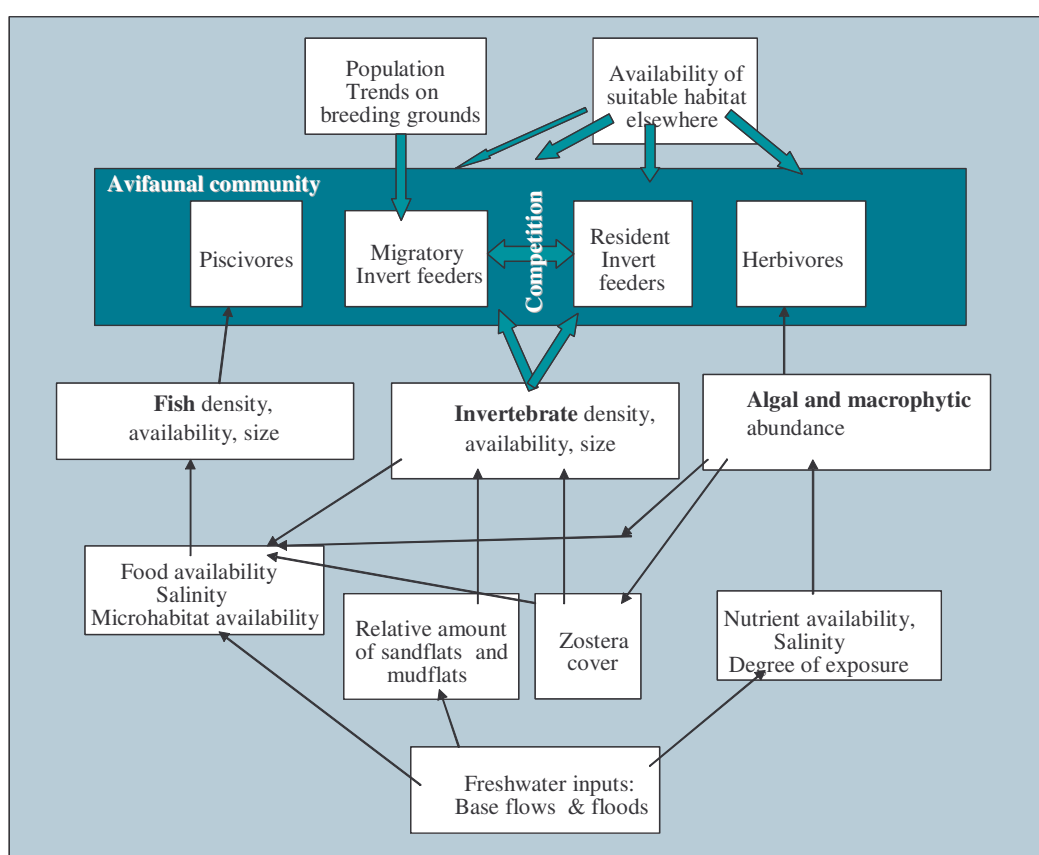


Figure 14. A simplified example of the types of relationships used in predicting the structure of an estuarine avifaunal community. Assumptions are made about the nature of relationships for each of the arrows depicted (from Turpie 2000).

Figure 14 only concentrates on the trophic interactions and feeding habitats. Other variables, such as availability of roosting, perching or breeding sites, may feature strongly in determining the presence and abundance of certain species.

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. Similarly, certain waterfowl are associated with low salinity areas.

In some cases, predictions about the avifaunal community can be made directly from the estimates of the other specialists. In cases where insufficient information is given the bird specialist is forced to second-guess the responses of the other biotic groups before estimating the avifaunal response.

RDM methodology requires that the responses of birds to the following factors are described:

Mouth condition: No scenarios lead to mouth closure, and the dramatic effects this would have are thus not considered here. However, it is worth noting that the closure of the 'central channel' (*sensu* Morant 1984) or 'blind arm' has had a major impact on the system in terms of its value as bird habitat. The blind arm provides particularly important shallow water and intertidal feeding habitat, as well as substantially increasing the availability of saltmarsh in the lower estuary. The latter is extremely important as a roosting area. On the other hand, the closure of the blind arm has connected "Die Eiland" to the mainland, and has thus reduced the attractiveness of the island as a safe roosting area. The island may have thus provided a more important roosting habitat for gulls and waders when the blind arm was open.

Intertidal area: Intertidal areas in the lower estuary provide the main foraging habitat for waders, and an increase would be expected to lead to an increase in wader numbers. In the middle reaches, the narrow but substantial intertidal areas are somewhat drier and are important habitat for a different suite of waders (mostly resident) and are vital 'loafing' habitat for waterfowl. Thus availability of intertidal area in the middle to upper reaches will affect these species.

Sediment processes and characteristics: Sediment size and distribution is important in determining suitability of feeding and roosting areas for different species. The formation of sandbanks in the mouth area are important roosting habitat for terns, whereas muddier sediments are preferable for waders. Fine silts are less suitable in terms of availability of suitable food. Different waders have finer scale preferences in terms of the spectrum of particle size and organic content. This is due to types of food available as well as penetrability of sediment.

Water retention time. This does not impact on birds directly, but has indirect impacts due to its impact on the productivity of the system.

Flow velocity. This does not have much direct impact, except possibly for a short period during floods when some birds would be unable to use the system, and some waterfowl prefer stiller waters than others (but velocities at margins are usually low enough to accommodate these).

Volume of water in the estuary. This affects the amount of habitat available for birds that feed in the water column (e.g. piscivores). In particular, water volume affects the availability of habitats of different depths, which are favoured by different species. In the case of the Olifants, water depth does not vary significantly under different scenarios.

Salinity The distributions of certain waterfowl and some wading birds and other waterbirds are correlated with salinity, although the relationship is probably largely indirect, through the impact of salinity on the distribution of certain habitats (e.g. reeds) and food sources (e.g. potamogeton).

Other water quality variables. These do not have direct effects, but are indirectly important through impacts on habitat and food. Turbidity may have an impact on the abundance of certain piscivores, but this relationship is not well understood.

Other biotic components. Food and habitat are the main drivers of the abundance of all groups of birds (see discussion above). Apart from intertidal mud/sandflats, biotic habitats that affect bird abundance include reedmarsh, saltmarsh and riparian vegetation. Most of the biotic components are a food source for bird species, e.g. phytoplankton, benthic microalgae, macrophytes, zooplankton, benthic macrofauna, and fish. The productivity of each of these groups and biomass distribution among size classes is an important factor.

Man-made structures; No significant influences on the estuary itself.

Consumptive and non-consumptive use of estuary. Fishing activity on the estuary may have a disturbance impact on birds, however, this is relatively minor. There is very little recreational disturbance. Overall disturbance is very low for an estuary of this size. However, there is some disturbance of birds in the saltpan.

Floodplain development. The construction of dams adjacent to the estuary has created a major attraction for waterfowl in the area. The artificial manipulation of water in the saltpan near the mouth affects the quality of this habitat for resident waders.

Other. The increase in artificial water bodies and alien trees in the region has facilitated the range expansion of certain species into this estuary.

6. DERIVATION OF AVIFAUNAL HEALTH SCORES FOR PRESENT STATE AND FUTURE SCENARIOS

In past estuarine RDM studies, avifaunal scores have been derived on the basis of “gut-feel”, based on assumptions about the relationships between different groups of birds and biophysical factors such as those mentioned above. With increasing experience that has come from these studies, there is a tendency for specialists to try to become more accurate in their predictions, and to try and quantify models upon which scores can be based. Simple rule-based models are an obvious starting point, and it is expected that this process will become more refined with time. In the case of the ichthyofauna, fish abundance and community structure have been modelled on the basis of fish densities found in different salinity zones, with these densities being extrapolated to the different sized zones found under different scenarios (refer to Appendix G – Specialist Report on fish). Thus, expected fish abundance is modelled on salinity alone. Although it is acknowledged that other factors play a role, it is important at this stage to identify the most important linkages in order to provide rough estimates.

In this study, the scores for different physical and biotic components were examined and hypothetical relationships to birds were quantified as far as possible. The aim was to derive scores in a transparent way which allows the hypothetical relationships to be tested and refined in future. The relevant specialists were consulted in the estimation of changes in biotic variables (see below).

The changes in flow in the estuary affect salinity distribution and the amount of nutrients, as indicated by dissolved nitrogen (Figure 15). The present state is considered to be only 50% similar to the reference condition, with higher salinities and higher nutrient loads. Improved base flows in scenarios 2 and 7 restore the salinity distribution to some extent, but nutrient enrichment increases. Scenario 5 is similar to the present state in terms of salinity distribution, but nutrient loads are slightly higher. Scenarios 17 and 10 involve a progressively more saline and nutrient enriched estuary.

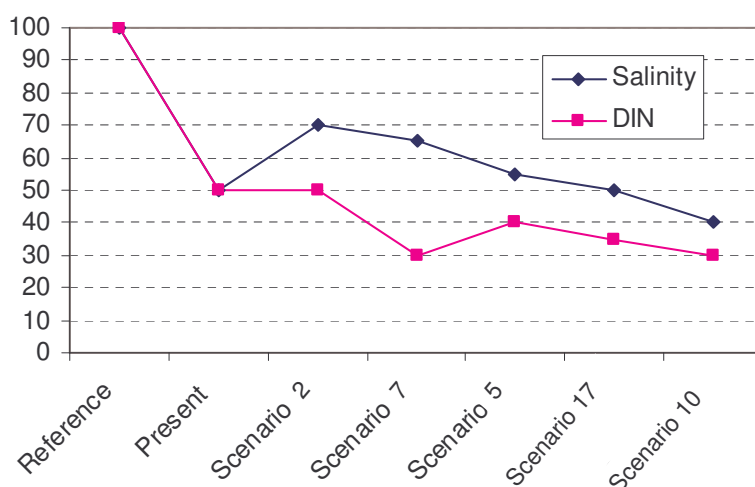


Figure 15. Health scores for salinity and dissolved nitrogen under different scenarios.

The changes in flooding, salinity distribution and nutrient loads lead to changes in vegetated and non-vegetated habitats. Intertidal area in the upper estuary has decreased by 10% since the reference condition, and is further decreased in Scenario 10. Intertidal area in the lower estuary has increased substantially since the reference state due to closure of the central channel to form the blind arm. The intertidal area is expected to increase further in Scenarios 7, 5, 17 & 10.

The area of the freshwater weed *Potamageton* in the upper estuary has increased due to nutrient enrichment, and can be expected to increase further under most scenarios, though this is ameliorated in scenarios where base flow is increased (Figure 16). Reedmarsh area has decreased slightly, and is expected to decrease further in Scenarios 17 and 10. *Zostera* area is not expected to change except in Scenario 10. A significant amount of saltmarsh has been lost, and would only recover to some extent in scenarios where base flows are increased (Figure 16).

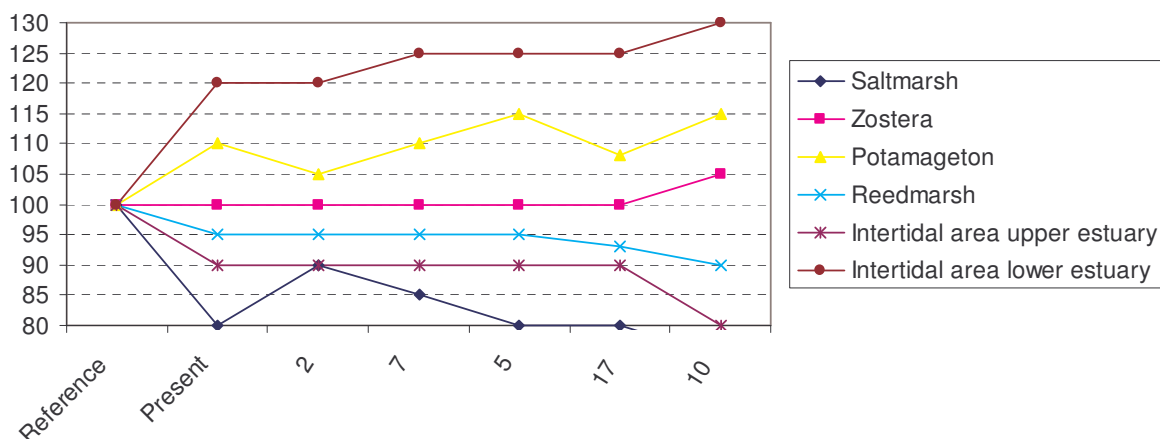


Figure 16. Changes in the amount of different habitat types relative to the reference condition under different scenarios.

Microalgal biomass is driven by a combination of nutrient inputs and water retention time in the estuary. It is expected to have increased since the reference state and continues to increase under each successive scenario, reaching over 150% of original biomass in Scenario 10. Invertebrate biomass is driven by microalgal biomass and the availability of habitat. It is expected to have increased by 50% since the reference state, and increases up to over three times the original biomass in Scenario 10. It should be noted that the specialists were somewhat uncomfortable with the apparent discrepancy in these two results.

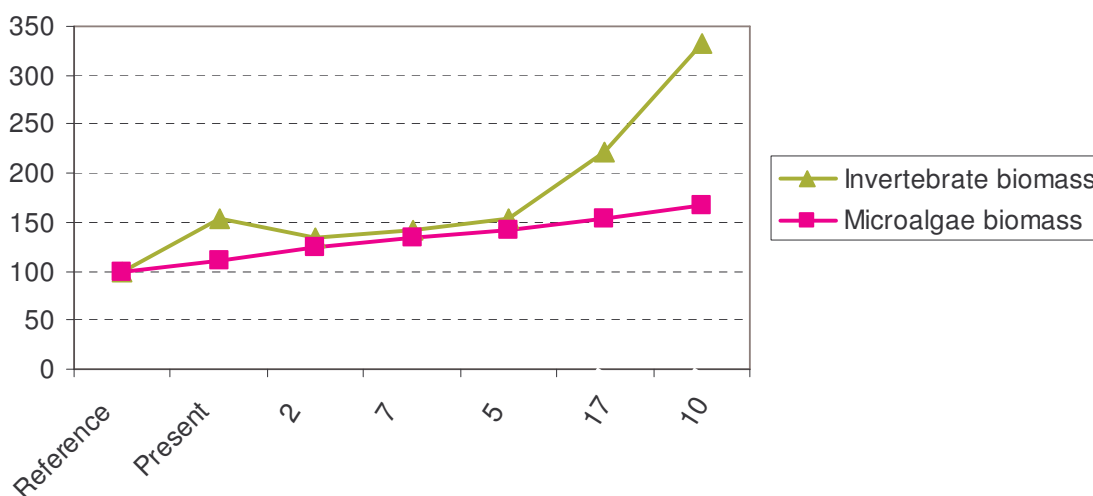


Figure 17. Estimated relative biomass of microalgae and invertebrates under different scenarios.

Fish productivity was estimated to have increased, but the impact of the fishery outweighs increased productivity, with the result that estimated fish biomass is lower than the reference state (Figure 18). The impact of increased productivity only outweighs the fishery impacts in Scenarios 17 and 10.

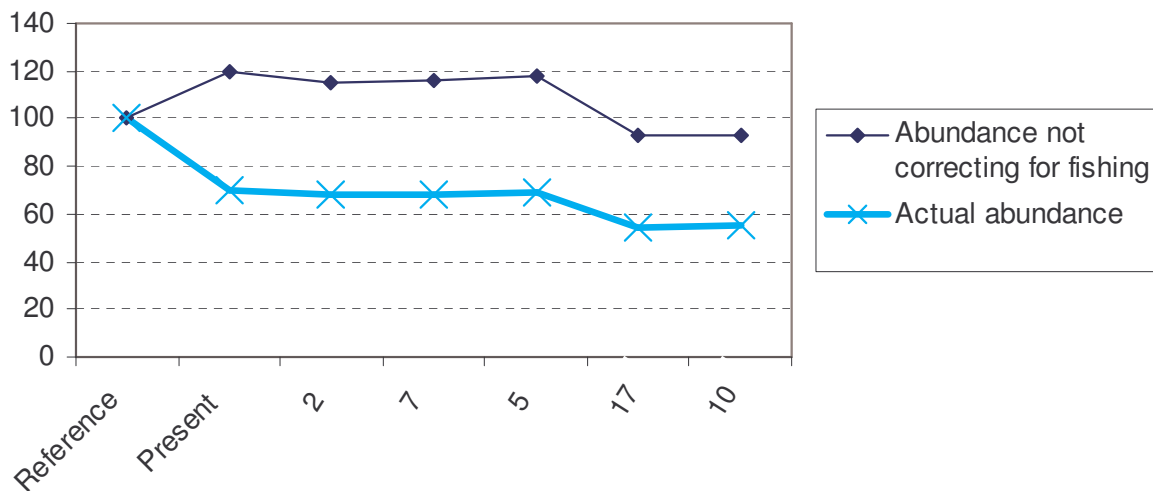


Figure 18. Estimated relative biomass of fish (a) with reference condition extrapolated from current (fished) densities and hence giving an indication of relative productivity, and (b) with all estimates adjusted to include the impact of fishing on biomass relative to reference condition

Changes in the relative density of three main trophic groups of waterbirds were estimated based on the above data. Invertebrate feeders were expected to increase with increasing invertebrate food, but with this increase being tempered by space constraints. A direct relationship with fish was used for estimation of changes in piscivore numbers. In the case of herbivores, changes in the amount of freshwater habitat was used as the main consideration. The resultant estimated changes in each group are shown in Figure 19. It should be noted that these are extremely rough estimates, with similarly low confidence as scores derived for other biotic groups without any numerical manipulation. Nevertheless, they provide a testable hypothesis. As for other biotic groups, this does not capture the high level of interannual variability, but is modelled on the current year of study. As it turned out, this was not a typical year, but was a particularly dry year.

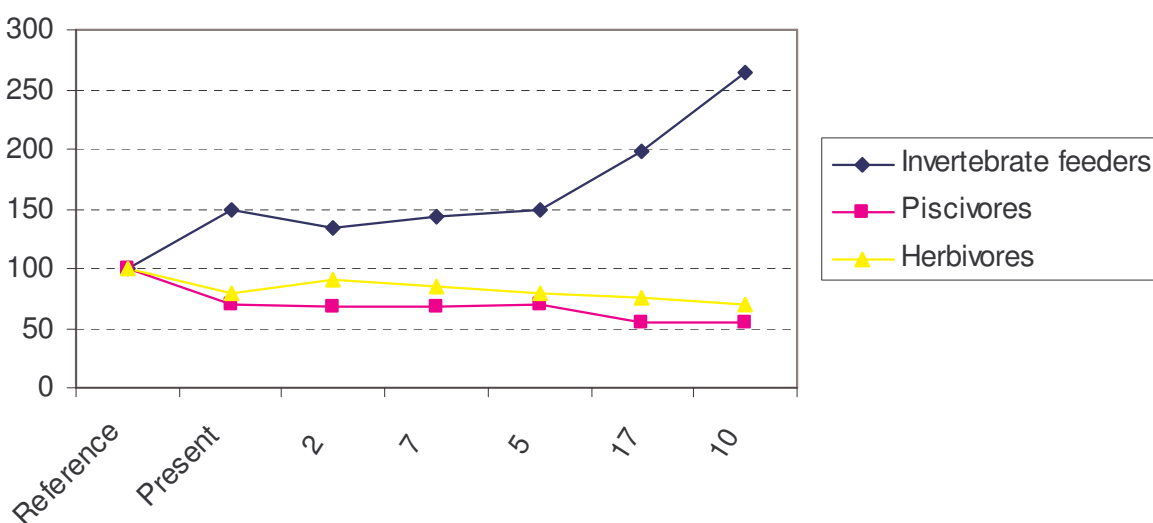


Figure 19. Estimated relative numbers of birds under different scenarios.

Using the relative abundance of these three groups over summer and winter under present conditions, the above estimates of degree of change were used to estimate changes in the total abundance of birds on the estuary. Total abundance was estimated to have changed very little from the reference state, and the largest change is seen in scenario 10 (**Figure 20**). This was then converted to percentage change from reference condition.

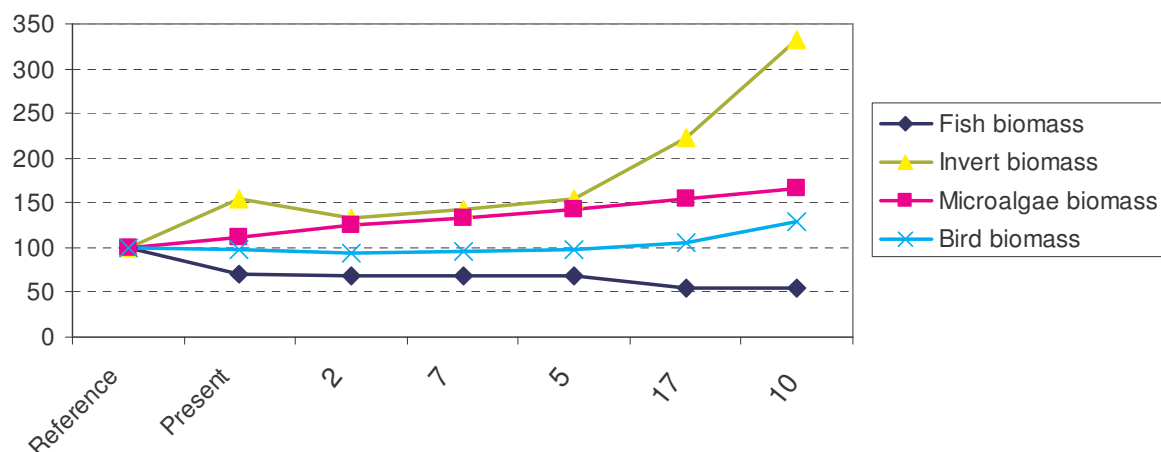


Figure 20. Estimated relative biomass of birds in relation to other biotic components under different scenarios.

Since the above analysis provided estimates of the numbers of birds in each trophic group (Table 6), it was possible to perform a coarse analysis of community composition. A similarity analysis was used to estimate the percentage similarity of different scenarios to the reference condition, thus deriving the latter scores mathematically for the first time. Despite the rather significant changes shown in Table 6, calculated similarity is very high in all cases. This is possibly somewhat higher than “gut-feel” scoring would have produced. This is possibly because proportions, rather than actual numbers, are used. Overall scores are summarised in Table 8, and described in detail in the following sections.

Table 6. Actual proportion of different trophic groups under present conditions, and estimated composition under different scenarios.

Proportion of guilds	Reference	Present	2	7	5	17	10
Invertebrate feeders	34	50	46	48	50	61	68
Piscivores	50	23	23	23	23	17	14
Herbivores	16	27	31	29	27	23	18

Table 7. Similarity matrix of community composition.

Similarity matrix	Reference	Present	2	7	5	17
Present	95					
1	95	98				
2	95	99	99			
3	95	100	98	99		
4	92	96	95	96	97	
5	91	92	91	91	93	96

Table 8. Bird health scores for the different scenarios.

	Reference	Present	2	7	5	17	10
Species richness (score)	100	100	100	100	100	90	80
Abundance	100	98	94	96	98	94	78
Community composition	100	95	95	95	95	92	91
Minimum	100	95	94	95	95	90	78

7. THE REFERENCE CONDITION

The Olifants estuary is one of the least developed permanently open estuaries in South Africa, with very little infrastructural development along its length. However, there have been upstream impoundments that have had significant impacts on flow. The Bulshoek irrigation barrage, which supplies water to farms along 90km of the lower Olifants River, was completed in 1919. The barrage regulates flow which enters a canal system which supplies the farmers. The Clanwilliam Dam was built in 1932, and its dam wall was raised in 1966 (Morant 1984). A causeway was built at Lutzville, near the top of the estuary.

In the reference condition, without these dams, the flood peaks from the Olifants river would have been higher than at present. Those from the Doring River are unaffected. The upper estuary would have been slightly shallower and 10% wider in the reference condition, due to slightly higher sediment loads. The estuary would have penetrated slightly beyond the Lutzville causeway.

Irrigated agriculture has affected water quality, with nutrients accumulating in the soil and being flushed into the river during rains.

The estuary would have been more freshwater dominated in the reference state. Microalgal density was probably about 25% lower than at present. Macrophytes would not have colonised as far up the estuary, and have increased due to nutrient inputs. Slower flows and nutrient enrichment have led to increased Potamageton in upper estuary (top of estuary is fairly choked with it). Increased salinity may have decreased the distribution of brackish reeds and sedges. Some brackish salt marsh dominated by *Cotula* and *Juncus* may also have been lost.

The biomass of zooplankton and hyperbenthos is thought to have been lower in the reference state due to river dominance and low salinity, and low residence time. Benthic invertebrate biomass would have been significantly lower in the upper reaches, and biomass of sand prawn and mud prawn would have been much less because of strong river dominance.

Fish biomass would have been dominated by estuarine species, mostly *Gilchristella*, rather than by *Liza*. *Mugil cephalus* would have been twice as abundant in the upper reaches. Indigenous freshwater species would have penetrated further down the estuary in winter. In the absence of fishing, estuarine dependent marine species (e.g. *L. lithognathus*) would have been slightly less abundant. Species such as *Liza* would have been half as abundant. However, overall fish biomass is now about 70% of that under reference conditions because of the impact of fishing.

Biomass

In the reference state, the estuary would have been somewhat less productive overall, because nutrient inputs and retention times would have been lower. This has implications all the way up the food chain. In addition, the intertidal area would have been 10% greater in the upper estuary and 20% smaller in the lower estuary, due to the central arm having been open. There would have been more freshwater habitat in the estuary than in the present condition, due to higher base flows in summer.

Invertebrate feeders (such as the waders) are expected to be less abundant due to less habitat and lower densities of invertebrates in the estuary. However, since the changes are lowest in the lower estuary, where most birds occur, it is unlikely that there has been a major change. Moreover, the waders, which dominate the invertebrate feeders and avifauna in general, depend mostly on polychaetes and other small benthic invertebrates, which are thought to have changed relatively little (perhaps having increased by only 10-20% - Wooldridge, pers. comm)

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) would be affected by the change in fish availability. Although the productivity of the fish component would have been lower in the reference state, the fish are expected to have been more abundant than at present, since they would not have been subject to the fishing pressure which keeps abundance down in the present state. Piscivorous birds would thus be more abundant in the reference state, and their composition would have been different, since some species have only colonised the estuary relatively recently.

Among piscivores, terns, which are the most numerous, may be least affected, since they feed in the mouth of the estuary.

Waterfowl may have been more abundant in the reference state when there was more freshwater habitat in the estuary and more intertidal area in the middle to upper reaches. However, the freshwater habitat would not have been as productive as in the present state, offsetting the above to some degree.

Species richness

At least five species have colonised the estuary since the reference state. This is due to range expansions of species due to increases in artificial water bodies and alien trees. There is no reason to believe that any species have been lost.

Seasonal variability

There would not have been any significant changes in seasonal patterns of bird numbers.

Table 9. Calculation of the biotic health score for birds.

<i>VARIABLE</i>	<i>SCORE</i>	<i>MOTIVATION</i>	<i>CONFIDENCE</i>
<i>1. Species richness</i>	<i>100</i>	<i>At least five species that occur at present would not have been present in the reference state. These species are species whose ranges have expanded and that would only have reached the estuary in the past 20 – 30 years. However the score only considers change in occurrence of original species. It is unlikely that there have been any losses of species.</i>	<i>Medium</i>
<i>2a. Abundance</i>	<i>98</i>	<i>Without considering exogenous factors such as changes in source populations of migratory species, waterbirds were probably not as abundant in the reference state as at present, although the difference is probably very slight. There would be slightly fewer invertebrate feeders (less food and habitat), slightly more piscivorous birds (more fish) and more waterfowl (more freshwater habitat) in the reference condition. However, there is also less productivity in the upper reaches. Calculation of the score is described in a previous section. .</i>	<i>Medium</i>
<i>2b. Community composition</i>	<i>95</i>	<i>Given the rather slight changes in different trophic groups outlined above, the community composition is not very different in the reference state from the present state. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.</i>	<i>Medium</i>
<i>Bird score</i>	<i>95</i>		

8. EFFECT OF FUTURE DEVELOPMENT SCENARIOS

8.1 Scenario 2

8.1.1 Biomass

In Scenario 2, freshwater releases increase base flows, so restoring the flow patterns towards the reference state. However, nutrient inputs would not be diminished. Thus the estuary would more productive than in the reference state, but not as productive as at present, because of the shorter retention times. This has implications all the way up the food chain, with increased microphyte and invertebrate production, except that fish are still less abundant than in the reference state due to fishing pressure (about the same as in the present state). The intertidal area remains slightly smaller in the upper estuary (10% less than reference state) and is larger in the lower estuary (20% more than reference state, same as at present). However, there would be less freshwater habitat in the estuary than in the reference condition (but more than at present), due to lower base flows in summer than under natural conditions. Freshwater habitat would be more productive though.

Invertebrate feeders (such as the waders) are expected to be more abundant than in the reference condition due to more habitat and higher densities of invertebrates in the estuary. However, since the changes are smallest in the lower estuary, where most birds occur, it is unlikely that there has been a major change.

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) may decrease due to the reduction in availability of fish. Their composition would be different, since some species have only colonised the estuary relatively recently.

Waterfowl may be less abundant than in the reference state due to the smaller freshwater habitat and narrower intertidal in the mid to upper estuary, but would increase relative to the present state. However, the freshwater habitat would be somewhat more productive than the reference state, offsetting this effect to some degree.

8.1.2 Species richness

Apart from the recent colonisers, there is no reason to believe that any other species would be lost or gained.

8.1.3 Seasonal variability

There would not have been any significant changes in seasonal patterns of bird numbers.

<i>VARIABLE</i>	<i>SCORE</i>	<i>MOTIVATION</i>	<i>CONFIDENCE</i>
<i>1. Species richness</i>	<i>100</i>	<i>It is unlikely that there would be a loss in average instantaneous species richness</i>	<i>Medium</i>
<i>2a. Abundance</i>	<i>94</i>	<i>Waterbirds are probably not as abundant in scenario 2 as at present, although the difference is probably very slight. There would be slightly fewer invertebrate feeders (less food), slightly fewer piscivorous birds (fewer fish) and more waterfowl (more freshwater habitat and greater productivity). The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined above.</i>	<i>Medium</i>
<i>2b. Community composition</i>	<i>95</i>	<i>Given the rather slight changes in different trophic groups outlined above, the community composition is not very different in the reference state from the present state. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.</i>	<i>Medium</i>
<i>Bird score</i>	<i>94</i>		

8.2 Scenario 7

8.2.1 Biomass

In Scenario 7, freshwater releases increase base flows towards reference condition as for the previous scenario, but the raising of the dam wall reduces floods, ie. moving further away from reference condition than at present. The change in base flows has more of an impact than the change in flooding. Thus changes are similar to the previous scenario, but there are gains in intertidal area (due to lack of flushing) relative to present. Waterweed is similar to the present state, but saltmarsh area is greater than at present, but not as large as in the reference state. Nutrient inputs are still high, and dissolved nitrogen is higher than in the previous scenario. Thus the estuary would more productive than in the reference state and present state, and than in scenario 2. This has implications all the way up the food chain, with increased invertebrate production, and fish are similar in abundance to the present state and scenario 2. The intertidal area remains slightly smaller in the upper estuary (10% less than reference state) and is larger in the lower estuary (25% more than reference state). There would be less freshwater habitat in the estuary than in the reference condition (but more than at present), due to lower base flows in summer than under natural conditions. Freshwater habitat would be more productive than in previous scenarios.

Invertebrate feeders (such as the waders) are expected to be more abundant than in the reference condition due to more habitat and higher densities of invertebrates in the estuary. However, since the changes in food are smallest in the lower estuary, where most birds occur, it is unlikely that there has been a major change.

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) may decrease due to the reduction in availability of fish. Their composition would be different, since some species have only colonised the estuary relatively recently.

Waterfowl may be less abundant than in the reference state due to the smaller freshwater habitat and smaller intertidal in the mid to upper estuary, but would increase relative to the present state. However, the freshwater habitat would be somewhat more productive than the reference state, offsetting this effect to some degree.

8.2.2 Species richness

Apart from the recent colonisers, there is no reason to believe that any other species would be lost or gained.

8.2.3 Seasonal variability

There would not have been any significant changes in seasonal patterns of bird numbers.

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	<i>It is unlikely that there would be a loss in average instantaneous species richness</i>	Medium
2a. Abundance	96	<i>Waterbirds are probably not as abundant in scenario 7 as at present, although the difference is probably very slight. There would be slightly fewer invertebrate feeders (less food), slightly fewer piscivorous birds (fewer fish) and more waterfowl (more freshwater habitat and greater productivity).</i> <i>The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined above.</i>	Medium
2b. Community composition	95	<i>Given the rather slight changes in different trophic groups outlined above, the community composition is not very different in the reference state from the present state. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.</i>	Medium
Bird score	95		

8.3 Scenario 5

8.3.1 Biomass

In Scenario 5, base flows are reduced as at present, and freshwater flows are further reduced in terms of reduction in floods, ie. flow patterns in general moving further away from reference condition than at present. The change in flooding exacerbates the problems already caused by reduced base flows. Nutrient inputs are still high, but dissolved nitrogen is not as high as in the previous scenario. The estuary is more productive than in previous scenarios. This has implications all the way up the food chain, with increased invertebrate production, and fish are similar in abundance to the present state and scenarios 2 and 7. Waterweed is more abundant than in any previous scenarios, but other plant habitats remain similar to the present state. The intertidal area remains slightly smaller in the upper estuary (10% less than reference state) and is larger in the lower estuary (25% more than reference state). There would be less freshwater habitat in the estuary than in the reference condition, and very slightly more than in the present state. Freshwater habitat would be more productive than in previous scenarios.

Invertebrate feeders (such as the waders) are expected to be more abundant than in the reference condition due to more habitat and higher densities of invertebrates in the estuary. However, since the changes in food are smallest in the lower estuary, where most birds occur, it is unlikely that there has been a major change.

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) would be similar in abundance to previous scenarios. Their composition would be slightly different from reference state, since some species have only colonised the estuary relatively recently.

Waterfowl may be less abundant than in the reference state due to the smaller freshwater habitat and smaller intertidal in the mid to upper estuary, but would be similar or slightly higher than in the present state – freshwater habitat is slightly more, and its productivity is much greater.

8.3.2 Species richness

Apart from the recent colonisers, there is no reason to believe that any other species would be lost or gained.

8.3.3 Seasonal variability

There would not have been any significant changes in seasonal patterns of bird numbers.

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
<i>1. Species richness</i>	<i>100</i>	<i>It is unlikely that there would be a loss in average instantaneous species richness</i>	Medium
<i>2a. Abundance</i>	<i>98</i>	<i>Waterbirds numbers are probably similar to present.</i> <i>The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined above.</i>	Medium
<i>2b. Community composition</i>	<i>95</i>	<i>Given the rather slight changes in different trophic groups outlined above, the community composition is not very different in the reference state from the present state. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.</i>	Medium
Bird score			

8.4 Scenario 17

8.4.1 Biomass

In Scenario 17, base flows are reduced further than at present, but there is no significant reduction in floods. This degrades the system further than in previous scenarios. Nutrient inputs are still high, dissolved nitrogen is higher than in previous scenarios and salinity distribution is as far from reference condition as the present state. The estuary is more productive than in all previous scenarios. This has implications all the way up the food chain, with increased invertebrate production, except that fish less abundant than in previous scenarios. There is less waterweed than in the previous two scenarios, and reedmarsh area has also decreased. The intertidal area remains slightly smaller in the upper estuary (10% less than reference state) and is larger in the lower estuary (25% more than reference state). There would be less freshwater habitat in the estuary than in the reference condition, similar to the present state. Freshwater habitat would be more productive than in previous scenarios.

Invertebrate feeders (such as the waders) are expected to be more abundant than in the reference condition due to more habitat and higher densities of invertebrates in the estuary. However, since the changes in food are smallest in the lower estuary, where most birds occur, it is unlikely that there has been a major change.

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) would be less abundant than in previous scenarios. Their composition would be slightly different from reference state, since some species have only colonised the estuary relatively recently.

Waterfowl would be less abundant than in the reference state due to the smaller freshwater habitat and smaller intertidal in the mid to upper estuary, and may be fewer than in the present state – freshwater is similar, but upper intertidal and reedmarsh is reduced, although productivity in the upper estuary is much greater.

8.4.2 Species richness

It could be expected that average species richness might decline in the upper estuary due to reduction in availability of freshwater habitat.

8.4.3 Seasonal variability

There would not have been any significant changes in seasonal patterns of bird numbers.

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
<i>1. Species richness</i>	90 (95%)	<i>It is possible that there would be a loss in average instantaneous species richness due to loss of freshwater habitat</i>	Medium
<i>2a. Abundance</i>	94	<i>Waterbirds numbers are probably slightly more abundant than at present and higher than in the reference condition. Invertebrate feeders are more abundant, piscivores are fewer, and herbivores slightly less abundant than the present state.</i> <i>The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined above.</i>	Medium
<i>2b. Community composition</i>	92	<i>Given the rather slight changes in different trophic groups outlined above, the community composition is not very different in the reference state from the present state. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.</i>	Medium
Bird score			

8.5 Scenario 10

8.5.1 Biomass

In Scenario 10, base flows are reduced further than at present, and there is significant reduction in floods. This degrades the system even further than in previous scenarios. Nutrient inputs are still high, dissolved nitrogen is higher than in previous scenarios and salinity distribution further from reference condition than the present state. The estuary is more productive than in all previous scenarios. This has implications all the way up the food chain, with increased invertebrate production, except that fish less abundant than in previous scenarios. Abundance of waterweed is similar to scenario 5, and reedmarsh area has decreased further. The intertidal area remains slightly smaller in the upper estuary (10% less than reference state) and has increased in the lower estuary relative to previous scenarios (30% more than reference state). There would be less freshwater habitat in the estuary than in the reference condition and less than in the present state. Freshwater habitat would be more productive than in previous scenarios.

Invertebrate feeders (such as the waders) are expected to be more abundant than in the reference condition due to more habitat and higher densities of invertebrates in the estuary. However, since the changes in food are smallest in the lower estuary, where most birds occur, it is unlikely that there has been a major change.

Piscivorous birds (such as pelicans, cormorants, ibises, wading birds and terns) would be less abundant than in previous scenarios. Their composition would be slightly different from reference state, since some species have only colonised the estuary relatively recently.

Waterfowl would be less abundant than in previous scenarios due to the smaller freshwater habitat and smaller intertidal in the mid to upper estuary, even though productivity in the upper estuary is much greater.

8.5.2 Species richness

It could be expected that average species richness might decline in the upper estuary due to reduction in availability of freshwater habitat.

8.5.3 Seasonal variability

There would not have been any significant changes in seasonal patterns of bird numbers.

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
<i>1. Species richness</i>	80 (90%)	<i>It is possible that there would be a loss in average instantaneous species richness due to loss of freshwater habitat</i>	Medium
<i>2a. Abundance</i>	78	<i>Waterbirds numbers are probably significantly more abundant than at present and higher than in the reference condition. Invertebrate feeders are more abundant, piscivores are fewer, and herbivores slightly less abundant than the present state.</i> <i>The abundance score is calculated based on estimated changes in different trophic groups, based on relative productivity of other biota, quantified estimates of changes in habitat, and assumptions outlined above.</i>	Medium
<i>2b. Community composition</i>	91	<i>Given the changes in different trophic groups outlined above, the community composition is somewhat different from the reference state and from the present state. The score is based on a similarity analysis (percentage similarity) of relative proportions of three main trophic groups.</i>	Medium
Bird score			

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APPENDIX I

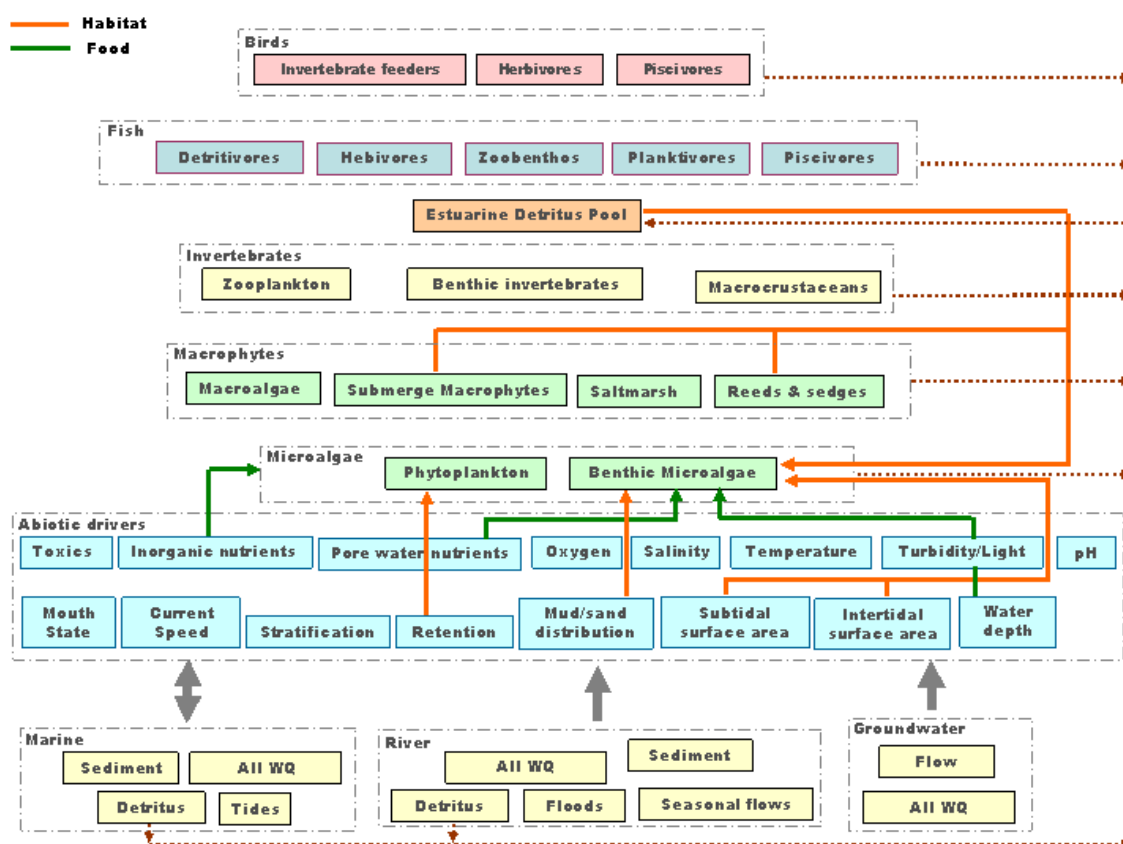
SUMMARY OF IMPORTANT ECOSYSTEM LINKS IN THE OLIFANTS ESTUARY AS DEFINED BY SPECIALISTS DURING THE WORKSHOP

During the workshop biological specialists were requested to indicate the key ecosystem links relevant to their specific component. In particular, they were asked to:

- Indicate the main habitat drivers relevant to each biotic group – highlighting the 3 most important ones
- Indicate main food web links
- For the different subcomponents within a biotic group, give an indication which are sensitive to changes in flow and which are most abundant

The outcome of this exercise is summarised below:

Microalgae:



The most important drivers for the Microalgae were ranked as:

Benthic Microalgae

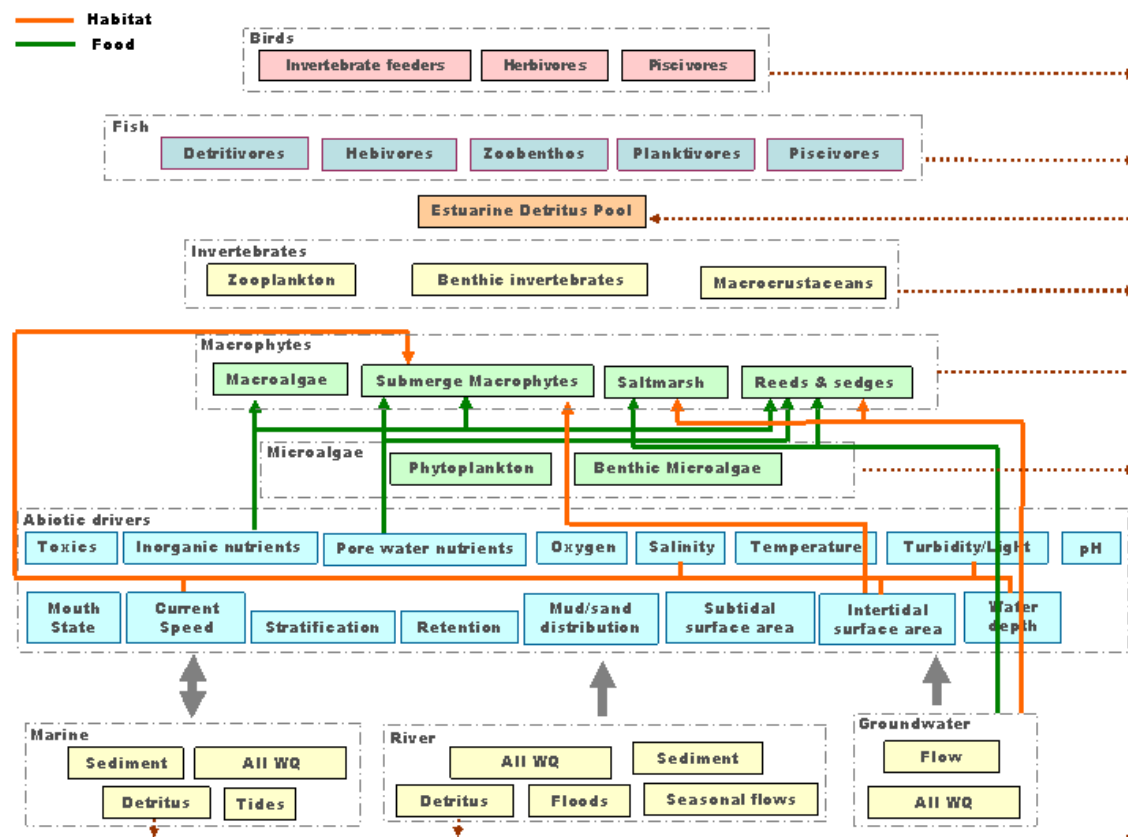
1. All surface area (sediment, macrophytes, detritus)
2. Water column (inorganic) nutrients
3. Pore water (inorganic) nutrients

Phytoplankton

1. Flow (retention)
2. Water column (inorganic) nutrients

In terms of microalgae, benthic microalgae were considered the most abundant component in the system and therefore an important food source for the estuary. Phytoplankton was seen as the most sensitive to changes in flow and was therefore a good indicator of change.

Macrophytes:



The most important drivers for the Macrophytes were ranked as:

Submerged Macrophytes

1. Nutrients, current speed
2. Turbidity and light
3. Salinity
4. Water column depth
5. Intertidal area

Reeds and sedges

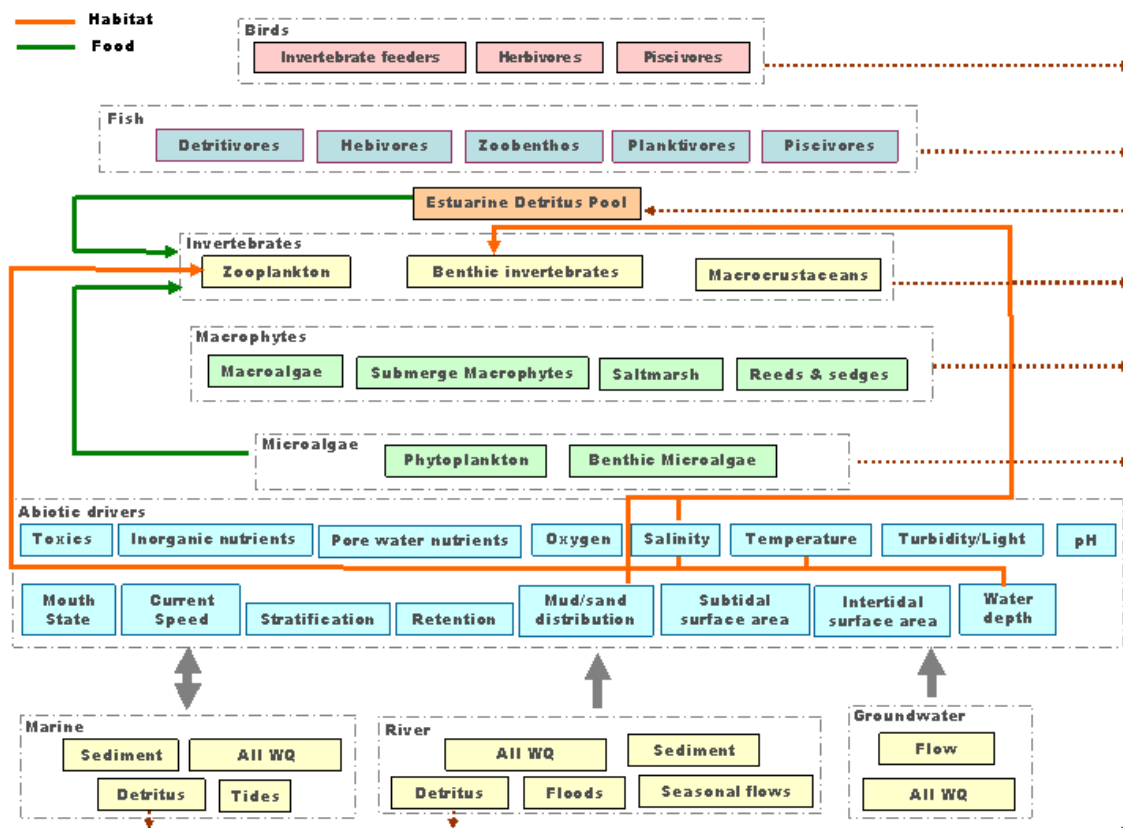
1. Salinity
2. Nutrients
3. Ground water (salinity and pore nutrients)
4. Water column depth

Saltmarsh

1. Salinity
2. Groundwater (depth and salinity)
3. Intertidal are for intertidal saltmarsh

Submerged Macrophytes, Reeds and sedges, and Saltmarsh were considered the highly sensitive to changes in flow. In addition they were also of high abundance and therefore important to the estuarine ecosystems.

Invertebrates:



The most important drivers for the Invertebrates were ranked as:

Zooplankton

1. Salinity
2. Depth
3. Temperature

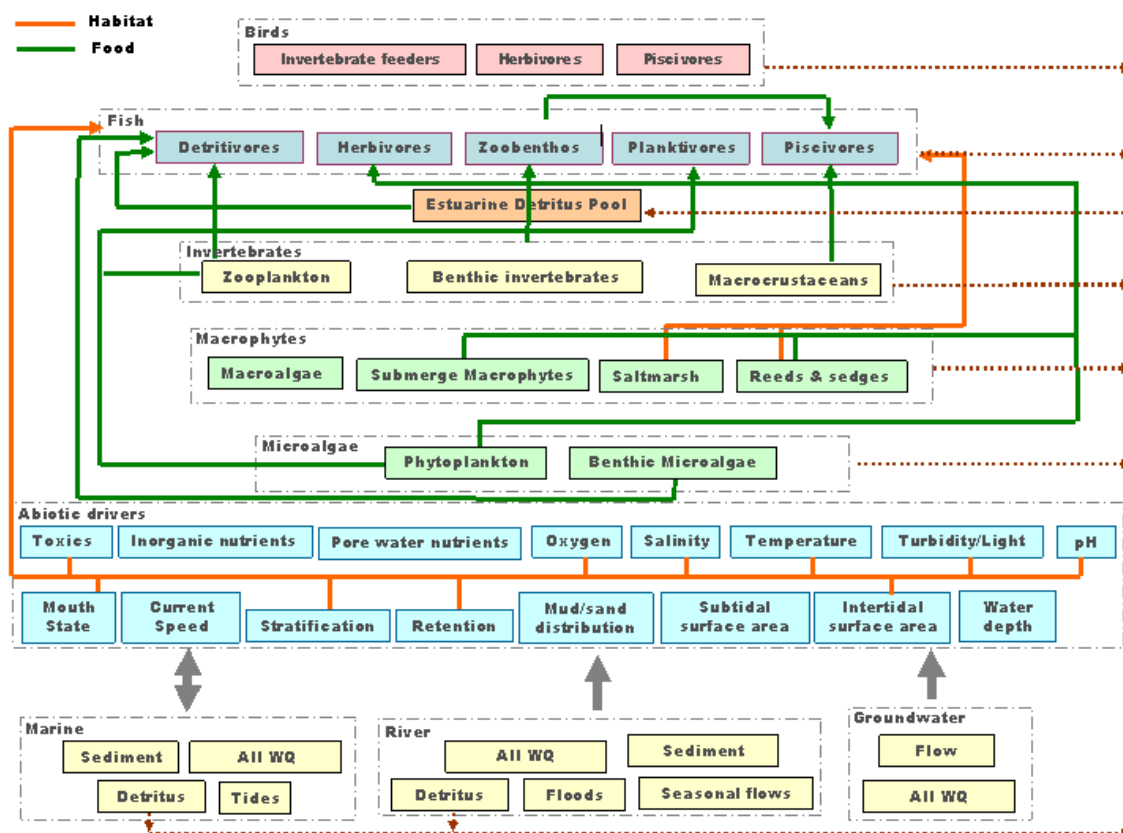
Benthic Invertebrates

1. Salinity
2. Sediment particle size

Zooplankton was mainly feeding on benthic microalgae, phytoplankton and detritus. Benthic Invertebrates were mainly feeding on benthic microalgae and detritus.

Zooplankton, Benthic Invertebrates and Macrocrustacea were considered to be sensitive to changes in flow, but only Zooplankton and Benthic Invertebrates were of high abundance in the system.

Fish:



The most important drivers for the fish were ranked as:

Fish

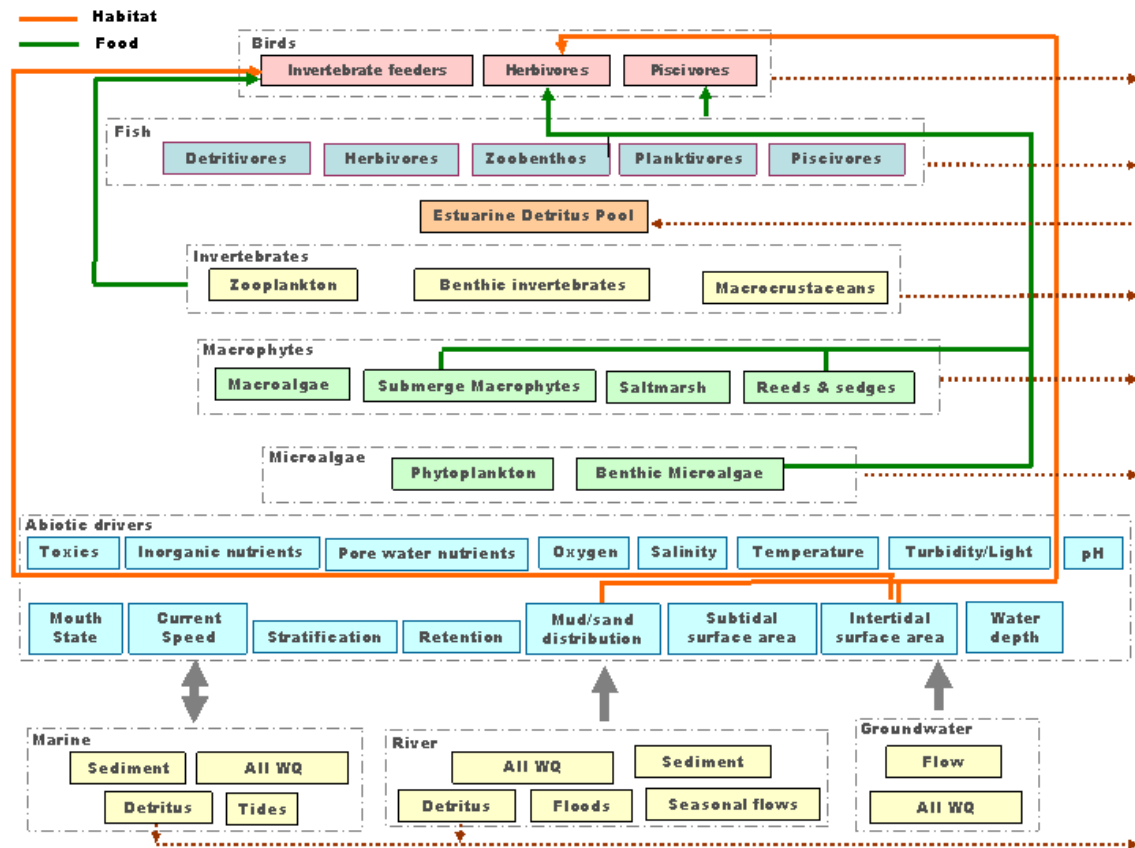
1. Salinity
2. Turbidity and light
3. Oxygen
4. Retention, State of mouth, Stratification
5. Mud and sand distribution
6. Intertidal area
7. Toxic substances
8. pH

The main food sources for fish were grouped as:

- *Detritivores*: Zooplankton, detritus, benthic microalgae; benthic invertebrates
- *Herbivores*: Submerge macrophytes, Reeds and sedges
- *Zoobenthos feeders*: Zooplankton, benthic invertebrates, macrocrustaceans
- *Planktivores*: benthic microalgae, zooplankton
- *Piscivores*: Fish, macrocrustaceans

Detritivores, Herbivores, Zoobenthos, Planktivores and Piscivores were all considered the highly sensitive to changes in flow. Only the detritivores and planktivores were of high abundance in the system and therefore considered the major food sources to the ecosystem.

Birds:



The most important drivers for the birds were ranked as:

Invertebrate feeders

1. Intertidal area
2. Mud/Sand distribution
3. Saltmarshes

Herbivores

1. Intertidal area
2. Salinity
3. Reeds and sedges

Piscivores

1. Reeds and sedges

The main food sources for birds were grouped as:

- *Invertebrate feeders*: Zooplankton, benthic invertebrates, macrocrustaceans
- *Herbivores*: Benthic microalgae, submerge macrophytes
- *Piscivores*: Fish (smaller size classes)

The Herbivores were considered the most sensitive to changes in flow. While the Invertebrate feeders and Piscivores were of the highest abundance in the estuary.