Determination of the Ecological Reserve for the Uilkraals Estuary

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Anchor Environmental Consultants CC
8 Steenberg House
Silverwood Close,
Tokai 7945
Republic of South Africa

Tel: (21) 701 3420
Fax: (086) 542 8711

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Prepared by:

	Anchor Environmental Consultants CC
Physical/Postal Address:	8 Steenberg House, Silverwood Close Tokai 7945

APPROVAL

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MAIN AUTHORS:	B.M. Clark, J.K. Turpie, S. Mallory, L. van Niekerk, S. Taljaard, J.B. Adams and A. Biccard.
REVIEWERS:	Nompumelelo Thwala and Wilna Kloppers
LEAD CONSULTANT:	Anchor Environmental Consultants
EDITORS:	J.K. Turpie
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Approved for
Anchor Environmental Consultants by:

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Barry Clark
Director

Approved for the Department of Water Affairs by:

____

Ms Barbara Weston
Deputy Director: Resource Directed Measures

EXECUTIVE SUMMARY

Introduction

This study was commissioned to determine the Ecological Reserve for the Uilkraals estuary, which entails following a set of procedures to determine the Present Ecological Status (health state), the Recommended Ecological Category (the future state of health) and the quantity and quality of freshwater inflows and other conditions required to maintain this. The analysis involves estimating the characteristics of the system in its original condition as well us under a range of potential future scenarios.

Location and delineation of the Uilkraals estuary

The Uilkraals Estuary is situated approximately 60 km northwest of Cape Agulhas and 11 km east of Danger Point on the south-west coast within the cool temperate biogeographic region of South Africa. It enters the sea at 34˚36’23”S 19˚24’33”E (Whitfield 2000). The geographical boundaries for the study are defined as follows:

Downstream boundary:	Estuary mouth 34˚36’23”S, 19˚24’33”E
Upstream boundary:	34°35'38.03"S, 19°28'0.05"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

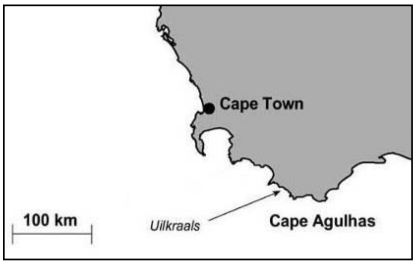

Figure I. Map of the south western tip of South Africa, showing the position of the Uilkraals Estuary

Figure 1.1. Geographical boundaries of the Uilkraals Estuary

Baseline description and health assessment

Overall context and pressures

The Uilkraals catchment lies within the Overberg District Municipality in the Western Cape Province and the estuary is located within the Overstrand Local Municipality. The river is 46 km from the mouth to the source of the Sondagskloof, one of its major tributaries. The Sondagskloof and Perdeberg rivers join to form the Uilkraals River about 30 km from the mouth. The Boesmans River joins the Uilkraals approximately 6 km from the mouth. The size of the estuary from the mouth to the the confluence of the Uilkraals and Boesmans is approximately 260 ha (Heydorn & Bickerton 1982). A 220 m bridge spans the estuary 800 m from the mouth. The catchment is 313 km^2, in extent, is dominated by Table Mountain Sandstone and lies within a winter rainfall area. Average rainfall is 500-600 mm and Mean Annual Runoff (MAR) is approximately 22 x 10^6 m^3. Vegetation is dominated by fynbos, but the lower areas of the catchment have been altered by increased anthropogenic activities, mainly agriculture and alien plant invasion. About 75 000 people live in the catchment. Activities are mainly agricultural (wine, fruit and flowers), but there is a resort development at the mouth and a settlement (Franskraal) nearby. The towns of Gansbaai and Stanford are just outside the catchment.

Flows are affected by the Kraaibosch Dam of 5.5 x 10^6 m^3 capacity about 10km upstream of the estuary mouth. According to the dam's permit conditions only winter flow is allowed to be retained and all summer flow is let through. There is another large dam (the Nieuwedam) on the Boesmansrivier tributuary. There is an unknown number of small dams and water abstraction points by local farmers on the river below the Nieuwedam, but at present the volume of water abstractions is unknown. The Breede Water Management Area (WMA) Internal Strategic Perspective (ISP) anticipates that there will be a 40% increase in summer allocations out of the Kraaibosch Dam as a result of increasing demand from agriculture.

Several other catchment activities affect water quality and biodiversity in the estuary. These include agricultural pollutants and direct introduction of sewage pollution into the estuary, the road bridge, low lying developments around the estuary, recreational activities and illegal fishing in the estuary. In addition, artificial breaching has taken place since 2008 in response to its starting to close for the first time.

Hydrology

Daily rainfall time series were obtained from a representative rain gauge near the catchment and used to patch and extend the WR2005 spatial rainfall record from 1920 to 2010. Hydrological simulations were made for 90 years (1920-2010) using the the enhanced WRSM2000 model (Pitman monthly model). Water use within the catchment consists of irrigation and domestic use. The assumption was made that rainfall contributes to crop water requirements. With the aid of an irrigation model the water requirements for the above crops was estimated to be 4.1 x 10^6 m^3/annum. Gansbaai have an allocation of 2 x 10^6 m^3/annum but are not fully utilising this allocation. The maximum abstraction to date has been only 0.53 x 10^6 m^3/annum.

The net natural runoff for G40M published in the WR2005 and WR90 studies is 15.4 x 10^6 m^3/annum and 20.8 x 10^6 m^3/annum respectively. This is considerably less than the 36.3 x 10^6 m^3/annum obtained from this study, but it must be borne in mind that this is the first hydrological analysis to make use of the observed data at the Avoco weir to calibrate the Pitman model. Sasman & du Preez (1999) reported that the calculated natural MAR of the Uilkraals River at the dam site is 19.7 x 10^6 m^3/annum which is very similar to the findings of this study. The Water Resources Modelling Platform was set up to simulate various scenarios for the G40M catchment. This model also has a module to model stream flow reduction due to invasive alien plants.

MAR has been reduced from 39.3 x 10^6 m^3 to 29.2 x 10^6 m^3. The current developments in the catchment have already led to very low to zero flows at the estuary. This is due largely due to the IAPs in the lower reaches of the catchment and not due to lawful abstractions or the Kraaibosch Dam. Months in which low flows could occur increased from 38% under Reference to 53% under Present State. In the 35% of months of lowest flows, the average flows are 7% of those during the Reference State. The present day flood regime was judged to be 95% similar to the reference and the dams in the catchment are relatively small and the Kraaibosch Dam is never drawn down completely.

Present health score: 25

Physical habitats

Topographical surveys were conducted in 1997 and 1999. Some sedimentation may have occurred in the lower reaches in the last two decades due to the reduction in river inflow causing the marine sediment to start accumulating in the lower reaches. The bridge is also likely to have caused a reduction in tidal flows which also may have led to increases in the amount of marine sediment in the lower reaches. In its reference state, the estuary was sandy, deriving sediments from marine and nearby dune areas. At present there is a surface layer of mud in the mid to upper reaches, from catchment erosion, and the dune areas are under alien vegetation. The bridge has also caused some infilling in the middle reaches. The most important change has been the loss of functional intertidal areas in recent years due to closure of the mouth.

Physical habitat score: 51

Hydrodynamics and abiotic states

Originally an open estuary, the estuary closed in 2008, and has remained closed for most of the time since then, apart from three intervals of a few months following artificial breaching. The height of the berm has been measured as 1.91 to 1.98 m above mean sea level (amsl).

Three distinct 'states' can be identified for the Uilkraals Estuary, related to mouth condition, tidal exchange, salinity distribution and water quality: 1. Closed; 2. Open and tidally-dominated; and 3. Open and fluvially-dominated. These are primarily determined by river inflow patterns, state of the tide and wave conditions. The transition between the different states may not always take place gradually and may occur within a few hours. At present the estuary is in the Closed state for 39% of the time, compared with (maximum) 5% in the Reference state (note: this is a modelled output and the estuary may not have closed in the Reference state).

Hydrodynamics and mouth condition health score: 65

Water quality

For the purpose of this analysis the estuary was divided into lower (up to the bridge), middle and upper zones, which account for 20%, 50% and 30% of the water volume, respectively, when the estuary is open. Data on the present state were collected during this study, and results from the Palmiet Estuary EWR study (also a black water system in the area) were used to estimate the Reference condition for the Uilkraals.

At present, the estuary tends to be hypersaline under closed conditions when inflow is very low, but turns brackish once the system starts to fill up before a breaching. The estuary is a blackwater system, and transparency averages 1 m. This would be less under higher flows. It is generally well-oxygenated (>6 mg/l). However, because of wastewater inputs, dissolved oxygen (DO) concentrations have been decreased under States 1 and 2 in the narrow upper reaches (estimated from 4 to 2 mg/l), and there is higher dissolved inorganic nitrogen (DIN) and phosphorus (DIP) than in the reference state.

Water quality health score: 64

Microalgae

Chlorophyll-a measurements taken in April and August 2011 were low, indicating that microphytobenthos are probably more important than phytoplankton as primary producers in this shallow water system.

There were no available data on the different phytoplankton groups in the Uilkraals Estuary and therefore for the purposes of this study changes are described for phytoplankton and MPB. The increase in nutrient concentrations and closed mouth conditions would have decreased species richness, and loss of intertidal habitat would have decreased MPB species richness in the intertidal zone. The changes will have promoted microphytobenthos growth particularly in shallow sheltered areas of the estuary, but loss of intertidal habitat would have led to loss of benthic microalgae. Blue-green algae would have outcompeted other algal groups under nutrient rich, freshwater conditions in the present state, and mouth closure would have resulted in a loss of intertidal benthic microalgal communities but a gain in subtidal habitat.

Microalgal health score: 55

Macrophytes

The estuary area proper (121.5 ha) is dominated by supratidal saltmarsh (47 ha) and intertidal sandflats (46 ha). There are small areas of submerged macrophytes beds (1.4 ha), reeds and sedges (5.6 ha) and macroalgae (0.5 ha). The remainder (21 ha) is the surface water area at low tide. About 60 plant species are found in the estuary. The salt marsh is particularly important, having high species richness and endemism.

Mouth condition, water retention time, flow velocity, floods, salinity, turbidity, oxygen, nutrients and sedimentation all play an important role in determining the abundance and composition of the different plant groups. Mouth closure and increased nutrient inputs have had the most significant impacts on the macrophytes. The increased nutrients would have stimulated growth of all primary producers, particularly reeds, sedges and macroalgae. Macroalgal growth has resulted in thick mats remaining on the salt marsh after water levels drop, which inhibits germination and growth. Also the increase in biomass and organic load could result in anoxic conditions during decomposition. The salt marsh dies back during closed mouth, high water level conditions. There has also been a small loss of macrophyte habitat due to development and building of the road bridge.

Macrophyte health score: 54

Invertebrates

Benthic macrofauna (>1mm) were sampled during this study but there is little information on invertebrates from prior to this. At least 19 functional groups could be identified, based on the factors that influence them (e.g. sediments, salinity, diet). In the present state, benthic macrofauna are dominated by polychaete worms, anomurans and prawns in the lower reaches, while amphipods become more common in the upper reaches.

The invertebrate community is influenced by mouth condition, tidal conditions, sediment characteristics, retention times and salinity, among others.

Under reference conditions, the system was strongly tidal with extensive intertidal sand and mud flats, which would have provided ideal habitat for both estuary associated and marine species such as *Callianassa kraussi, Upogebia africana* and in particular *Arenicola loveni* towards the mouth and lower reaches. With the mouth permanently open, *Upogebia africana* would constitute a greater proportion of the prawn population in comparison to the present temporary open mouth condition where *Callianassa kraussi* is by far the dominant prawn species. We would also expect to find additional marine dominated and estuary associated species present in similar permanently open-mouth systems like the nearby Heuningnes Estuary. Such species would be represented by the following taxa: polychaetes (e.g. *Ceratonereis erythraeensis*, *Lumbrinereis brevicirra*, *Nephtys capensis*), isopods (e.g. *Pontogeloides latipes*), gastropods (e.g. *Natica spp.*), brachyurans (e.g. *Paratylodiplax spp.*), carids (e.g. *Palaemon pacificus*) and various species of marine associated zooplankton. A greater tidal range would exist in the lower reaches of the system with saltwater penetrating further upward in comparison to the present scenario. This would influence the distribution of estuarine, brackish and freshwater taxa in a similar fashion – pushing them up towards the middle reaches of the system.

Invertebrate health score: 47

Fish

A few surveys have been undertaken of fish of the Uilkraals estuary in the last two decades (1994, 1996 and twice in 2011). Up to 12 species have been recorded in any survey. Fish are numerically dominated by resident species that breed only in estuaries (41%) and species that breed in estuaries and the sea (19%).

Under reference conditions, the estuary was probably very strongly tidal and had extensive sandy intertidal areas that provided ideal foraging and nursery areas for adults and juveniles of a wide range of marine migrant species (both estuary-associated marine species as well as marine 'vagrants' – e.g. white steenbras *Lithognathus lithognathus*, leervis *Lichia amia*, white stumpnose *Rhabdosargus globiceps*, sand shark *Rhinobatos blochii*). These species, together with sand (as opposed to mud) associated estuarine resident species such as the Cape sole *Heteromycteris capensis* and knysna sand goby *Psammogobius knysnaensis* most likely dominated the ichtyofauna of the estuary under these conditions. Mud associated resident species would most likely have been largely confined to the narrower channels in the upper reaches of the estuary. The silverside *Atherina breviceps* and various species of mullet (*Liza richardsonii, L. tricuspidens, L. dumerilii,* and *Mugil cephalus*) would have been very important in the system while *Gilchristella aestuaria* (currently the most abundant species) would have been less important. Eels *Anguilla mossambica* and *A. marmorata* although they have not been recorded in the system in recent times, probably still move through the estuary on their way upstream but nowhere near in the numbers that were historically present.

Fish health score: 52

Birds

A few counts of birds have been conducted at the Uilkraals estuary, most of which have been in summer, and some of which have been partial counts, either in terms of estuary coverage or the types of birds counted. Counts were also conducted for this study. A total of 51 water-associated bird species have been recorded at the Uilkraals Estuary, with about 30 species recorded per count. In recent counts (2010-11) between 429 and 657 birds have been recorded on the estuary. The estuary has moderate conservation importance for birds.

Nine functional groups of birds were identified for this study: piscivorous cormorants; piscivorous wading birds; herbivorous waterfowl; omnivorous waterfowl; benthivorous waders; piscivorous gulls & terns; piscivorous kingfishers; piscivorous birds of prey; and other birds of prey. Waders, gulls and terns are the dominant groups in summer and winter.

In its reference condition the estuary is likely to have been similar to the conditions found in the early 1980s, where the avifauna were typical of a fairly large open estuary with extensive productive mudflats and sandy islands in the mouth area. The main changes have been the loss of large numbers of migratory terns and waders that once dominated the avifauna but are now almost absent. Changes in waterfowl numbers have probably been relatively minor.

Bird health score: 24

Present ecological status

Table 1 summarises the above findings. The EHI score for the Uilkraals Estuary in its present state was estimated to be 49 (i.e. 49% similar to natural condition, which translates into a Present

Ecological Status (PES) of D. This arises from major changes in the mouth condition of the estuary, coupled with sewage-related pollution of the system.

Table I. Present ecological status of the Uilkraals Estuary

Variable	Health score/100	Health score net of non-flow related impacts	Confidence score	Confidence
Hydrology	25	25	30	Very low
Hydrodynamics and mouth condition	65	65	30	Very low
Water quality	59	83	50	Low
Physical habitat alteration	51	66	50	Low
Habitat health score	**50**	**59**	**40**	**Very low**
Microalgae	59	67	43	Low
Macrophytes	60	68	63	Medium
Invertebrates	47	47	50	Low
Fish	52	66	57	Low
Birds	24	66	70	Medium
Biotic health score	**48**	**63**	**57**	**Low**
ESTUARY HEALTH SCORE	**49**	**61**		
PRESENT ECOLOGICAL STATUS	**D**	**C**		
OVERALL CONFIDENCE			**48**	**Low**

Relative contribution of flow and non-flow related impacts on health

Estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an adjusted health score of 61, which would raise the PES to a C category. This suggests that non-flow impacts have played a major role in the degradation of the estuary to a D, but that flow-related impacts are the main cause of its degradation. Thus the highest priority is to address the quantity and quality of influent water. Of the non-flow-related impacts, water quality problem as a result of sewage pollution in the estuary was found to be the most important factor that influenced the health of the system.

Overall confidence

Confidence levels were very low for three of the components. The fact that these included hydrology and hydrodynamics meant that they affected the confidence of all subsequent components. Only two components had enough data to yield medium-confidence assessments. The overall confidence of the study was LOW. The implications of this are that

(a) one has to be extremely cautious and apply the precautionary principle in setting the Preliminary Reserve; and

(b) efforts should be made to collect baseline and monitoring data that will help to fill some key gaps in understanding.

Recommended Ecological Category (REC)

Conservation importance

The Estuary Importance Score (EIS) for the estuary takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account, and the overall score was 74, which corresponds to a rating of "Important".

Criterion	Weight	Score
Estuary Size	15	80
Zonal Rarity Type	10	90
Habitat Diversity	25	10
Biodiversity Importance	25	82
Functional Importance	25	70
Weighted Estuary Importance Score		**74**

Recommended Ecological Category

The PES for the Uilkraals is a D. The estuary is rated as "Important", and it is designated as a desired protected area in the Biodiversity Plan for the National Biodiversity Assessment. Thus the Recommended Ecological Category for the estuary is its **Best Attainable State.**

Operational and ecological reserve scenarios

Three scenarios were evaluated as part of this study (Table II):

- **Scenario 1** describes the situation where the full allocation to water users is used. This scenario could be considered the "Business as Usual' scenario, in which water demand increases over time, and the water available for the estuary decreases.
- **Scenario 2** describes situation as at present but with invasive alien plants (IAPs) having been removed from the entire catchment. This scenario represents an improvement over the present, as a result of restoring much of the original base flow flows in the catchment.
- **Scenario 3** was devised during the workshop in order to find the Best Attainable State, and represents an ecological improvement over Scenario 2. This scenario was the same as Scenario 2, except that the mouth was also kept open (the means of keeping the mouth open is deliberately not specified as various options for this still need to be investigated), and the sewage-related pollution problems are significantly ameliorated. No additional hydrological monitoring was undertaken for this scenario.

The following sections describe the flows and abiotic states under these scenarios.

Clearing of alien vegetation leads to increased low flows in the catchment (applicable for Scenarios 2 and 3), and because of the operating rules of the dam, these flows are allowed through to the head of the estuary. The open mouth condition (Scenario 3 only) does not have any bearing on freshwater inflows, thus the hydrological aspects are identical for the two scenarios.

Table II. Summary of the scenarios evaluated in this study.

Scenario name	Description	MAR (x 10^6 m^3)	Percentage remaining
Natural	Natural Flow	39.3	100.0
Present	Present (Includes Irrigation From Run Of River, Afforestation and Alien Invasive Plants)	29.2	74.3
Scenario 1 (Full allocation)	Full allocation	26.3	66.9
Scenario 2 (No IAPs)	Present day flows with invasive alien plants removed	35.2	89.6
Scenario 3 (No IAPs, Open, WQ)	Present day flows with invasive alien plants removed, mouth kept open, reduced pollution	35.2	89.6

The individual EHI scores, as well as the corresponding ecological category under different scenarios are provided in Table III. The estuary is currently in a D-category. It will deteriorate slightly under Scenario 1 (Full allocation), but is expected to remain in a D-category. The estuary will improve under Scenario 2 (No IAPs) to a C category, and overall health improves markedly under Scenario 3 (No IAPs, Open, WQ), though remaining in a C-category. A rough estimate of the contribution of non-flow related impacts suggests that if these are removed, the estuary could be raised to a C-class, and if this is done in conjunction with Scenario 3, the estuary may reach a B health category. The Recommended Ecological Category is Best Attainable State, which is a B category.

Table III. EHI score and corresponding Ecological Category under the different runoff scenarios

	Wt	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)	Conf
Hydrology	25	25	25	55	55	30
Hydrodynamics and mouth condition	25	65	65	76	96	30
Water quality	25	59	58	64	68	50
Physical habitat alteration	25	51	51	64	66	50
Habitat health score		**50**	**50**	**65**	**72**	**40**
Microalgae	20	59	63	64	71	43
Macrophytes	20	60	60	65	70	63
Invertebrates	20	47	40	66	77	50
Fish	20	52	47	64	71	57
Birds	20	24	23	31	56	70
Biotic health score		**48**	**46**	**58**	**69**	**57**
ESTUARY HEALTH SCORE		**49**	**48**	**61**	**70**	**48**

PRESENT ECOLOGICAL STATUS	**D**	**D**	**C**	**C**	**Low**
EHI after non-flow impacts removed	61	60	72	78	
PES after non-flow impacts removed	C	D	C	B	

Recommended ecological flow requirement

For a high confidence study, the **'recommended Ecological Flow Requirement' scenario,** is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the recommended Ecological Category. Where any component of the health score is less than 40, then modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. For lower confidence studies, such as this one, a more conservative flow scenario (or a slight modification thereof to address low-scoring components) should be chosen, using the following guidelines. Based on this assessment, we have ascertained that the Best Attainable State for the estuary could be a **B-category**. It should be noted, however, that some of these impacts would be difficult to remove, such as the global impacts on migratory birds, and the status of marine fish stocks. **The flow requirements for the estuary are the same as those described for Scenarios 2 and 3**, and are summarised in Table IV.

Table IV. Summary of the monthly flow (in m^3.s^{-1}) distribution under Scenario 2 and 3

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	9.084	8.383	3.626	2.946	2.378	4.337	6.399	9.151	10.336	9.502	14.116	8.958
90%ile	2.345	2.612	0.553	0.037	0.198	0.347	2.191	2.823	4.360	6.384	6.851	3.044
80%ile	1.157	1.119	0.052	0.026	0.029	0.097	0.841	1.960	2.955	3.383	4.846	2.357
70%ile	0.676	0.231	0.034	0.026	0.029	0.030	0.359	1.120	2.014	2.524	3.226	1.914
60%ile	0.470	0.123	0.030	0.026	0.025	0.026	0.208	0.646	1.300	1.684	2.102	1.327
50%ile	0.347	0.081	0.030	0.022	0.025	0.022	0.112	0.396	0.953	1.333	1.680	0.949
40%ile	0.231	0.050	0.026	0.022	0.025	0.022	0.050	0.224	0.575	1.019	1.258	0.729
30%ile	0.153	0.046	0.026	0.022	0.025	0.022	0.039	0.172	0.432	0.754	0.904	0.502
20%ile	0.127	0.042	0.026	0.022	0.021	0.022	0.027	0.101	0.258	0.549	0.538	0.332
10%ile	0.060	0.039	0.022	0.019	0.021	0.019	0.023	0.037	0.127	0.392	0.362	0.181
1%ile	0.048	0.031	0.022	0.019	0.021	0.019	0.023	0.029	0.057	0.091	0.127	0.084

Resource quality objectives

Since the estuary has to be restored from a D to a B-category, the thresholds of potential concern (TPCs) should be seen as targets to be met within 5 years. Thereafter the estuary should be maintained such that these thresholds are not breached. The TPCs for the Uilkraals Estuary area listed in Tables V and VI.

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

Abiotic Component	Ecological Specification	Threshold of Potential Concern
Water quality	Salinity intrusion should not cause exceedance of TPCs for fish, invertebrates, macrophytes and microalgae (see above)	Salinity greater than 20 PSU for longer than 3 months in Zone C at Site 8 (4 km) upstream from the mouth (this would have an impact on the brackish saltmarsh, reeds and sedges) Salinity greater than 35 ppt DO < 4 mg/l in more than 75% of estuary DIN and DIP concentrations >100 µg/land > 50 µg/l, respectively , unless from natural origin (e.g. occasional upwelling which will be indicate by low seawater temperatures)
Hydrodynamics	Maintain a flow regime to create the required habitat for birds, fish, macrophytes, microalgae and water quality	River inflow distribution patterns differ by more than 5 % from that of Scenario 1/ 3 (i.e. recommended flow scenario for the Uilkraals). River inflow below 0.03 m^3/s persist for longer than 2 months Mouth closure occurs Water level in the estuary above 1.0 m MSL for 3 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	River inflow distribution patterns of intermediate and high flows (flood components) differ by more than 10% (in terms of magnitude, timing and variability) from that of the Present State (2012) Suspended sediment concentration from river inflow deviates by more than 20 % of the sediment load-discharge relationship to be determined as part of baseline studies (present state 2012). Findings from the bathymetric surveys undertaken as part of the monitoring programme indicate changes in the sedimentation and erosion patterns in the estuary have occurred (± 0.25 m).

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

Component	Ecological Specification	Threshold of Potential Concern
Microalgae	Phytoplankton biomass, measured as water column chlorophyll should not exceed 10 ug l^{-1}. Maintain high subtidal benthic microalgal biomass during the closed mouth phase and high intertidal benthic microalgal biomass during the open phase.	Phytoplankton biomass greater than 10 ug l^{-1}. Deviation in benthic microalgal biomass by 20 % compared with Present State concentrations. No brackish epipelic diatoms are found during the closed phase

Component	Ecological Specification	Threshold of Potential Concern
Macrophytes	Maintain the distribution of plant community types i.e. Submerged macrophyte, *Ruppia cirrhosa* beds during closed mouth brackish conditions, salt marsh, *Salicornia meyeriana* marsh during open mouth conditions, *Phragmites australis* stands in the middle / upper reaches and salt marsh grasses indicative of brackish conditions.	Greater than 20 % change in the area covered by different macrophyte habitats for baseline open and closed mouth conditions.
Benthic Invertebrates	The estuary should have viable populations of *Callianassa kraussi* in sandy zones and *U. Africana* in muddy zones. Breeding in both species ceases at salinities lower than 17ppt during prolonged mouth phase. In *U. africana* and export of larvae into marine and postlarvae back to estuary ceases.	Abundance of *C. kraussi* and *U. Africana* drops below 50% of recorded total abundances in each season. No recruits in population recorded. (Identify zones where these are abundant based from the study and these would be where the above would be assessed)
Zooplankton	Prolonged close mouth would result in a loss of marine species (e.g. *Pseudodiaptomus sp.) from the* zooplankton community,	Absence of indicator marine species (*Pseudodiaptomus sp.) changes by more than 50% of current levels (still to be determined)*.
Fish	Retain the following fish assemblages in the estuary (based on abundance): estuarine species (30-40%), estuarine associated marine species (60-70%) and indigenous freshwater species (<1%). All numerically dominant species are represented by 0+ juveniles.	Level of estuary associated marine species drops below 50% of total abundance. Level of estuarine species increases above 50% of total abundance. Occurrence of alien freshwater species in the estuary. Absence of 0+ juveniles of any of the dominant fish species.
Birds	The estuary should contain a rich avifaunal community that includes representatives of all the original groups, significant numbers of migratory waders and terns, as well as a healthy breeding population of resident waders. The estuary should support thousands of birds in summer and hundreds in winter.	Numbers of White-fronted Plovers fall below 60 during the breeding season Numbers of terns recorded in midsummer are fewer than 2000 Numbers of bird species drop below 20 for 3 consecutive counts.

Mouth management

While it would be highly desirable to maintain the mouth of the Uilkraals estuary in a permanently open state, this may not be easy given existing demands for freshwater in this catchment. Some key research questions that need to be answered prior to developing and implementing a mouth management plan. It would be desirable to keep the mouth open in order to maintain connectivity with the sea and prevent the deterioration of the estuary, including reducing the risk of sediment build-up which would keep the mouth closed. Prior to developing the plan, a study needs to be commissioned on the topography and sediment processes, and continuous water level monitoring is required.

Invasive alien plants

Invasive alien plants (IAPs) make a significant impact on flows in the Uilkraals catchment, reducing options for water use. The IAPs need to be cleared from the catchment in order to restore the Uilkraals estuary to its best attainable state. Thereafter the catchment needs to be kept free of IAPs.

Water quality management

There appear to be two main sources of organic pollution into the estuary –spillover from the waste water treatment works to the west, and seepage from sewage systems in the resort development at the mouth. Pollution from these sources needs to be eliminated. This will probably involve a combination of compliance issues and seeking new engineering solutions. A specialist study needs to be commissioned on how best to achieve this

Estuary monitoring requirements

Recommended minimum monitoring requirements to ascertain impacts of changes in freshwater flow to the estuary and any improvement or reductions therein are listed in Table VII.

Table VII. Recommended minimum requirements for long term monitoring

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. Stations)
Hydrodynamics	Record water levels	Continuous	At bridge
	Measure freshwater inflow into the estuary	Continuous	At Kraaibosch dam and Boesmans above the estuary
	Aerial photographs of estuary (spring low tide)	Every 3 years	Entire estuary
Sediment dynamics	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detailed in the mouth (every 100m). The vertical accuracy should be about 5 cm.	Every 3 years	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	Every 3 years (with invert sampling)	Entire estuary
Water quality	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow	Monthly continuous	At river inflow

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. Stations)
	Assess and better quantify wastewater input (e.g. nutrients and organics) from diffuse sources (e.g. caravan park, WWTW).	Once-off detailed Possibly long-term (e.g. peak seasons) if input remains significant (preferably these should be mitigated)	In stream (source/s)
	Record longitudinal salinity and temperature profiles (and any other in situ measurements possible e.g. pH, DO, turbidity)	Seasonally, every year	Entire estuary (10 stns)
	Take water quality measurements along the length of the estuary (surface and bottom samples) for system variable (pH, dissolved oxygen, suspended solids/turbidity) and inorganic nutrients in addition to the longitudinal salinity and temperature profiles	Seasonal surveys, every 3 years or when significant change in water inflows or quality expected	Entire estuary (10 stns)
Microalgae	Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. HPLC, fluoroprobe Intertidal and subtidal benthic chlorophyll-a measurements,	Summer and winter survey every 3 years	Entire estuary (5 stns)
Macrophytes	Ground-truthed maps; Record 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; Record percentage plant cover, salinity, water level, sediment moisture content and turbidity on a series of permanent transects along an elevation gradient; Take measurements of depth to water table and ground water salinity in supratidal marsh areas	Summer survey every 3 years	Entire estuary (5 stns)
Benthic Invertebrates	Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary. Record benthic invertebrate species and abundance, based on van Veen type grab samples in subtidal and core samples in intertidal at a series of stations up the estuary, and counts of hole densities. Measures of sediment characteristics at each station	Summer and winter every 3 years	Entire estuary 5stn
Zooplankton	Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary.	Summer and winter every 3 years	Entire estuary 5stn
Fish	Record species and abundance of fish, based on seine net and gill net sampling.	Summer and winter survey every 3 years	Entire estuary (5 stns)

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. Stations)
Birds	Undertake counts of all water associated birds, identified to species level.	A series of monthly counts, followed by winter and summer survey every year	Entire estuary (3 sections)

ACKNOWLEDGEMENTS

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- Nompumelelo Thwala and Wilna Kloppers for reviewing the first draft of this report

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ACRONYMS AND ABBREVIATIONS

AMSL	Above Mean Sea Level
BAS	Best Attainable State
CD	Chief Directorate
CPUE	Catch-per-unit-effort
CSIR	Centre of Scientific and Industrial Research
DEA: O&C	Department of Environmental Affairs: Oceans and Coast
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphate
DO	Dissolved Oxygen
DRP	Dissolved Reactive Phosphate
DRS	Dissolved Reactive Silicate
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EHI	Estuarine Health Index
EIS	Estuarine Importance Score
ERC	Ecological Reserve Category
EWR	Ecological Water Requirement
H	High
L	Low
M	Medium
MAR	Mean Annual Runoff
MSL	Mean Sea Level
NMMU	Nelson Mandela Metropolitan University
NWA	National Water Act (1998)
PES	Present Ecological Status
ppt	Parts per thousand
RDM	Resource Directed Measures
REI	River Estuary Interface
RQO	Resource Quality Objectives
SA	South Africa
SDF	Standard Design Flood
VL	Very low
WMA	Water Management Area

1 INTRODUCTION

1.1 Water Resources Management in South Africa

South Africa's National Water Act (NWA) (No. 36 of 1998) requires the implementation of four types of regulatory activities in order to make optimal use of the country's water resources while minimising ecological damage:

1. **resource-directed measures**, i.e. defining a desired level of protection for a water resource, and on that basis, setting environmental flows and specific goals for the quality of the resource (the Resource Quality Objectives);
2. **source-directed controls**, i.e. controlling impacts on the water resource through the use of regulatory measures such as registration, permits, directives and prosecution, and economic incentives such as levies and fees, to ensure that the Resource Quality Objectives are met;
3. **managing demand** on water resources to keep utilisation within the limits required for protection; and
4. **monitoring** the status of the country's water resources on a continual basis, to ensure that the Resource Quality Objectives are being met, and to enable us to modify programmes for resource management and impact control as and when necessary.

The objective of Resource Directed Measures (RDM) is to ensure the protection of water resources, in the sense of protecting ecosystem functioning and maintaining a desired state of health (integrity or condition) of aquatic and groundwater-dependent ecosystems. This objective is met through various processes, including the setting of 'environmental flows', known as the **Ecological Reserve** (the quantity and quality of water reserved to support ecosystem function).

Water resources (river reaches, wetlands, estuaries, etc.) must first be classified according to a **National Water Resource Classification System** (NWRCS or "Classification System") (Dollar *et al.* 2010), to determine the future level of protection and define specific objectives for the resource (Resource Quality Objectives), which is then used to determine the quantity and quality of water to be allocated to the Reserve

Recognising that it will take some time to classify all water resources in the country, provision has been made in the NWA for the determination of a **Preliminary Reserve** and hence an interim framework issuing of water use licences. Methods to determine the Preliminary Reserve were established soon after the promulgation of the NWA and have been in use since then (DWAF 2008).

These methods follow a generic methodology which can be carried out at different levels of effort to produce a determination of the ecologists' Recommended Ecological Category and the associated Ecological Reserve. The methods have been slightly modified in the development and evolution of methods for rivers, estuaries, wetlands and groundwater, but the same process is essentially followed in each. This study follows the latest method for estuaries (Version 3 – DWA 2012). Four of the main authors of the method were on the study team of the Uilkraals assessment. The steps of the method are outlined below.

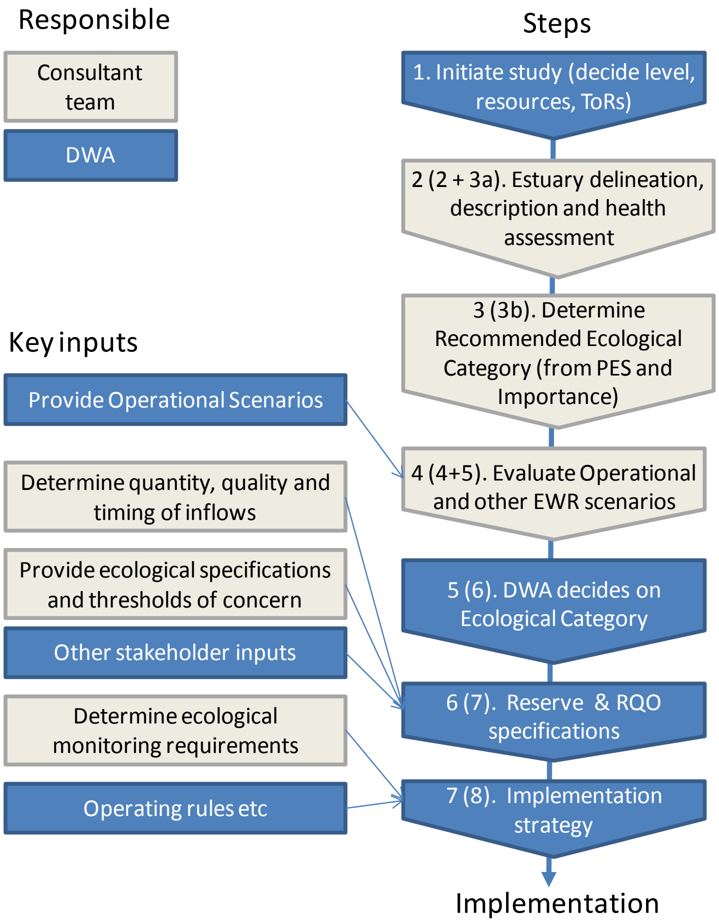


Figure 1.1. Procedures for determination of the preliminary Reserve for estuaries, giving Version 3 step numbers and former step numbers in parentheses (DWA 2012).

Step 1: Initiate the study

This entails defining the study area, the study team, and the level of study.

Step 2: Define the resource units.

Delineate the geographical boundaries of the resource by breaking down the catchment into water resource units which are each significantly different from the other to warrant their own specification of the reserve, and clearly delineate the geographic boundaries of each unit.

Step 3: Determine Recommended Ecological Category (i.e. preliminary classification)

This step entails estimating the reference and present condition and ecological importance in order to determine the Recommended Ecological Category. The Reference Condition refers to the natural, unimpacted characteristics of a water resource, and must represent a stable baseline. This usually requires expert judgement in conjunction with local knowledge and historical data. Reference conditions are generally described in terms of:

- water quantity (amount, timing, pattern and levels of flow, including seasonal and inter-annual variability, flood and drought cycles)
- water quality (the concentrations of key water quality constituents, including their seasonal and inter-annual variability, and going as far as diurnal patterns of variability for constituents such as temperature, dissolved oxygen and pH)
- geomorphological and vegetation aspects of habitat. In the case of estuaries, this also include mouth condition.
- character, composition and distribution of aquatic biota

The Present Ecological Status of resource quality (water quantity, water quality, habitat and biota), is assessed in terms of the degree of similarity to reference conditions. This helps to identify what may be desirable or achievable as a future management class. The assessment is summarised in terms of the classification system of A to F described in Table 1.1.

The Recommended Ecological Category is set as one of the first four ecological categories (A to D) utilized in identifying the present status assessment (Table 1.1). This category is the target for protection and management of the resource. This could be the same as the Present Ecological Status, or could be higher if an improvement in resource condition is desired. It has always been intended that when the full ecological Reserve implementation phase begins (using the Classification Process), the process of assigning the Ecological Class will be a consultative one, aimed at involving stakeholders in deciding the level of resource protection which is required. Criteria for assigning a class to a resource include:

- the sensitivity of the resource to impacts of water use (whether due to ecological sensitivity, or the sensitivity of water users)
- the importance of the resource, in ecological, social, cultural or economic terms
- the value of the resource, in ecological, social, cultural or economic terms
- what can be achieved towards improvement of resource quality, given that not all past impacts may be reversible

Step 4: Quantify Ecological Water Requirements

The reserve is quantified for the recommended category and alternative categories. This is the most technically demanding of the steps; the rules are rigorous procedures for deriving site-specific numerical objectives which are appropriate for the reference conditions of a particular resource.

Step 5: Ecological consequences of operational scenarios

Operational scenarios are evaluated in terms of the predicted future condition of the resource under each scenario.

Step 6: Decide on management category (DWA process)

DWA considers the recommended category in the light of other factors, and makes a decision (A to D).

Step 7: Reserve specification

This entails setting the Resource Quality Objectives (quantitative specifications), and the water quantity and quality parameters of the Reserve. In a Reserve determination study, these are presented as recommendations.

Step 8: Implementation strategy

This entails the strategy for implementation of flows (operating rules in the case of a dam) and other mitigation measures as well as designing a monitoring programme. In a Reserve determination study, these are presented as recommendations.

Table 1.1 The six Ecological Classes for indicating the present ecological status of the resource, as well as selecting the future ecological status (italics). Categories A to D are within the desired range, whereas E and F are not (Kleynhans 1996, MacKay 1999).

EC	Description
A	**Unmodified, or approximates natural condition**; the natural abiotic template should not be modified. The characteristics of the resource should be determined by unmodified natural disturbance regimes. There should be no human induced risks to the abiotic and biotic maintenance of the resource. The supply capacity of the resource will not be used.
B	**Largely natural with few modifications**. A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged. *Only a small risk of modifying the natural abiotic template and exceeding the resource base should not be allowed. Although the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a very limited number of localities may be slightly higher than expected under natural conditions, the resilience and adaptability of biota must not be compromised. The impact of acute disturbances must be totally mitigated by the presence of sufficient refuge areas.*
C	**Moderately modified**. A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. *A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the wellbeing and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least partly be mitigated by the presence of sufficient refuge areas.*
D	**Largely modified**. A large loss of natural habitat, biota and basic ecosystem functions has occurred. Large risk of modifying the abiotic template and exceeding the resource base may be allowed. Risk to the well-being and survival of intolerant biota depending on (the nature of the disturbance) may be allowed to generally increase substantially with resulting low abundances and frequency of occurrence, and a reduction of resilience and adaptability at a large number of localities. However, the associated increase in the abundance of tolerant species must not be allowed to assume pest proportions. The impact of local and acute disturbances must at least to some extent be mitigated by refuge areas.
E	**Seriously modified**. The loss of natural habitat, biota and basic ecosystem functions is extensive

F	**Critically modified**. Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible

1.2 Definition of confidence levels

The level of available historical data in combination with the level of effort expended during the assessment determines the level of confidence of the study. Three levels of study have been recognised in the past in terms of the effort expended during the assessment – rapid, intermediate and comprehensive. In this study, effort lay somewhere between a rapid and intermediate study, in that some field data collection was carried out, but overall would be classed as a 'Rapid' study. Nevertheless, the paucity of historical data on the system meant that we expected the confidence of the study to be low. This is a situation that can only be remedied with some comprehensive and long term data collection on the system. Criteria for the confidence limits attached to statements in this study are shown in Table 1.2.

Table 1.2. Confidence levels for an Estuarine EWR study

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

1.3 Specialist team

The following specialists were on the study team:

Specialist	Affiliation	Area of responsibility
Dr Barry Clark	Anchor Environmental Consultants	Study leader and fish
Stephen Mallory	Institute for Water Research	Hydrology
Ms Lara van Niekerk	CSIR	Hydrodynamics & sediments
Dr Susan Taljaard	CSIR	Water quality
Prof Janine Adams	Nelson Mandela Metropolitan University	Microalgae and macrophytes
Mr Aiden Biccard	Anchor Environmental Consultants	Invertebrates
Dr Jane Turpie	Anchor Environmental Consultants	Birds & overall method & editing

1.4 Assumptions and limitations for this study

The following assumptions and limitations should be taken into account:

- Only limited new data were collected as part of this study during two two-day field visits to the estuary in April and August 2011. All assumptions made as part of this assessment are thus mostly based on historical data and expert opinion.
- The hydrology of the catchment was modelled using the Pitman Monthly hydrological model using WR2005 zonal rainfall data and rainfall data from four sites in the catchment covering the period 1933-1992. Rainfall data from one station outside the catchment (Station 0007263W) was used to extend the WR2005 zonal rainfall from 2004 to the end of the 2010 hydrological year (September 2011). The enhanced WRSM2000 model was used to simulate flows for the period 2002 to 2010 and were calibrated using data from the Avoca weir upstream of Kraaibosch Dam obtained from Wayne Gabb of Lomond Farm. The WR2005 calibration (Pitman) parameters were initially chosen from regional parameter datasets provided in the WR2005 reports (Middelton and Bailey 2009) and then adjusted until the statistics of the simulated flow were similar to the observed flow for this period.
- The overall confidence in the hydrological data provided to the estuarine team by the IWR Water Resources was Low.
- The accuracy of the predicted abiotic states for the Uilkraals Estuary and the distribution of these states under the reference condition, present state and future flow scenarios depend largely on the accuracy of the simulated runoff data and measured data.

1.5 Structure of this report

The report is structured as follows:

Chapter 1 provides an overview of the process, the level of effort and confidence of the study and study team.

Chapter 2 defines the geographical boundaries of the study area;

Chapter 3 provides a baseline description and health assessment of the estuary. This chapter starts by introducing the context of the estuary, then describes each of the abiotic and biotic aspects of the estuary, from hydrology to birds. For each of these components, our understanding of the present situation is described, the reference situation is estimated, and then the present state is scored in terms of its similarity to the estimated reference state. The overall state of health is then computed using the Estuary Health Index.

Chapter 4 combines the EHI score with the Importance score for the system to determine the Recommended Ecological Category. It also summarises the overall confidence of the study and the degree to which non-flow factors have contributed to the degradation of the system.

Chapter 5 describes three alternative future scenarios, and determines the Ecological Category for each of these.

Chapter 6 provides the recommendations regarding the flow requirements for the system, the ecological specifications that must be met, and recommendations for a monitoring programme. It also discusses the way forward for management of the estuary mouth.

Appendix A provides a summary of the data that were available and/or collected for the study.

2 LOCATION AND DELINEATION OF THE UILKRAALS ESTUARY

The Uilkraals Estuary is situated approximately 60 km northwest of Cape Agulhas and 11 km east of Danger Point on the south-west coast within the cool temperate biogeographic region of South Africa (Whitfield 1998; Figure 2.1). It is the first estuary east of Danger Point (Heydorn & Bickerton 1982). The Uilkraals River runs southward and drains into the Indian Ocean 6 km southeast of Gansbaai. It enters the sea at 34˚36’23”S, 19˚24’33”E (Whitfield 2000).

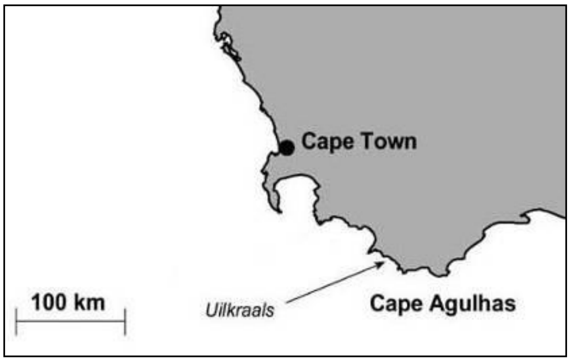


Figure 2.1. Map of the south western tip of South Africa, showing the position of the Uilkraals Estuary.

The geographical boundaries of the Uilkraals Estuary study area are defined as follows:

Downstream boundary:	Estuary mouth 34˚36’23”S, 19˚24’33”E
Upstream boundary:	34°35'38.03"S, 19°28'0.05"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

Figure 2.2. Geographical boundaries of the Uilkraals Estuary

3 BASELINE DESCRIPTION AND HEALTH ASSESSMENT

3.1 Overall context and pressures

The following descriptions are drawn from the Situation Assessment prepared for the development of the Uilkraals Estuary Management Plan (Anchor Environmental Consultants 2011).

3.1.1 Catchment description

The Uilkraals catchment lies within the Overberg District Municipality in the Western Cape Province and the estuary is located within the Overstrand Local Municipality (Figure 3.1 and Figure 3.2). The river is approximately 46 km in length from the mouth to the source of the Sondagskloof, one of its major tributaries. The junction of the Sondagskloof and the Perdeberg rivers forms the Uilkraals at an approximate elevation of 200 m roughly 30 km from the mouth. In the lower catchment, the Boesmans River joins the Uilkraals approximately 6 km from the mouth. The size of the estuary from the mouth to the confluence of the Uilkraals and Bosmans is approximately 260 ha (Heydorn & Bickerton 1982). A bridge approximately 220 m long spans the estuary approximately 800 m from the mouth. A causeway approximately 120 m in length supports the eastern road access to the bridge whilst the remaining 100 m is spanned and supported by large concrete pylons (Heydorn & Bickerton 1982).

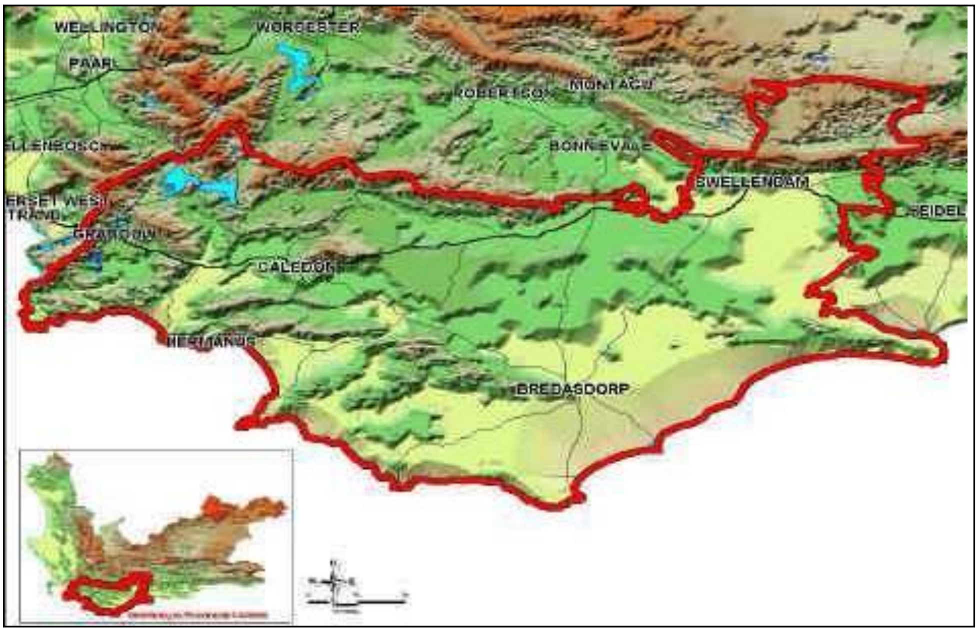


Figure 3.1. Map showing Overberg region in which the Uilkraals Estuary is located.

The Uilkraals River Catchment is relatively small at 313 km^2, is dominated by Table Mountain Sandstone (Heydorn & Bickerton 1982) and lies wholly within the Western Cape Province, which receives most precipitation during the winter rainfall season. Mean Annual Runoff (MAR) for the whole catchment is approximately 22 x 10^6 m^3 (van Niekerk, unpubl. data) and the average annual rainfall in the catchment ranges between 500 and 606 mm (Heydorn & Tinley 1980, Heydorn & Bickerton 1982) with peaks in June and July. The river flow is therefore high in winter with run-off declining in summer. For Franskraal, located at the estuary mouth, the annual average daily maximum temperature is 22°, with the monthly average maximum temperature ranging from 27°C in February to 18°C in June, July and August. The annual average daily minimum temperature is 11°C. The settlement of Franskraal receives on average 506 mm annually with most of the rain falling in the winter months from May to August (South African Rain Atlas 2010; Figure 3.3).

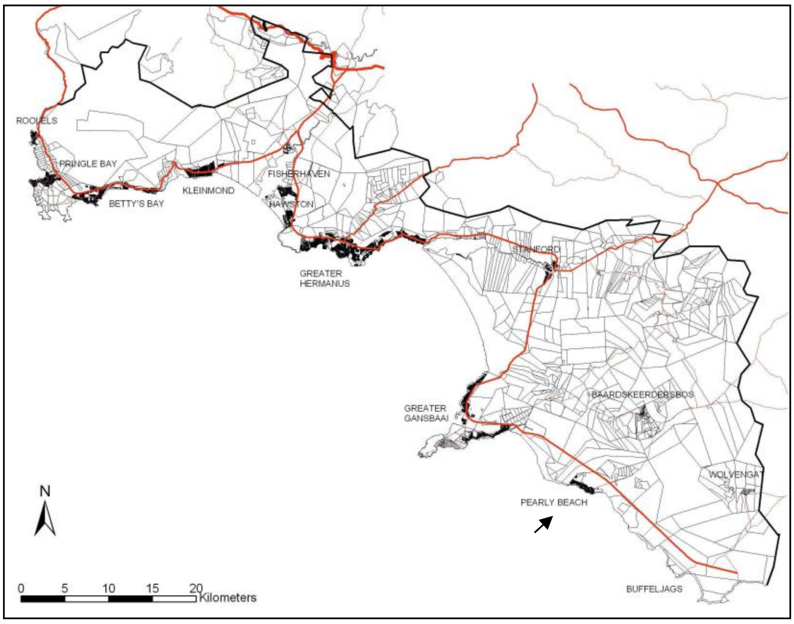


Figure 3.2. Overstrand Local Municipality map showing the main settlements. The Uilkraals Estuary (shown by the arrow) is located between Gansbaai and Pearly Beach (Source: Overstrand SDF 2009).

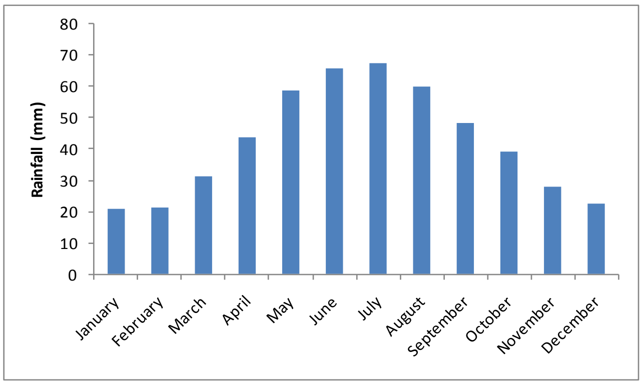


Figure 3.3. Monthly rainfall in the Uilkraals catchment

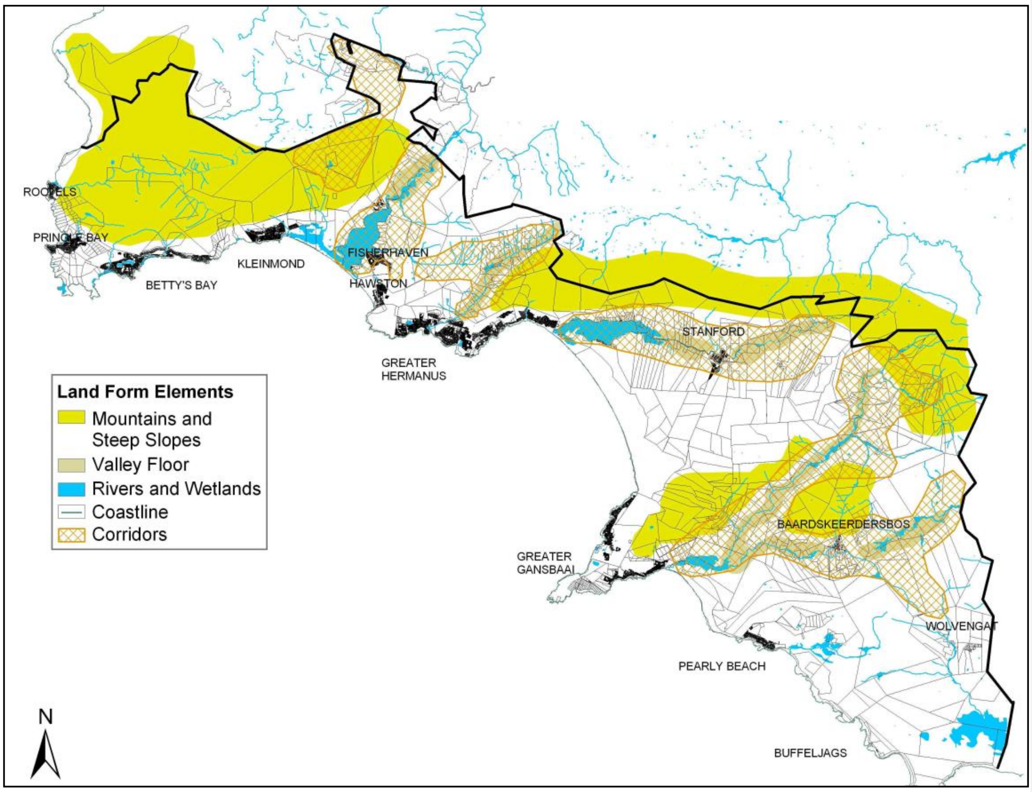


Figure 3.4. Overstrand Local Municipality physical morphology and landscape map (Source: Overstrand SDF 2009).

The spatial patterns in the natural vegetation within the Uilkraals River Catchment are determined primarily by the underlying geology and regional rainfall. The upper catchment is characterised by the acidic and nutrient poor Table Mountain Group (TMG) sandstones and quartzites, which are dominated by mountain fynbos. Lower down in the river valley, rocks of the Malmesbury Formation outcrop and support limestone fynbos. The mountain fynbos vegetation in the higher lying areas of the Uilkraals River catchment remain predominantly intact. The lower areas of the catchment have been altered by increased anthropogenic activities, mainly agriculture and alien plant invasion. Natural riparian vegetation along most of the Uilkraals River's course (with the exeption of the saltmarsh alongside the estuary) has been replaced by invasive exotics, in particular gums, poplars, Port Jackson and rooikrans (Gale 1998).

3.1.2 Catchment population

The total population living within the Overstrand Local Municipality, in which the Uilkraals River Catchment is located, was estimated at 74 546 as per the 2007 StatsSA Community Survey. The population density was estimated at 35 people per square kilometre and total household count was

24 485. Majority of the population in the Overstrand Local Municipality are classified as Coloured (37%) and White (34%), followed by Black Africans (29%) (Local Economic Development 2008). The overall population of the Uilkraals River catchment (G40M) is a small proportion of the total for the Overstrand Local Municipality as it contains a relatively small urban area. Larger settlements such as Gansbaai with approximately 20 000 residents and Stanford with 8 000 residents are located outside of the boundaries of the Uilkraals catchment. The Overberg District Municipality population growth has been declining since 1995, and the average annual growth rate is only 3%. If the current trend of population growth continues, the Overberg will soon have a negative growth rate, as is already seen in the Cape Agulhas Local Municipality (Local Economic Development 2008). Approximately 56% of the population in the Overberg area is employed, with 20% of the population being unemployed (Local Economic Development 2008). Agriculture and trade are the economic sectors with the highest employment at 20.1% and 16.5% respectively. The geographic trend in economic activity along the catchment is predominately agriculturally based in the middle and upper reaches and tourism and fishing industry based near the mouth. One of the larger tourism developments within the catchment is the Uilenkraalsmond Holiday Resort, located at the estuary mouth, which includes permanent holiday cottages, caravan sites and recreational amenities.

3.1.3 Land use

The catchment consists mainly of agricultural areas and an ecological corridor/area, with some private conservation areas and other statutory conservation areas. Development within the catchment includes small urbanised areas along the coast and larger areas developed for agricultural purposes, with agriculture, fruit farming, stock-farming, viticulture and nature conservation being the main land use activities. Agriculturally based industries dominate in the Overstrand and include wineries, fruit and fynbos cultivation (Overberg Spatial Development Framework 2004). The Overstrand Local Municipality lists the Uilkraals River Catchment as an intensive agricultural resource area (Figure 3.5). Urban development accounts for a very small proportion of the catchment land cover. The major towns in the area, Gansbaai and Stanford lie adjacent to the Uilkraals catchment. The largest town within the catchment is Franskraal, which is located at the mouth of the estuary on the coast.

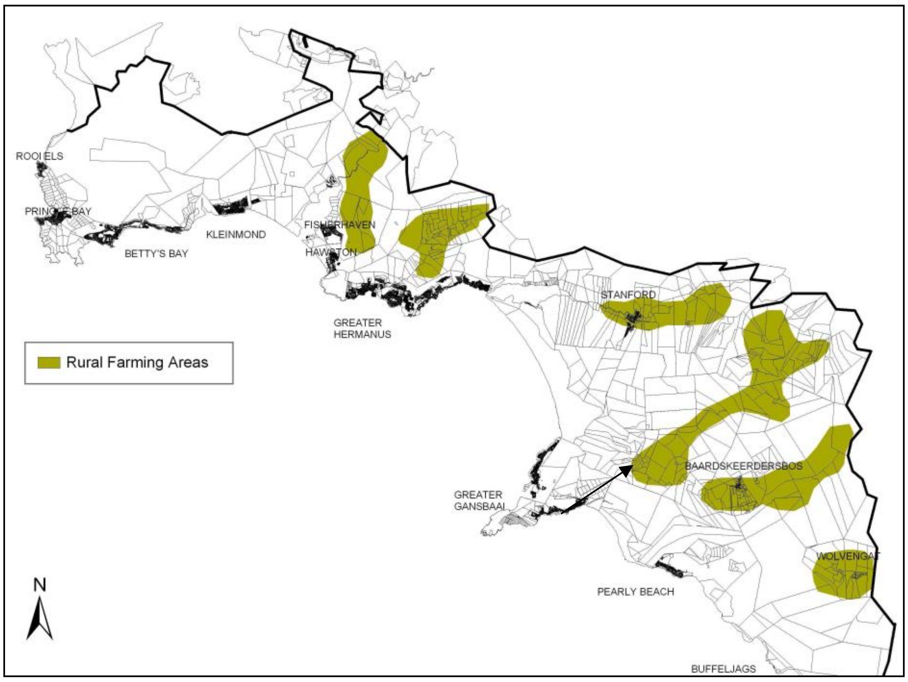


Figure 3.5. Intensive agricultural resource areas showing the Uilkraals River Catchment as being one of the larger agricultural areas in the Overstrand (Source: Overstrand SDF 2009).

Agriculture dominates much of the upper Uilkraals River Catchment, with wineries, fruit cultivation and fynbos cultivation being the most important contributors to this sector. Tourism is a major economic contributor across the catchment, through nature based recreation and holiday destinations. The estuary is considered a bird watching destination and recreational fishing remains a draw card. In addition Pearly Beach and the Uilenkraalsmond Resort are big attractions to the Uilkraals catchment, where the popularity as a holiday destination results in a fourfold increase in the population over the holiday seasons. The Overstrand has had the highest positive annual Gross Domestic Product growth in the Overberg District since 1995 (Local Economic Development 2008). In 2008, the Gross Domestic Product for the Overberg District was estimated to be in the region of R4 billion, equivalent to approximately only 0.3% of the national GDP (Local Economic Development 2008).

3.1.4 Human influences affecting the estuary

3.1.4.1 Flow-related influences

The Kraaibosch dam (Figure 3.6) was constructed on the Uilkraals River in 1999 to supply the town of Gansbaai with water and the surrounding areas with water for irrigation purposes. The dam wall lies appproximately 10 km upriver from the estuary mouth (du Preez & Sasman 1999), covers 102 ha and can hold 5.5 x 10^6 m^3. According to the dam's permit conditions only winter flow is allowed to be retained and all summer flow is let through. Detailed flow records of river inflow, spillage, rainfall and outflow are kept on a daily basis. This data shows that every summer the river inflow decreases to zero for up to several months, but summer flooding does sporadically occur. The amount of water flowing into the system in summer is at least the same as before the dam was built, and while these flows are largely natural in the upper reaches, there are substantial decreases in the downstream flow compared with the natural condition. Retaining winter flow decreases riverine base flows and floods which changes the physical functioning of the estuary. Estuaries are not only reliant on base flow but also require flood peaks to scour them and maintain their dynamics, something that cannot easily be supported where in-channel storage dams are developed (DWAF 2004a).

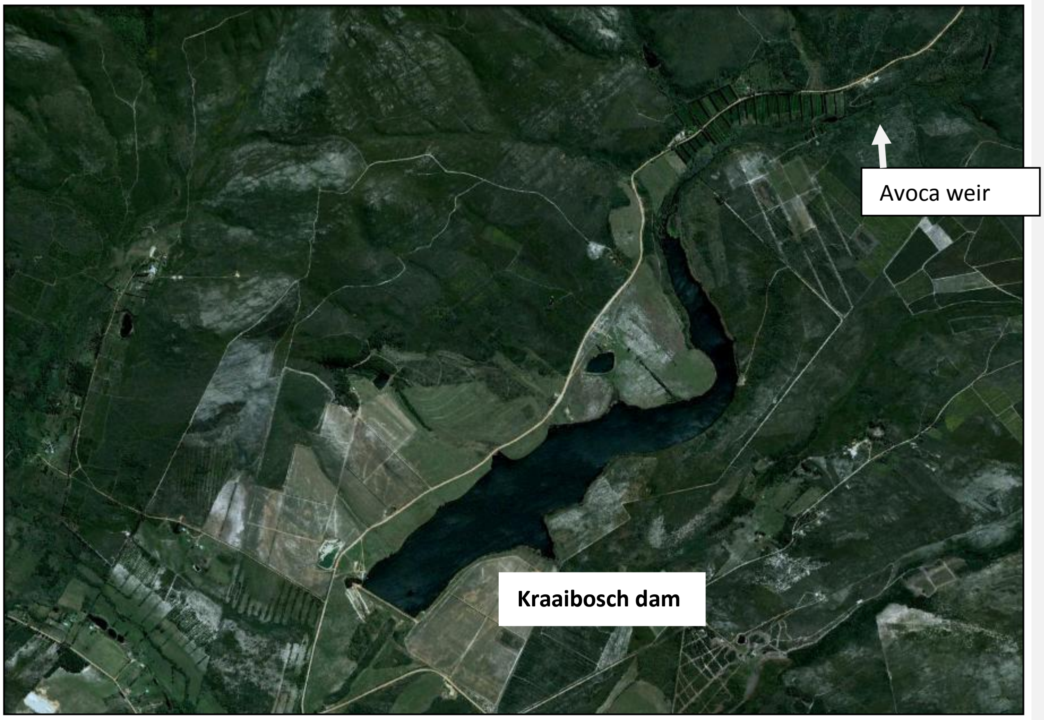


Figure 3.6. Kraaibosch Dam (Source: Google Earth)

The Boesmansrivier which joins the Uilkraals approximately 6 km from the mouth has a large dam upstream called the Nieuwedam. There is an unknown number of small dams and water abstraction points by local farmers on the river below the Nieuwedam, but at present the volume of water abstractions is unknown. The Breede Water Management Area (WMA) Internal Strategic Perspective (ISP) anticipated that the Uilkraals River Catchment (G40M) would have a 40% increase in summer allocations out of the Kraaibosch Dam (DWAF 2004a) indicating increasing demand, through the progressive implementation of agricultural development in the catchment.

Much of the catchment, including lower-lying areas, is infested with invasive alien plants, mainly *Acacia*. A summary of flow related impacts affecting the Uilkraals estuary is presented in Table 3.1.

The estuary is not affected by any industrial activities, mariculture or shipping, and there are no golf courses in the catchment area.

Table 3.1. Activities affecting the quality and quantity of flows into the estuary

Activity	Extent of problem
Agricultural and pastoral run-off containing fertilisers, pesticides and herbicides	Some
Septic and conservancy tank seepage	Probably significant , from the caravan park and cottages
Litter	Very minor

3.1.4.2 Non flow-related influences

Non-flow-related influences on the estuary refer to impacts that occur directly within the estuary zone, and include direct introductions of pollutants into the estuary that are not transported via drainage from the catchment. A summary of non-flow related impacts affecting the abiotic and biotic components of the Uilkraals estuary is presented in Table 3.2 and Table 3.3, respectively.

Table 3.2. Land-use and development related activities affecting the abiotic characteristics in the estuary

Activity	Describe impact
Municipal waste (including sewage disposal)/infrastructure problems	Aerial photos suggest wastewater input from a wastewater facility entering the estuary just upstream of bridge; the discharge is unplanned. Seepage of sewage from the caravan park is also a potential concern (this needs to be confirmed).
Bridge(s)	A 220 m long road bridge was constructed in 1973 and crosses the river approximately 800 m from the mouth. It is supported on the eastern side by a high embankment of rubble spanning almost two-thirds of the original high tide river width (Gaigher 1984). The remaining 100 m are supported by concrete pylons, effectively halving the width of the estuary there and concentrating the river flow against the western bank (Heydorn & Bickerton 1982).
Artificial breaching	Artificial breaching has taken place since 2008
Bank stabilisation and destabilisation	In 1978 a 150 m long rubble and rock embankment was built on the beach in front of the beach facing bungalows, forcing the estuary mouth eastwards, away from the caravan park (Heydorn & Bickerton 1982). However, the embankment was quickly eroded by wave and tidal action and a shallow, stagnant pool of water and a series of sand dunes formed on the beach in front of the bungalows.
Low-lying developments	There is a holiday resort in the floodplain
Migration barrier in river	Kraaibosch dam forms a barrier to migratory fish

Table 3.3. Summary of living resources utilisation in the Uilkraals Estuary

Activity	Present	Describe impact
Recreational fishing	Yes	Low recreational fishing pressure at present due to low abundance of target species (i.e. large marine migrants).
Commercial/Subsistence fishing (e.g. gillnet fishery)	Yes	Anecdotal reports suggests that there is some illegal gill netting in the estuary, mostly for mullet.
Illegal fishing (Poaching)	Yes	See Commercial/Subsistence fishing above
Bait collection	Yes	Bait collecting effort in the estuary can be high during peak holiday season but is low for most of the year due to absence of key target species (e.g. bloodworm) and low biomass of others (sand and mud prawns).
Grazing and trampling of salt mashes	Yes	Low density of livestock present on the flood plain in the upper reaches of the estuary.
Translocated or alien fauna and flora	Yes	High abundance of alien invasive vegetation in the catchment (mostly black wattle *Acacia mernsii*) and also some encroachment of alien invasive vegetation on to the floodplain and historic intertidal sand flats and salt marsh in the middle and lower reaches of the estuary (most rookrans *Acacia cyclops*). No alien fish species have been recorded in the estuary.
Recreational disturbance of waterbirds	Yes	Minor, highly seasonal

3.2 Hydrology

The analysis of the hydrological regimes of estuaries is important to better understand the ecological functioning of the estuary. In the absence of observed stream flow records, the inflow time series is simulated using a rainfall-runoff model (i.e. Pitman monthly model) while development scenarios are generally simulate using a water resources model. The purpose of this study was to simulate the monthly river inflow to the Uilkraals Estuary located in the G40M quaternary catchment, in the Breede Water Management Area in Western Cape. See Figure 3.7. The gross catchment area of Uilkraals River is 393 km^2.

The Kraaibosch Dam was constructed on the Uilkraals River in 1999 to supply the town of Gansbaai with water for domestic and industrial use and the surrounding areas with water for irrigation. The dam wall is located approximately 10 km upstream from the estuary, has a surface are of 102 ha when full and has a full supply capacity of 5.5 x 10^6 m^3. Detailed flow records of river inflow, spillage, rainfall and outflow are kept on a daily basis, but were never made available to Department of Water Affairs. The recent study by the Water Research Commission (Middleton and Bailey, 2009) therefore did not take this valuable information into account when modelling this catchment. The catchment area of the dam is 220 km^2 which is approximately 56% of the total catchment and therefore the majority of the catchment Mean Annual Runoff (MAR) flows into the Kraaibosch dam.

The Boesmans River joins the Uilkraals River approximately 6 km from the estuary. The Nieuwedam is a significant farm dam located on this river upstream of the estuary. There are also a number of small dams with associated water abstraction for irrigation upstream of the Kraaibosch Dam. The total volumes abstracted from these dams are not known but can be estimated from the registered areas under irrigation.

Figure 3.7 **Map of Uilkraals River catchment**

3.2.1 Data and model calibration

3.2.1.1 Hydrology and climate

The catchment of the Uilkraals River is characterised by hilly slopes in the upper reaches of the catchment and a very flat coastal plain in the lower reaches. It is surmised that the rainfall-runoff relationship of these two areas will be very different with relatively high runoff from the upper reaches and much less runoff form the coastal plain. The hydrology of the upper reaches can be modelled realistically using the inflow records into the Kraaibosch Dam while there is no observed flow with which to calibrate the rainfall-runoff response of the coastal plain.

The focus of this study is to simulate the inflows into the estuary under the reference state, the present state and two alternative scenarios over as long a period as possible in order to cover the full spectrum of possible hydrological events form extreme droughts to extreme floods. Previous studies (WR90 and WR2005) did not use observed flows to calibrate Uilkraals river catchment . For this study, observed flow data (July 1992 to June 2011) at Avoca weir upstream of Kraaibosch Dam (Figure 3.6) obtained from **Wayne Gabb of Lomond Farm** were used to calibrate the Pitman hydrological model to realistically estimate the inflows into the dam and consequently model flows for the whole catchment.

The data and flow statistics over the observed period (Table 3.4) shows variable flows throughout the year with zero flows during the summer period (January to March) with floods occurring from April through to November.

Table 3.4 Monthly observed flow data for the Uilkraals River based on flow records from 2002 to 2010

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
2002	1.03	0.11	0.00	0.00	0.00	1.32	0.82	1.47	1.51	0.74	10.38	3.25
2003	1.17	0.07	0.03	0.00	0.00	0.00	0.01	0.05	0.18	0.49	1.17	0.35
2004	2.01	0.26	0.01	0.00	0.00	0.00	17.45	1.91	5.13	2.17	1.38	2.45
2005	0.82	0.51	0.03	0.00	0.00	0.00	0.01	0.26	0.73	5.50	15.87	2.74
2006	0.92	0.68	0.11	0.00	0.00	0.00	0.00	0.10	0.39	1.57	3.02	1.06
2007	1.25	4.22	1.92	0.27	0.00	0.00	0.01	0.05	0.31	1.25	0.74	2.47
2008	2.06	5.71	0.64	0.07	0.02	0.00	0.00	0.01	0.22	1.29	1.14	0.66
2009	5.26	0.75	0.03	0.00	0.00	0.00	0.00	0.01	0.13	0.78	0.27	0.14
Average Volume (10^6 m^3)	**1.81**	**1.54**	**0.34**	**0.04**	**0.00**	**0.16**	**2.29**	**0.48**	**1.07**	**1.72**	**4.24**	**1.64**
Average flow(m^3/s)	**0.68**	**0.59**	**0.13**	**0.02**	**0.00**	**0.06**	**0.88**	**0.18**	**0.41**	**0.64**	**1.59**	**0.63**

Daily rainfall time series from a representative rain gauge (Station Name: Boskloof; Code: 0007263W) were obtained from South African Weather Service. This is the only gauge with recent rainfall records within the proximity of the catchment. The rainfall time series data were used to patch and extend the WR2005 spatial rainfall record from 1920 to 2010. Information on regional mean monthly evaporation values were obtained from Midgley *et al*. (1994). The hydrological simulations were therefore extended to 90 years (1920-2010).

3.2.1.2 Water use

Water use within the catchment consists of irrigation and domestic use. Information on irrigation was obtained from the WARMS data base and is summarised in **Table 2.2** while the full list of crops is attached as Appendix A.

Table 3.5 Simplified crops types and area (from WARMS)

Crop Type	Crop area (ha)
Pastures	325
Deciduous fruit	192
Vegetable (summer)	74
Grapes	30
Maize	30
Total	**651**

The water use by crops is not uniform throughout the year but depends on the potential rate of evapotranspiration and rainfall. The assumption was made that rainfall contributes to crop water requirements. Hence if there is sufficient rainfall on any one day then the farmer will not need to irrigate. The assumption was also made that irrigators are sufficiently skilled to practice irrigation in this manner.

With the aid of an irrigation model the water requirements for the above crops was estimated to be 4.1 x 10^6 m^3/annum. It is not known exactly how this irrigation is distributed throughout the catchment but with the aid of Google maps the following distribution was made:

- Upstream of Kraaibosch Dam: 48%, supplied from farm dams
- Boesmans River: 24%, supplied from farm dams
- Kraaibosch Dam: 28%

The actual allocation to irrigators from the Kraaibosch Dam is 3.21 x 10^6 m^3/annum. However, records of abstractions from the dam indicate that at most they have used 1.04 x 10^6 m^3/annum. A plot of actual recorded abstraction from the dam for irrigation is shown in Figure 3.8.

The other significant water use from the catchment is domestic supply to the town of Gansbaai from the Kraaibosch Dam. Gansbaai have an allocation of 2 x 10^6 m^3/annum but are not fully utilising this allocation. The maximum abstraction to date has been only 0.53 x 10^6 m^3/annum. Figure 3.9 shows the historical abstraction from the dam for Gansbaai.

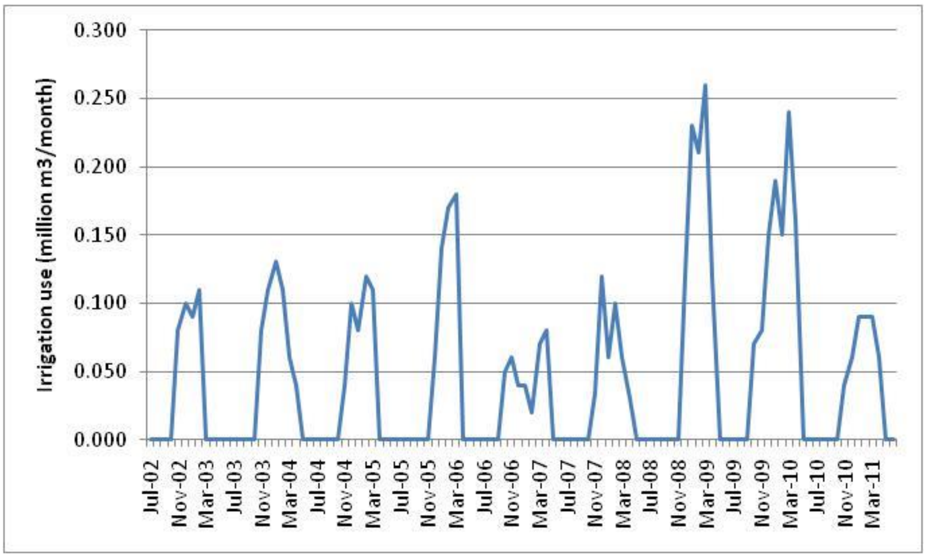


Figure 3.8. Recorded abstraction from Kraaibosch Dam for irrigation

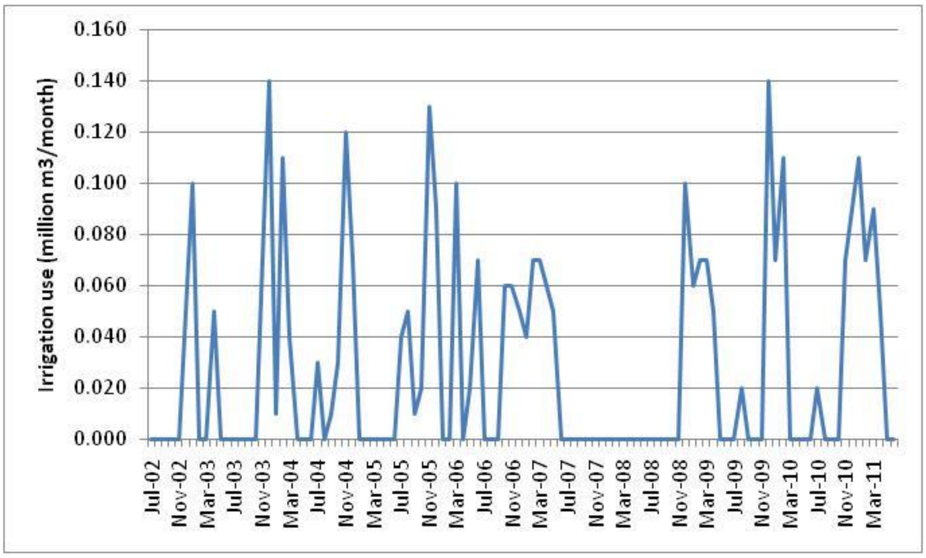


Figure 3.9. Recorded abstraction from the Kraaibosch Dam for Gansbaai

3.2.1.3 Rainfall

There are four rainfall stations in and around the G40M catchment (Figure 3.10 and Table 3.6). However, all of these except 0007263W are now closed. Rainfall data from station 0007263W was obtained from SAWS and used to extend the WR2005 zonal rainfall from 2004 to the end of the 2010 hydrological year (September 2011). It is important to note that this rainfall station is located outside the catchment and therefore poses a source of uncertainty in rainfall estimation. It was therefore only used to extend the rainfall record to 2011 while the original zonal rainfall data from 1920 to 2004 was maintained. Thus, Mean Annual Precipitation (MAP) that was used to generate the rainfall input to the Pitman model was 509mm to be consistent with spatial rainfall record in WR2005 study. The uncertainty in rainfall was therefore compensated by calibrating the model using the observed flow record. It would have been appropriate to use rainfall measurements at the dam site but the rainfall record is only 10 years long and the correlation of this data with other stations is not known. It is therefore recommended that the recording of rainfall at the Kraaibosch Dam continue in order to improve on the hydrological modelling in future.

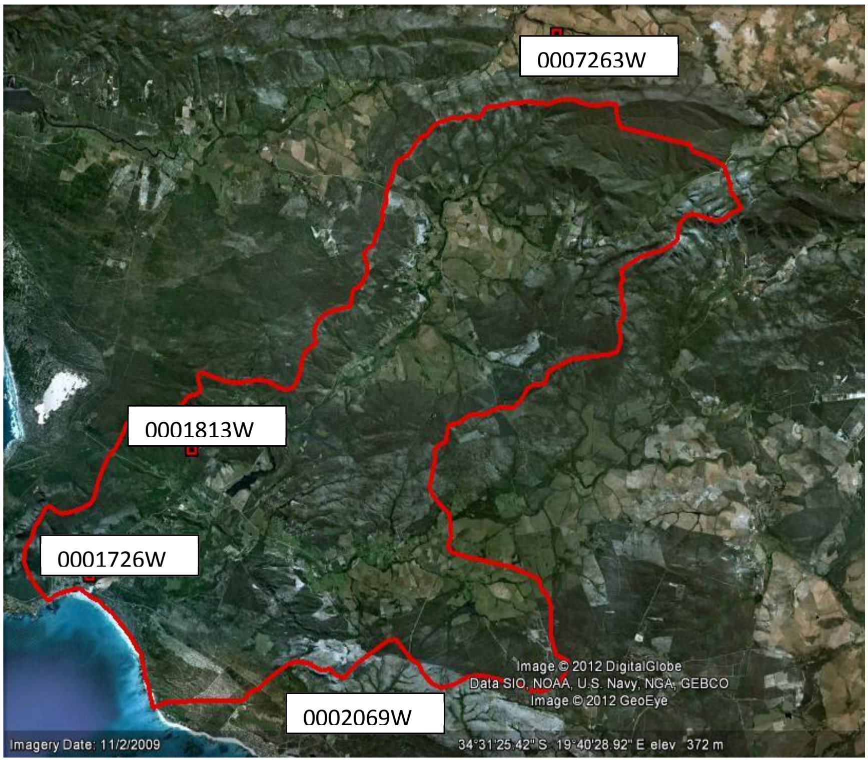


Figure 3.10 Map showing location of rainfall stations

Table 3.6 List of rainfall stations in and around Uilkraals River Catchment

Name	Lat	Long	Start	End	MAP(mm)	Condition
Uilenkraal (0001726W)	$-34^0.36'$	$19^0.25'$	1961	1992	500.6	Closed
Looefontein (0001813W)	$-34^0.33'$	$19^0.28'$	1949	1956	897.7	Closed
Peters Gate (0002069W)	$-34^0.39'$	$19^0.32'$	1943	1978	559.4	Closed
Boskloof (0007263W)	$-34^0.23'$	$19^0.39'$	1933	2011	456	Reliable

3.2.1.4 Model calibration

Following the collection and preparation of all required data to model the Uilkraals River Catchment, the enhanced WRSM2000 model was used to simulate flows for the period 2002 to 2010 in order to calibrate the model. The WR2005 calibration (Pitman) parameters were initially chosen from regional parameter datasets provided in the WR2005 reports (Middelton & Bailey 2009) and then adjusted until the statistics of the simulated flow were similar to the observed flow.

3.2.1.5 Assumptions in model set up

In order to realistically simulate the flows into the estuary the catchment was divided into three sub catchments and assumes:

i. 70% of the G40M catchment flows into the Kraaibosch dam (G40M-1 with area of 220km^2)
ii. The Boesmans River occupied 30% of the G40M catchment (G40M-2 with area of 92.3 km^2). The same parameters determined for the Kraaibosch Dam catchment were used to simulate runoff from this catchment.
iii. The coastal plain has a catchment area of 80.7 km^2. This area is overlain by deep coastal sand dunes and while the actual runoff from this type of terrain is unknown, it can be expected to be lower than the upper reaches of the catchment. In the absence of any data, the assumption was made that the unit runoff from the coastal plain is half that of the upper catchments. This catchment is referred to in Figure 3.11 as G40M-3.

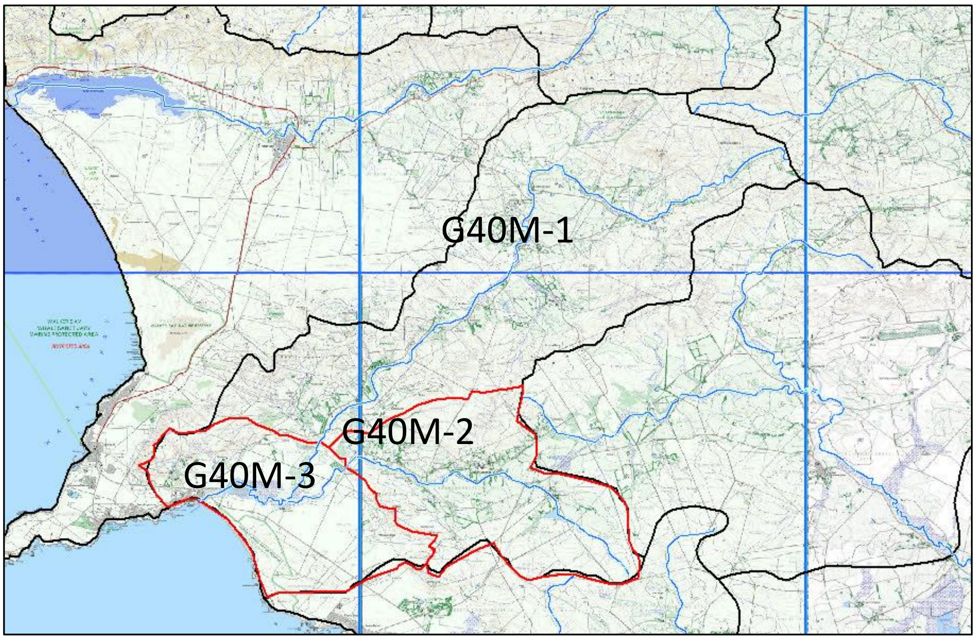


Figure 3.11 Sub-catchments of G40M quaternary catchment.

After the initial model set up with WR2005 parameters the result of the simulation is as presented in Figure 3.12. Clearly the model under simulates the observed flow when using the regional parameters.

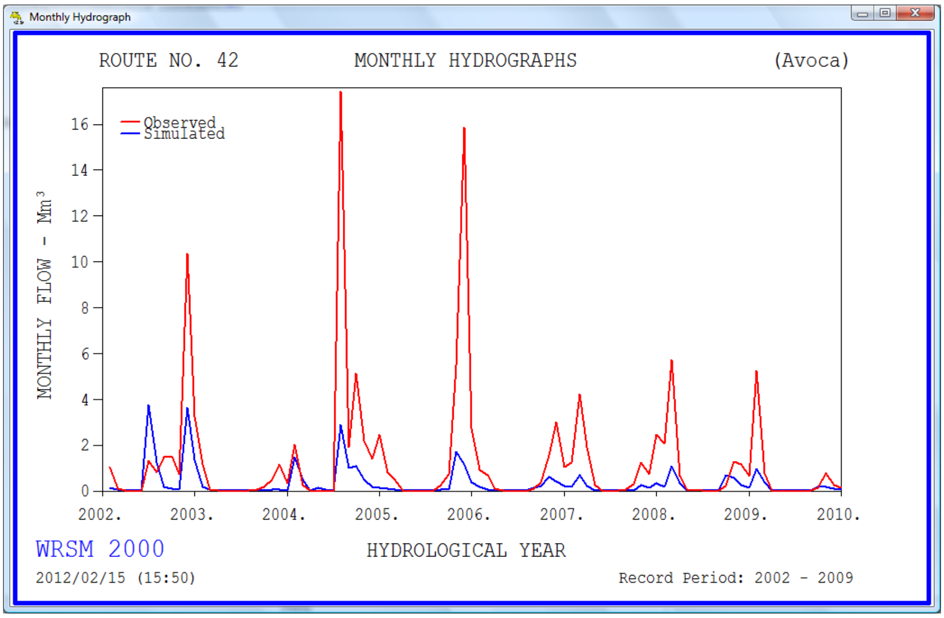


Figure 3.12 Comparison of observed and simulated flow before recalibration

In order to reproduce the observed flows at Avoca weir the following parameters were adjusted:

ST Soil moisture capacity in mm
FT Subsurface flow at soil moisture capacity in mm/month
ZMIN Minimum catchment absorption in mm/month
ZMAX Maximum catchment absorption in mm/month

The calibration was for a period October 2001 to September 2010 and the simulation results are as presented in Table 3.7 and the hydrographs shown in Figure 3.13.

Table 3.7 Calibration statistics

Statistics	Observed	Simulated
MAR (x 10^6 m^3/annum)	15.35	15.42
Mean (Log) (x 10^6 m^3/annum)	1.09	1.05
Std Deviation (x 10^6 m^3/annum)	10.25	10.75
Log Std Dev	0.32	0.44
Seasonal Index (%)	29.72	21.67

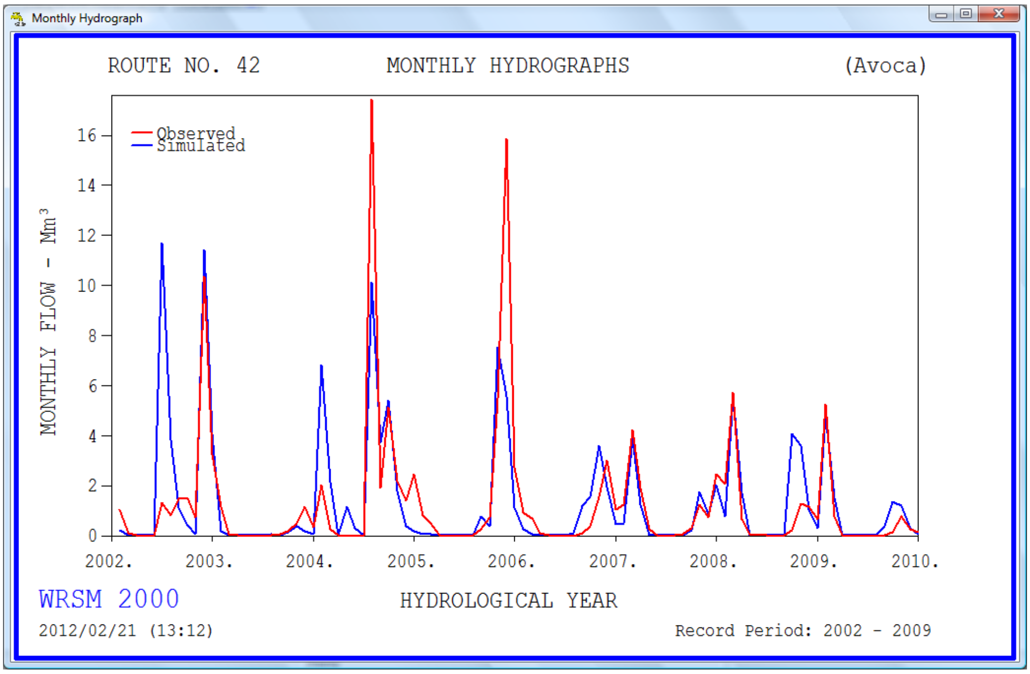


Figure 3.13 Comparison of observed and simulated flow after recalibration observed record at Avoca weir

Table 3.8 presents the incremental natural runoff from the three sub-catchments of Uilkraals River Catchment. The net natural runoff for G40M published in the WR2005 and WR90 studies is 15.4 x 10^6 m^3/annum and 20.8 x 10^6 m^3/annum respectively. This is considerably less than the 36.3 x 10^6 m^3/annum obtained from this study, but it must be borne in mind that this is the first hydrological analysis to make use of the observed data at the Avoco weir to calibrate the Pitman model. Sasman & du Preez (1999) reported that the calculated natural MAR of the Uilkraals River at the dam site is 19.7 x 10^6 m^3/annum which is very similar to the findings of this study.

Table 3.8 Incremental natural simulated runoff from sub-catchments

Sub-catchment	Area (km^2)	Net Incremental MAR (x 10^6 m^3/annum)	Net Unit Runoff (mm)
G40M-1	220.0	21.63	109
G40M-2	92.3	9.27	110
G40M-3	80.7	5.44	67
Total	**393**	**36.34**	-

3.2.2 Scenario modelling

3.2.2.1 Model setup

The Water Resources Modelling Platform (Mallory *et al.* 2010) was set up to simulate various scenarios for the G40M catchment. This model is a monthly time step model using natural incremental hydrology as its basic input. Water use is either incorporated as time series files (specified by the modeller) or (in the case of irrigation) modelled based on crop type, crop area, evapo-transpiration and rainfall. Dams are modelled by assuming a mass balance at each time step taking into account rainfall onto and evaporation from the surface to the dam.

This model also has a module to model stream flow reduction due to invasive alien plants (IAP) (Mallory *et al*. 2011). The survey of IAPs carried out in 2010 by the Agricultural Research Council indicates an area of 89 km^2 in the G40M catchment. The coastal plain (G40M-3) is highly infested with Bloukrantz Wattle while not much IAPs were observed higher in the catchment. It was assumed therefore that the 89 km^2 of IAPs are found primarily in the coastal sub-catchment (G40M3) with the remainder located in the lower reaches of the Boesmans River. The results of this large area of IAPs is that there is probably very little runoff from the coastal area. A systems diagram of the model setup is shown in Figure 3.14.

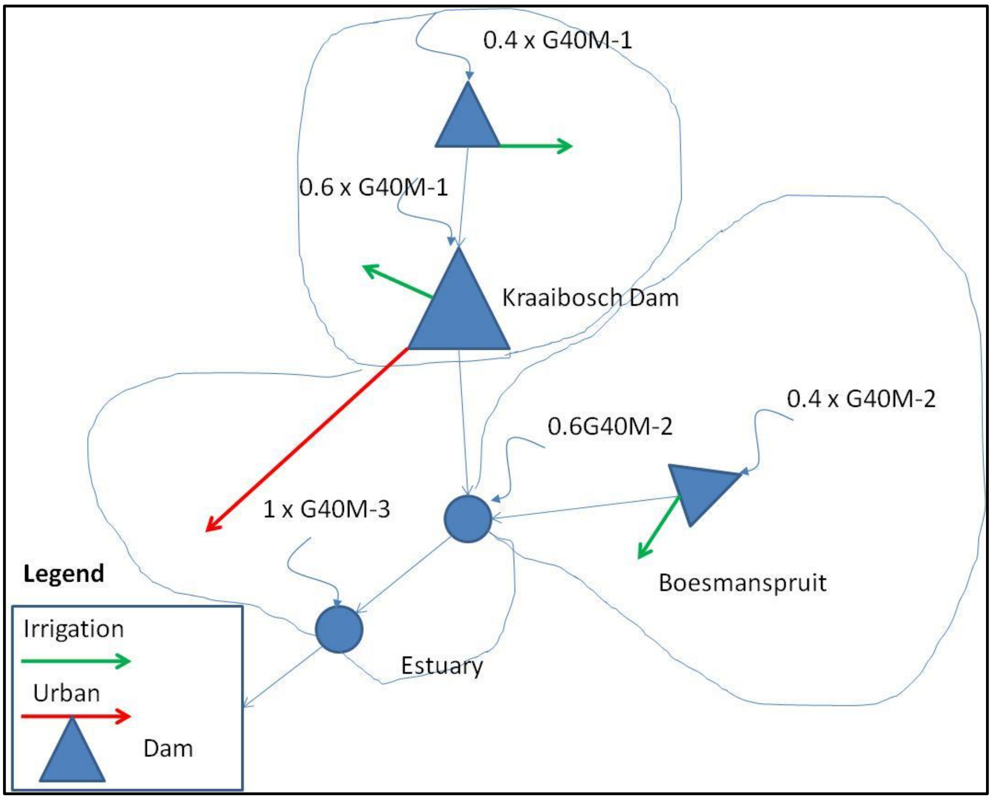


Figure 3.14 Water Resources modelling system diagram

An important consideration when setting up a water resources model is to consider how the dams in the catchment are operated and/or to model the dams in the way they should be operated in order to assess the impact of alternative operating rules. In the case of the Kraaibosch Dam, the records provided by the dam operators indicate that 40% of the inflow into the dam is released out of the dam, probably as an ecological flow. The dam outlet valves are adjusted at least once a week to adapt the release to the inflow.

3.2.2.2 Scenarios

The following scenarios have been modelled to produce monthly time series of flow into the estuary:

1. Natural conditions: Before any development or encroachment of IAPs. This is essentially the sum of the natural incremental flows.
2. Present day conditions: Includes the effect of farm dams, the Kraaibosch Dam, abstractions and IAPs.
3. Full use of allocations: Allocations from the Kraaibosch Dam have not been fully taken up. This scenario increases the abstractions to full allocation.
4. Present day conditions with IAPs removed.

3.2.2.3 Scenario results

The results of these scenarios are summarised in Table 3.9 while time series of flows are shown in Figure 3.15.

Table 3.9 Summary of flows into the estuary under various scenarios (units x 10^6 m^3/annum)

Scenario	MAR	Irrigation		Domestic		IAPs
		Requirement	Supply	Requirement	Supply	
Natural	39.3	0.0	0.0	0.0	0.0	0
Present Day	29.2	4.1	2.6	1.0	1.0	6.1
Full allocation	26.3	6.1	4.7	2.0	1.9	6.1
PD with no IAPs	35.2	4.1	2.6	1.0	1.0	0.0

Figure 3.16 shows that high flows are only moderately influenced by water use in the catchment while low flow is close to zero under natural conditions. Removal of IAPs will have a significant influence on medium to high flows, improving the MAR to the estuary significantly. The duration of low flow period is perhaps of significance and this is shown by means of a duration curve in Figure 3.16 and Figure 3.17.

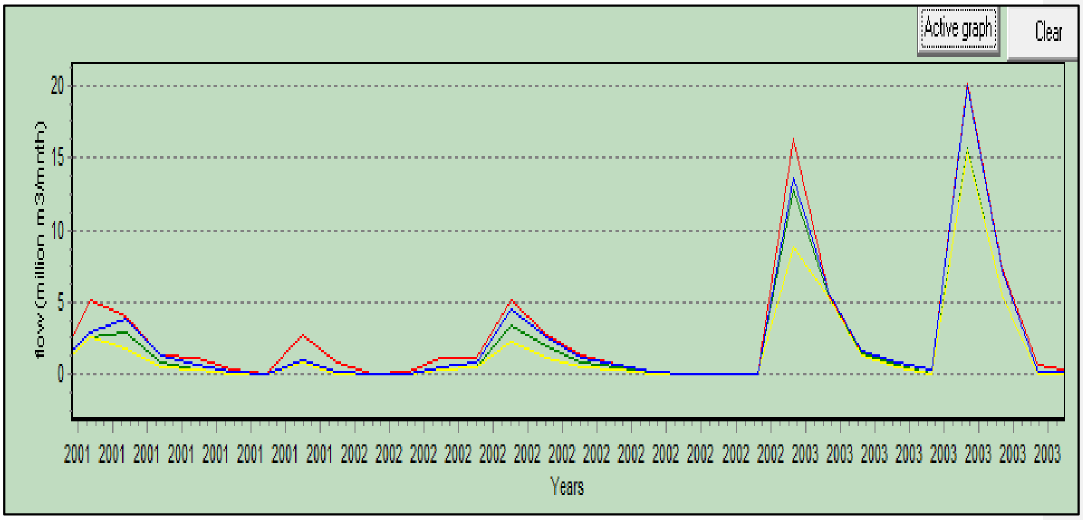


Figure 3.15 **Natural (red), present day (green) and full allocation (yellow) and IAPs removed (blue) flow scenarios**

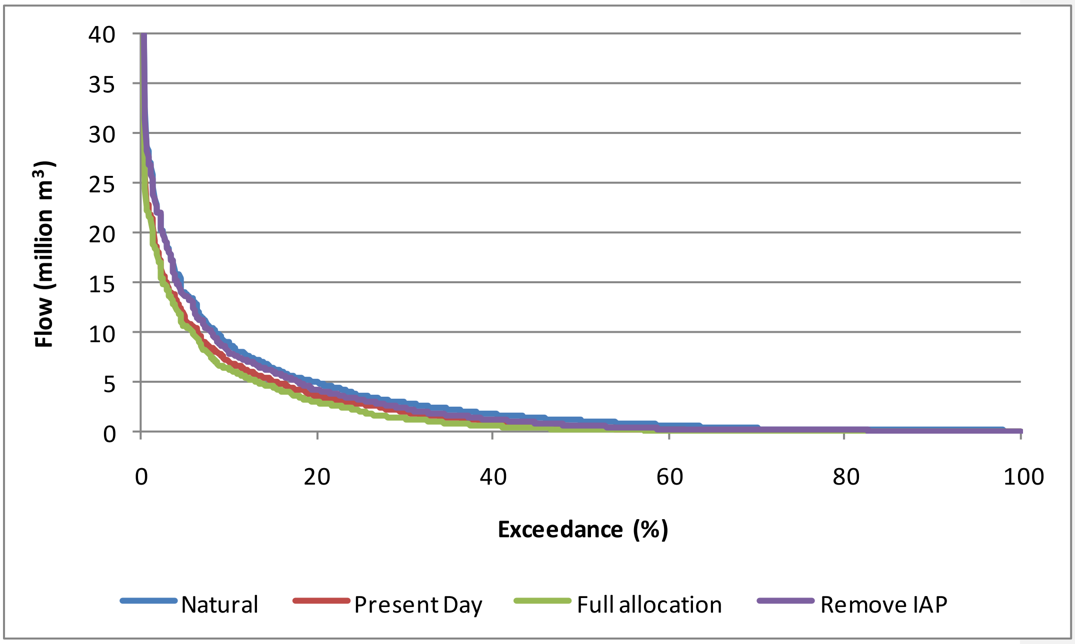


Figure 3.16 **Duration curves of flow at the estuary for four scenarios**

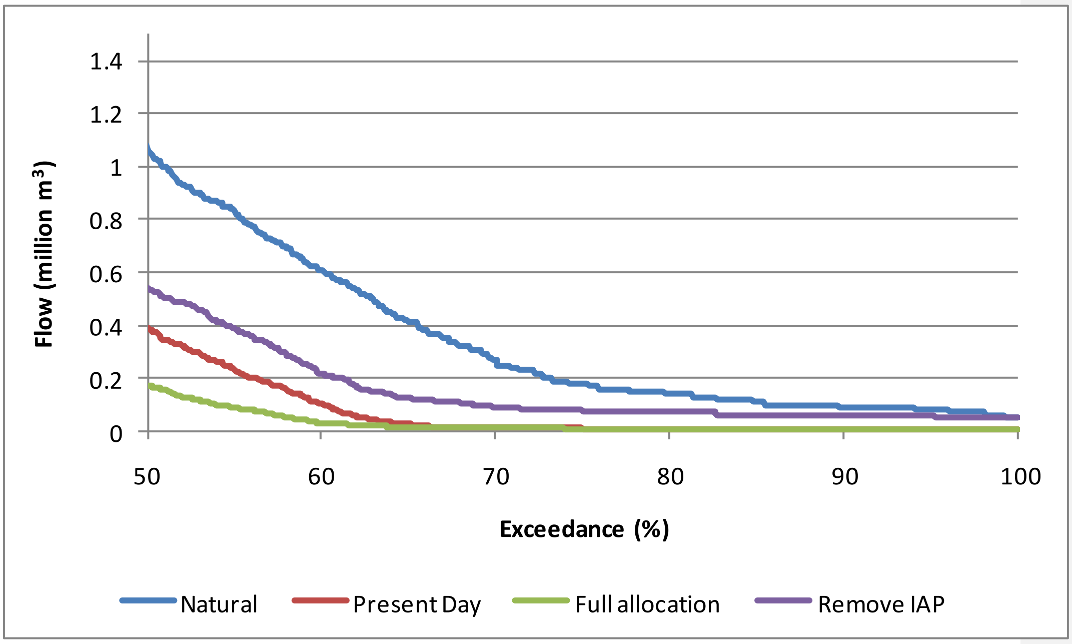


Figure 3.17 Duration curves of flow at the estuary for four scenario (zoomed in to lower flows)

The current developments in the catchment have already led to very low to zero flows at the estuary. This is due largely due to the IAPs in the lower reaches of the catchment and not due to lawful abstractions or the Kraaibosch Dam. Removal of IAPs could improve the low flows from present condition, possibly changing the system from non-perennial to a perennial system.

3.2.3 Flood hydrology

A flood analysis was carried out using the SDF method (Alexander, 2002). The results are summarised in Figure 3.19 while the details of the calculations are given in Appendix B.

Table 3.10 Flood peaks for the G40M catchment

	RECURRENCE (YEARS)					
	2	**10**	**20**	**50**	**100**	**200**
Peak Discharge (Q_T, m^3/s)	58	197	268	370	453	541
Runoff Volume (V_T, '000m^3)	2 816	9 628	13 082	18 070	22 152	26 424

3.2.4 Present hydrological health

The present day flood regime is judged to be very similar to the reference and the dams in the catchment are relatively small and the Kraaibosch Dam is never drawn down completely.

Months in which low flows could occur increased from 38% under Reference to 53% under Present State.

This score is calculated on the basis of the extent to which current inflow patterns resemble those of the Reference state, estimated on the basis of two parameters, as in Table 3.11: (a) general inflow patterns, highlighting the changes in low flows, and (b) the frequency and magnitude of flood events. The relative weighting of these two parameters (60:40) is set according to their assumed importance as drivers of the estuarine system. This may be altered a priori for particular systems, with justification.

Table 3.11. Calculation of the hydrological health score, giving examples in italics

Variable	Score	Motivation	Conf
a.% Similarity in period of low flows OR present MAR as a % of MAR in the Reference condition	7	Average monthly flow in 35% of months with lowest flows is 7% of that in the reference condition.	VL
b.% Similarity in mean annual frequency of floods	95	The dams in the catchment are relatively small and the Kraaibosch Dam is never drawn down completely. It is therefore estimated that the floods are very similar to present. This is an expert estimate.	L
Hydrology score	25		

3.3 Physical habitats

3.3.1 Available information on bathymetry and sediments

There is little data on the sediments or historical sedimentation processes of the Uilkraals estuary. Estuaries contain a mixture of river and marine sediments, the balance of which is determined by the amount of water moving in and out of the estuary during a tidal cycle, riverine base flows and floods. Historically the Uilkraals estuary was seen as a relative sandy system (Heydorn & Bickerton 1982). From the mouth to just upstream of the bridge, sediments consist of predominantly of quartz and shell fragments indicating a marine origin. The upper reaches displayed a thin layer of fine-grained sand overlying mud in March 1981, judged to be caused by catchment erosion. In the past, the middle and upper reach may also have received more fine blown wind sand from the adjacent dune field that was stabilised in the 1970s. The bridge has also caused some infilling in the middle reaches as a result of the construction process, and a subsequent decrease in flow velocities in this area. An aerial photograph analysis indicated that the channel configuration and mouth position is also significantly more stable since the construction of the bridge (Crowther 1988).

In 1988, surface sediments in the estuary consisted mainly of fine sand with a very narrow size range (Crowther 1988). The presence of fine sediment in the estuary are indicative of deposition under very low energy conditions. Coarser sands and pebble/shell lag deposits were limited to a small area on the right bank mostly around the bridge indicating high energy conditions in the vicinity of the bridge caused by constrictions (Figure 3.18). Upstream of the bridge, coarser mean sediments size may have resulted from higher flow events scouring away finer material (Crowther 1988). Well sorted areas generally corresponded to areas with fine sand and moderated sorted areas corresponded to larger mean grain sizes associated with the channels and the bridge. Crowther (1988) associated the well sorted material were with wind blow and marine sediments. He also indicated that the bridge may have reduced the amount of wind-blown sediment that can reach the upper part of the estuary. Core logs of the upper 5 m of sediment also consisted mainly of unstratified fine sand and lesser lag deposits which consisted of varying amounts of pebble and shell material (Crowder 1988). The fine sand was frequently interspersed with fine pebbles and shell material. Laminated mud and mud balls were also infrequently present. The core consisted mainly of fine sand (2 to 3 phi) which reflects low to medium energy conditions of deposition in the upper 5 m.

In 1997 and 1999, topographical surveys were done by the CSIR of the Uilkraals Estuary mouth using a 'wading survey' technique, which was performed using standard line surveying techniques. A survey team member walked the survey lines holding a rod supporting a surveying prism, and stopped at appropriate intervals to allow an instrument operator to read and record the distance and horizontal and vertical angles. The wading survey was continued seaward into the water until the rod holder could no longer stand steady with the survey rod. The land section was done preferably at low tide so that readings could extend as far seaward as possible. The electronic surveying instrument provided distance measurement accuracies of 5 mm. The angle measurements were done with an electronic single second theodolite.

The data indicate that very little change took place between 1997 and 1999. The surveys clearly show how shallow the system was, with areas above the bridge measured between 0.0 and 0.5 m

MSL on average. The lower reaches between the bridge and the mouth displayed some deeper areas measured between 0.0 and -0.8 m MSL.

Some sedimentation may have occurred in the lower reaches in the last two decades due to the reduction in river inflow causing the marine sediment to start accumulating in the lower reaches. The bridge is also likely to have caused a reduction in tidal flows which also may have led to increases in marine sediment in the lower reaches (Crowther 1988). While no accurate topographical data exist for the upper reaches of the estuary, field studies in 2010 indicated that the upper reaches had some deeper areas between 1 and 2 m deep.

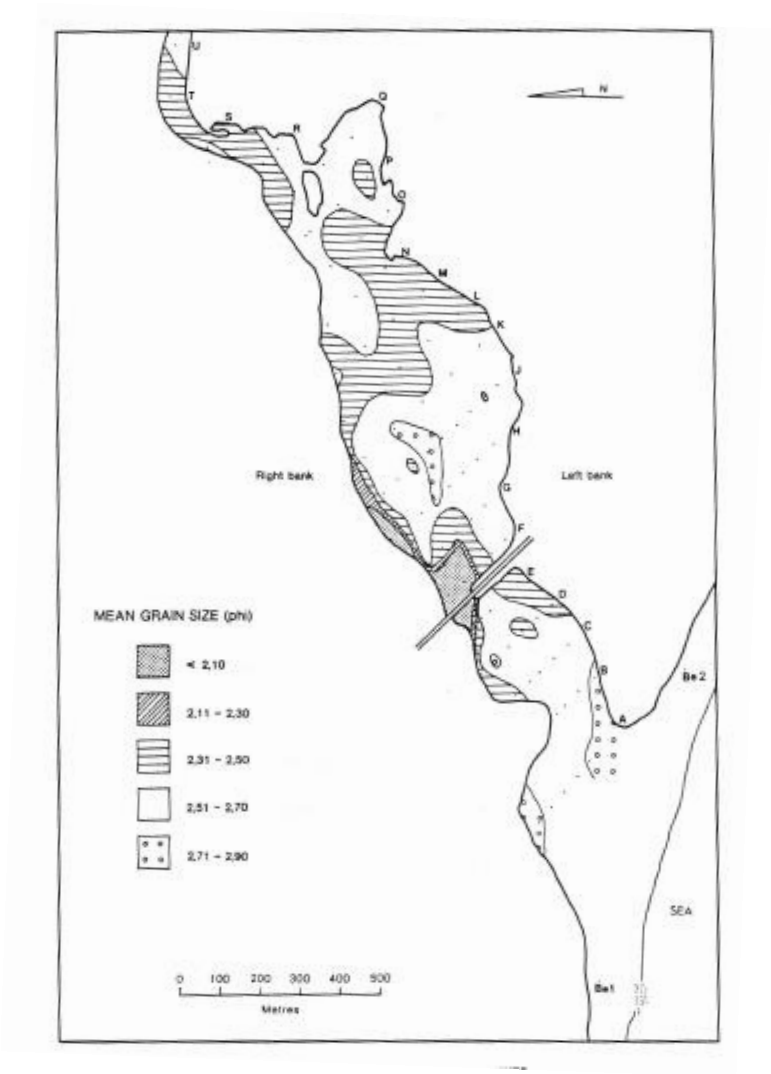


Figure 3.18. Mean grain size distribution of surface sediments in the Uilkraals estuary (Source: Crowther 1988).

2011 Closed mouth with extensive inundation of intertidal and flood plain area (Source: S Mathews)

2012 Closed mouth with low water levels due to evaporation (Source: S Mathews)

2012 Closed mouth and exposed in mouth region (Source: S Mathews)

2012 Closed mouth and exposed down stream from bridge (Source: S Mathews)

2012 Closed mouth and exposed up stream from bridge (Source: S Mathews)

2012 Closed mouth and exposed in upper reaches (Source: S Mathews)

Figure 3.19. Photographic record of water levels in the Uilkraals Estaury during the closed state

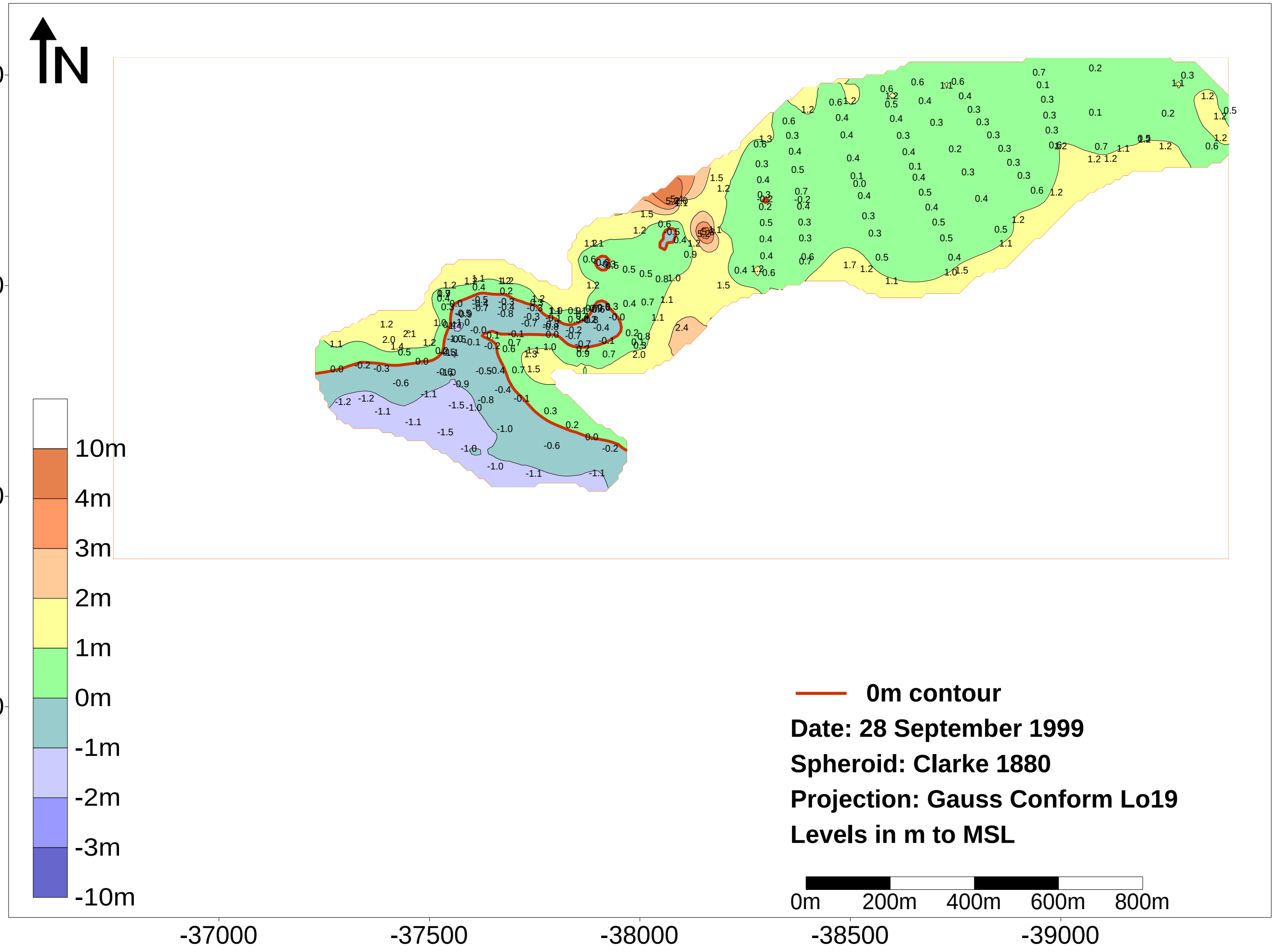


Figure 3.20. Bathymetry map of the Uilkraals estuary in 1999.

3.3.2 Physical habitat health

Estuarine sediment processes operate at different scales from hydrodynamic, biogeochemical and biological processes. Accretion and erosion of subtidal areas (also reflected as changes in volume) can occur at daily to monthly time scales, whereas intertidal areas may vary over seasonal to decadal time scales. Supratidal process cycles tend to be at even longer time scales as it requires major resetting events to reset or reconfigure these areas, typically linked to 1:20 year or larger events. Coastal development also tends have different impacts on the different habitat types and therefore needs to be assessed separately.

To provide context to present ecological health of an estuary, and future trajectories of change, the physical habitat of an estuary is disaggregated into is four principal physical habitat types and described below.

Table 3.12. Calculation of the physical habitat score and adjusted score (net of non-flow impacts).

Variable		**Change from natural**	**Score**	**Conf**
a	Supratidal area	Stabilisation of dune field and unconsolidated sediment in middle and upper reaches has led to a much more stable system in upper and middle reaches. Significant infilling of the supratidal area has occurred near bridge and caravan park	60	L
b	Intertidal area	Some infilling of the intertidal area has occurred, near bridge and caravan park, but most of the loss of **functional** intertidal area is due to the loss of open mouth conditions.	40	L
c	Subtidal area	Due to the sand trapping of the Kraaibosch dam, poor agricultural practises and stabilisation of dune field the upper reaches may be muddier, but the middle and lower reaches are still very similar to reference conditions.	70	L
d	Water column volume	Loss of subtidal area in middle reaches due to the obstruction the bridge present to flow. Slightly more stable system due to loss of some resetting events. Loss of baseflows and reduction in floods seem to have caused some infilling in lower reaches in mouth area.	80	L
Physical habitat score[1]			**51**	
% of impact due to non-flow factors			30	
Adjusted score			66	

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

3.4 Hydrodynamics and abiotic states

3.4.1 Mouth condition

Anecdotal records of the Uilkraals Estuary mouth state (provided by A Roux, S Mathews and B Clark) indicate that the estuary has closed five times since 2008 (Figure 3.21). No record exists of any closures before this time. The mouth first closed on 22-23 December 2008, for a few days. It then closed in January 2009 for about six months before being breached illegally. By the following December (2009) it closed again, and it was not until 23 October 2010 that it was opened again, this time by the Overstrand Municipality. It closed soon after, in December 2010, and was illegally opened several months later on 5 July 2011. It closed again on 12 October 2011, and was still closed at the time of writing this report (May 2012).

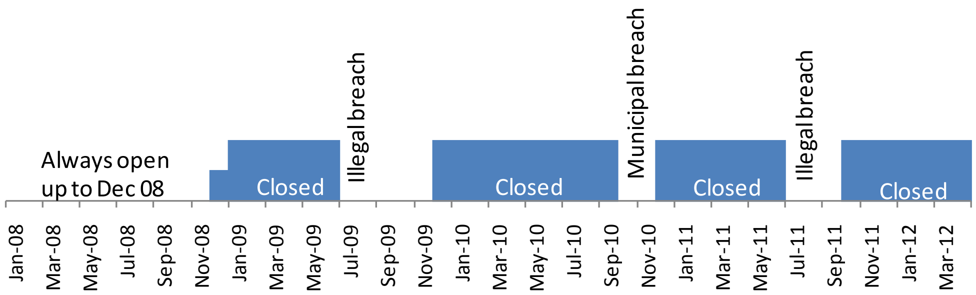


Figure 3.21. Summary of Uilraals Estuary mouth state

Superimposing the mouth state observational data on the present state simulated monthly flows (Table 3.13) indicates a high sensitivity to low flows, but as no continuous water level data exists, it is not clear at which flow ranges the estuary closes. What is clear is that the current base flow allocation is not sufficient to maintain an open mouth. In addition, artificial breaching of the system prevents accurate assessment of the duration of mouth closure. For this study it is assumed that the estuary mouth will be breached as soon as water levels become high enough to facilitate a breaching.

Table 3.13. Simulated monthly flows versus mouth State

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2007/8	0.295	1.609	0.127	0.004	0.004	0.004	0.004	0.007	0.054	0.459	0.250	0.791
2008/9	0.250	2.431	0.396	0.004	0.004	0.004	0.004	0.011	1.350	1.837	0.620	0.100
2009/10	2.106	0.374	0.004	0.004	0.004	0.004	0.004	0.037	0.316	0.325	0.082	0.012
2010/11	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.086	0.185	0.101	0.269	0.073

The Uilkraals mouth is relatively sheltered and measurements undertaken by Ed Lucas and Sue Mathews indicate a berm height of 1.91 to 1.98 m amsl on 9 October 2010.

All available historical aerial photographs of the Uilkraals estuary show the mouth in an open state (Figure 3.22-Figure 3.26).

Figure 3.22. The Uilkraals estuary in 1938 with open mouth and relatively deep meandering channels in the middle reaches

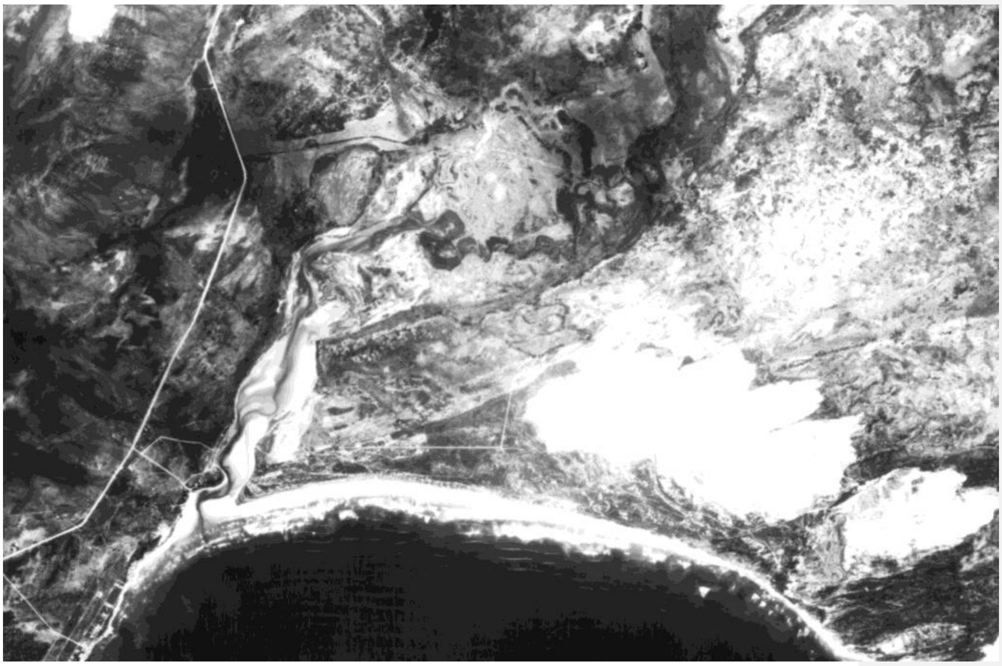


Figure 3.23. The Uilkraals estuary in 1961 with open mouth and relatively deep meandering channels in middle reaches. Note unstablised dune field on eastern side of system.

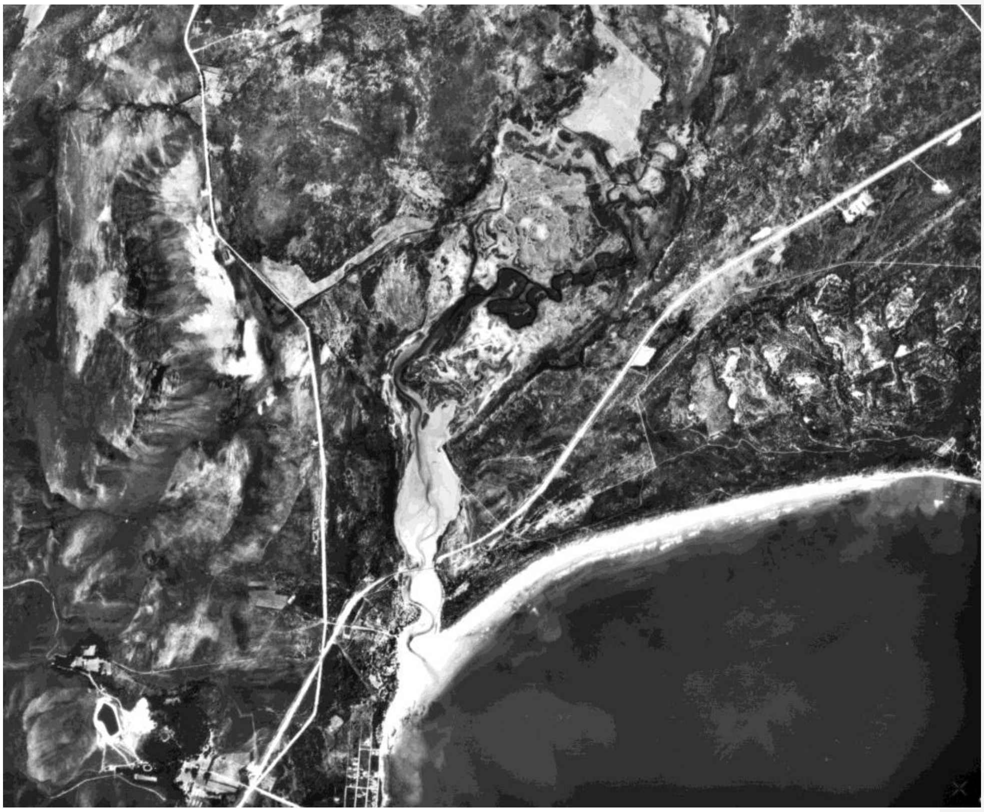


Figure 3.24. The Uilkraals Estuary in 1973 with open mouth. Note the road bridge over the middle reaches.

Figure 3.25. Uilkraals Estuary in 1990 with open mouth and relatively deep meandering channels in the middle reaches

Figure 3.26. The Uilkraals estuary in November 2005 with open mouth and relatively shallow meandering channels in the middle reaches.

3.4.2 Typical abiotic states

Based on available literature, three distinct 'states' can be identified for the Uilkraals Estuary, related to mouth condition, tidal exchange, salinity distribution and water quality (Table 3.14). These are primarily determined by river inflow patterns, state of the tide and wave conditions. The transition between the different states may not always take place gradually and may occur within a few hours.

Table 3.14. Summary of the abiotic states, and associated hydrodynamic characteristics, that can occur in the Uilkraals Estuary

PARAMETER	State 1: Closed	State 2: Open, tidally dominated	State 3: Open, fluvially dominated
Flow range ($m^3.s^{-1}$)	>3.0	0.03 – 3.0	<0.03
Mouth condition	Closed	Open	Open
Water level (m to MSL)	2.5 m MSL ?	<1.5 m MSL	1.5 m MSl
Inundation	Inundation of flood plain when full	None	Inundation of flood plain
Tidal range	None	1.0 m	1.0 m
Dominant circulation process	Wind	Tide	River
Retention	Duration of closed period	< 1 week	<0.5 day

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:

- Summary tables of the occurrence of different flows at increments of the 10%ile are listed separately to provide a quick comprehensive overview; and
- Colour coding (indicated above) was used to visually highlight the occurrence of the various abiotic states under different scenarios.

3.4.3 Present distribution of abiotic states

The occurrences of flow distributions (mean monthly flows in m^3s^{-1}) for the present state of the Uilkraals Estuary, derived from the 90-year simulated data set, are provided in Table 3.15. A graphic representation of the occurrence of the various abiotic states is presented in Figure 3.27. The 90-year series of simulated monthly runoff data for the present state is provided in Table 3.16.

Table 3.15. Summary of the monthly flow (in m3/s) distribution under the present state

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	7.788	7.551	3.288	2.783	2.224	4.090	5.990	7.957	8.399	7.945	11.145	7.089
90%ile	2.106	2.431	0.482	0.004	0.157	0.302	2.052	2.621	3.677	4.824	5.373	2.508
80%ile	1.034	1.019	0.019	0.004	0.004	0.067	0.756	1.829	2.743	2.931	3.875	1.867
70%ile	0.564	0.166	0.004	0.004	0.004	0.004	0.301	1.008	1.844	2.024	2.449	1.667
60%ile	0.370	0.073	0.004	0.004	0.004	0.004	0.166	0.556	1.173	1.523	1.725	1.150
50%ile	0.254	0.027	0.004	0.004	0.004	0.004	0.077	0.325	0.856	1.146	1.348	0.756
40%ile	0.146	0.008	0.004	0.004	0.004	0.004	0.023	0.175	0.459	0.892	1.083	0.586
30%ile	0.090	0.008	0.004	0.004	0.004	0.004	0.012	0.127	0.355	0.635	0.653	0.401
20%ile	0.060	0.004	0.004	0.004	0.004	0.004	0.004	0.063	0.185	0.455	0.433	0.231
10%ile	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.011	0.077	0.295	0.250	0.100
1%ile	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.015	0.026	0.055	0.015

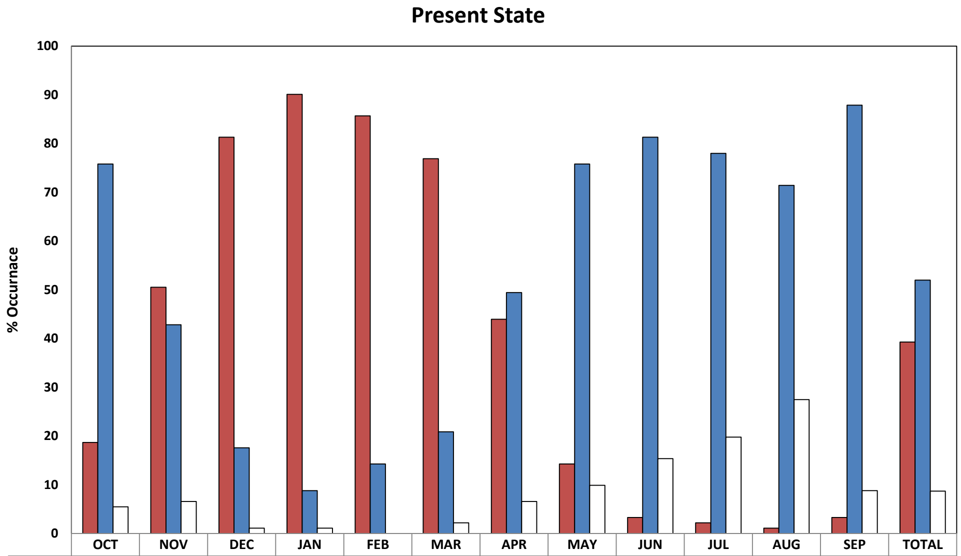
Table 3.16. Simulated monthly flows (m^3/s) under present state

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.004	0.004	0.019	0.004	0.054	0.004	0.004	0.004	8.395	2.804	0.840	1.705
1921	0.235	0.004	0.011	1.284	0.265	0.646	0.166	0.063	1.038	0.362	0.538	0.127
1922	0.015	3.970	0.810	0.004	0.004	0.004	3.368	4.648	2.758	1.781	1.004	0.644
1923	0.302	1.019	0.019	0.004	0.004	0.007	0.012	0.004	1.173	0.818	4.297	1.856
1924	0.246	3.094	0.560	0.004	0.004	0.004	0.004	0.004	3.032	1.430	1.146	0.293
1925	0.586	0.066	0.004	0.004	0.004	0.004	0.004	0.175	0.397	4.570	2.177	0.424
1926	8.527	2.558	0.004	0.004	0.004	0.004	0.004	0.523	0.231	0.060	0.941	0.320
1927	0.007	0.073	0.004	0.004	0.004	0.004	0.004	0.004	0.409	0.153	0.306	0.930
1928	0.112	0.270	0.004	0.004	0.004	0.030	0.085	0.131	0.127	2.785	1.236	0.066
1929	0.007	0.054	0.004	0.004	0.066	0.317	0.228	0.762	0.417	0.306	1.437	2.087
1930	0.553	0.193	0.004	0.004	0.004	0.004	2.191	1.034	0.096	1.258	1.822	0.783
1931	2.270	0.386	0.004	0.004	0.157	0.004	0.004	0.665	1.370	0.885	0.444	6.914
1932	2.109	0.008	0.004	0.004	0.004	0.004	0.004	0.161	2.095	1.568	1.542	0.513
1933	0.075	0.008	0.004	0.004	0.004	0.004	0.085	0.325	0.185	0.549	3.080	1.809
1934	0.414	0.008	0.004	0.004	0.004	0.004	0.552	1.277	1.150	14.699	24.825	7.076
1935	0.112	0.255	0.004	0.105	0.004	0.004	0.104	0.452	0.355	0.403	0.433	0.602
1936	0.097	1.458	0.620	0.004	0.004	0.015	0.019	0.011	2.766	5.332	1.557	1.682
1937	0.597	0.012	0.004	0.004	0.004	0.067	0.077	0.556	0.525	1.068	1.594	4.209
1938	1.292	0.054	0.004	0.004	0.004	0.067	0.147	0.127	0.054	1.184	3.875	1.323
1939	0.482	0.042	0.004	0.004	1.050	0.381	2.654	0.989	2.342	1.068	0.217	0.104
1940	0.119	1.308	0.235	0.388	0.004	0.004	2.971	4.790	4.637	1.964	1.348	3.256
1941	1.072	0.116	0.004	0.004	0.004	0.004	0.004	1.404	1.597	0.358	0.325	0.532
1942	0.060	0.004	0.138	3.935	1.186	0.284	0.556	0.877	0.386	0.657	1.083	0.424

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1943	0.306	5.316	1.370	0.004	0.004	0.004	0.004	2.587	7.176	2.098	3.603	7.207
1944	1.815	0.008	0.004	0.004	0.004	0.004	0.177	10.148	8.430	4.824	5.619	1.640
1945	5.167	1.647	0.004	0.004	0.004	0.343	0.143	0.067	0.158	0.190	0.269	1.026
1946	0.612	0.008	0.004	0.004	0.004	0.093	0.208	0.485	0.760	5.156	1.908	0.617
1947	0.284	0.058	0.004	0.004	0.004	0.351	0.301	0.097	0.394	1.113	0.373	0.633
1948	7.706	2.450	0.004	0.004	0.004	0.004	0.922	1.829	0.656	0.508	1.072	0.525
1949	0.007	1.265	0.112	0.004	0.004	0.004	0.397	0.175	0.054	3.159	1.217	1.150
1950	0.392	2.527	0.568	2.255	0.599	0.004	0.826	0.605	8.356	6.444	4.570	6.076
1951	1.493	0.008	0.004	0.004	0.004	0.004	0.015	0.388	0.509	1.639	5.261	2.373
1952	0.833	3.738	0.799	0.004	0.012	0.004	1.026	0.694	0.367	2.259	0.971	0.100
1953	0.108	0.166	0.004	0.004	0.004	0.004	0.112	7.714	3.677	5.156	8.322	2.326
1954	0.063	0.008	0.004	0.004	2.261	0.758	0.046	0.037	2.593	2.931	5.511	1.844
1955	1.034	0.050	0.004	0.004	0.004	0.004	0.035	2.061	2.743	1.146	1.523	0.586
1956	0.194	0.008	0.004	0.004	0.004	0.019	0.042	4.902	8.295	3.793	5.604	2.546
1957	4.484	1.092	0.004	0.004	0.004	0.112	0.559	5.193	2.311	0.295	4.129	1.412
1958	0.258	0.008	0.004	0.004	0.004	0.004	0.629	2.531	0.910	0.564	3.984	1.829
1959	0.900	0.035	0.004	0.004	0.004	0.004	0.015	0.041	0.421	0.635	0.407	0.127
1960	0.090	0.004	0.004	0.004	0.004	0.004	0.039	0.093	0.081	0.538	3.129	1.902
1961	0.370	0.004	0.004	0.004	0.004	0.142	0.421	0.205	3.461	1.408	6.489	2.303
1962	2.602	1.042	0.004	0.004	0.004	0.004	0.004	0.015	0.197	1.523	4.148	1.200
1963	0.007	0.004	0.004	0.004	0.004	0.004	0.027	0.041	2.596	2.173	2.445	1.022
1964	0.030	0.008	0.004	0.004	0.004	0.004	0.027	0.254	0.131	0.351	0.198	0.019
1965	0.134	0.004	0.004	0.004	0.004	0.004	0.023	0.026	0.012	0.131	0.653	0.718
1966	0.198	0.004	0.004	0.004	0.004	0.004	5.432	2.095	1.921	1.001	0.978	0.571
1967	0.261	0.008	0.004	0.004	0.004	0.004	0.004	0.246	1.161	0.945	1.023	0.401
1968	0.183	0.004	0.004	0.004	0.004	0.004	0.552	0.220	1.400	0.635	0.175	0.054
1969	0.019	0.004	0.004	0.004	0.004	0.004	0.004	0.071	1.003	1.826	3.136	1.238
1970	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.101	0.285	2.024	5.373	1.867
1971	0.463	0.023	0.004	0.004	0.004	0.004	1.181	1.281	1.130	0.728	4.648	1.840
1972	0.063	0.004	0.004	0.004	0.004	0.004	0.004	0.146	0.077	0.784	0.515	0.309
1973	0.075	0.004	0.004	0.004	0.004	0.004	0.008	1.008	0.752	0.243	8.531	4.174
1974	0.993	0.081	0.004	0.004	0.004	0.004	0.004	1.008	0.814	1.773	3.805	1.208
1975	0.190	0.008	0.004	0.004	0.004	0.004	0.397	0.213	5.988	3.450	1.284	0.818
1976	0.119	1.377	0.295	0.004	0.161	0.041	0.012	2.270	2.562	5.589	2.449	0.760
1977	0.254	0.008	0.258	0.004	0.004	0.004	0.189	0.123	0.104	0.403	2.024	0.849
1978	0.358	0.100	0.004	0.004	2.220	0.702	0.015	1.486	0.799	1.142	1.725	0.756
1979	0.392	0.008	0.004	0.004	0.004	0.004	0.008	0.131	0.976	0.530	0.190	0.069
1980	0.007	0.324	0.004	2.655	1.038	0.302	1.493	0.511	0.193	2.516	3.875	1.736
1981	0.302	0.096	0.004	0.004	0.004	0.004	1.694	0.844	0.856	0.455	0.187	0.093
1982	0.007	0.004	0.004	0.004	0.517	0.134	0.174	3.315	3.410	4.036	1.572	1.667
1983	0.515	0.008	0.004	0.004	0.004	0.004	0.004	2.621	1.408	0.511	0.489	0.532
1984	1.109	27.662	8.486	0.004	0.041	0.131	0.756	0.310	0.042	7.195	2.994	0.316
1985	0.777	0.054	0.004	0.004	0.004	0.078	0.066	0.011	0.367	0.892	9.625	3.438
1986	0.146	0.008	0.004	0.004	0.004	0.007	1.335	1.363	2.936	1.146	1.576	2.025
1987	0.511	0.004	0.004	0.004	0.004	0.004	0.197	0.112	1.844	1.195	2.277	1.204
1988	0.635	0.027	0.004	0.004	0.004	4.010	4.051	1.042	0.980	4.029	3.159	2.508
1989	1.740	0.123	0.004	0.004	0.004	0.004	3.438	2.363	6.339	2.031	0.433	0.150
1990	0.071	0.004	0.004	0.004	0.004	0.004	0.019	0.276	0.679	6.321	2.098	0.185
1991	1.355	0.220	0.004	0.004	0.004	0.004	0.127	0.530	1.377	1.154	1.135	1.601
1992	1.374	0.089	0.004	0.004	0.025	0.049	11.007	3.935	3.106	4.992	1.736	0.262
1993	0.007	0.004	0.004	0.004	0.004	0.004	0.872	0.556	6.998	2.539	0.433	0.231
1994	0.075	0.004	0.004	0.004	0.004	0.004	0.027	1.027	1.188	0.825	1.381	0.413
1995	0.078	0.077	0.482	0.004	0.004	0.004	0.015	0.011	0.258	3.065	1.146	0.602
1996	3.222	3.144	0.575	0.004	0.004	0.004	0.278	2.240	2.265	0.586	0.347	0.185
1997	0.007	0.004	0.004	0.004	0.004	0.004	0.135	3.450	1.586	0.299	0.258	0.120
1998	0.007	0.166	2.711	0.508	0.004	0.004	0.274	0.146	0.035	0.026	0.015	2.137
1999	0.564	0.004	0.004	0.004	0.004	0.004	0.023	0.011	0.015	0.821	0.612	0.752
2000	0.075	0.004	0.004	0.004	0.004	0.004	0.004	0.056	0.015	0.960	1.086	0.293
2001	0.123	0.008	0.004	0.325	0.029	0.004	0.004	0.146	0.216	1.273	0.713	0.305
2002	0.164	0.004	0.004	0.004	0.004	4.809	2.052	0.534	0.243	0.022	5.847	2.126

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2003	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.007	0.039	0.101	0.060	0.015
2004	2.285	0.741	0.004	0.090	0.004	0.004	4.460	1.848	2.897	0.986	0.235	0.050
2005	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.149	0.116	3.181	2.946	0.718
2006	0.041	0.012	0.004	0.004	0.004	0.004	0.004	0.269	0.459	1.609	1.098	0.289
2007	0.295	1.609	0.127	0.004	0.004	0.004	0.004	0.007	0.054	0.459	0.250	0.791
2008	0.250	2.431	0.396	0.004	0.004	0.004	0.004	0.011	1.350	1.837	0.620	0.100
2009	2.106	0.374	0.004	0.004	0.004	0.004	0.004	0.037	0.316	0.325	0.082	0.012
2010	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.086	0.185	0.101	0.269	0.073

State 1	<0.03	State 2	0.03-3.0	State 3	>3.0



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	18.7	50.5	81.3	90.1	85.7	76.9	44.0	14.3	3.3	2.2	1.1	3.3	39.3
State 2	75.8	42.9	17.6	8.8	14.3	20.9	49.5	75.8	81.3	78.0	71.4	87.9	52.0
State 3	5.5	6.6	1.1	1.1	0.0	2.2	6.6	9.9	15.4	19.8	27.5	8.8	8.7

Figure 3.27. Percentage occurrence of the various abiotic states under present conditions.

3.4.4 Abiotic states under the Reference Condition

According to the hydrological data provided for this study, under the Reference condition the MAR into the Uilkraals Estuary was 39.3 x 10^6 m^3. The flow distributions (mean monthly flows in m^3/s) under the Reference condition, derived from a 90-year simulated data set are provided in Table 3.17). A graphic representation of the percentage occurrence of the various abiotic states is presented in Figure 3.28. The 90-years of simulated monthly runoff data under the Reference condition are provided in Table 3.18.

Table 3.17. Summary of the monthly flow (in m^3/s) distribution under the Reference Condition

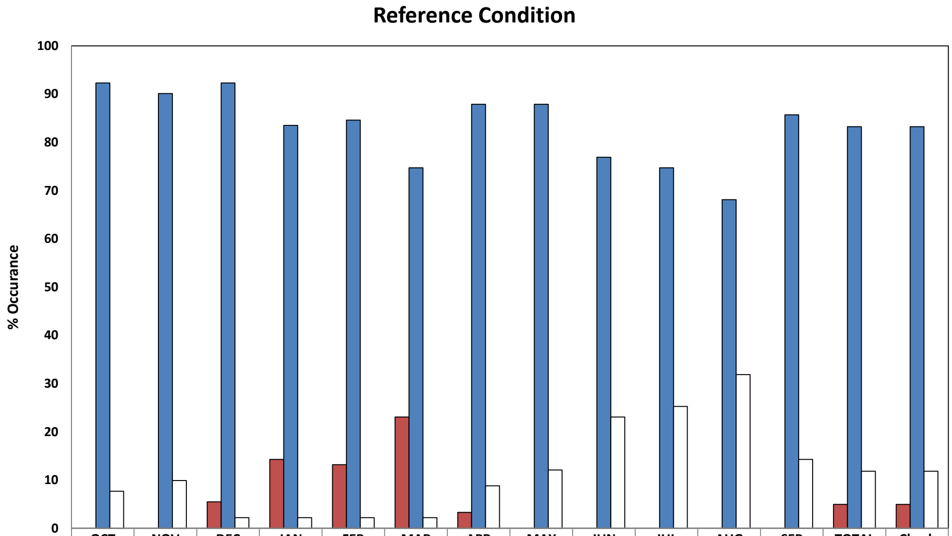
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99%ile	9.250	8.713	4.133	3.528	3.073	5.267	7.267	9.707	10.485	9.526	14.133	9.007
90%ile	2.524	2.886	0.918	0.317	0.405	0.605	2.662	3.674	4.344	6.369	6.903	3.152
80%ile	1.310	1.215	0.317	0.123	0.194	0.306	1.181	2.024	3.279	3.543	4.865	2.407
70%ile	0.799	0.559	0.217	0.067	0.079	0.119	0.667	1.322	2.218	2.599	3.215	2.018
60%ile	0.650	0.394	0.105	0.056	0.050	0.060	0.370	0.930	1.628	1.897	2.117	1.381
50%ile	0.519	0.274	0.071	0.045	0.041	0.045	0.220	0.627	1.073	1.400	1.691	1.007
40%ile	0.414	0.212	0.060	0.037	0.037	0.037	0.104	0.422	0.849	1.206	1.303	0.810
30%ile	0.291	0.158	0.056	0.037	0.037	0.034	0.069	0.317	0.532	0.956	0.982	0.594
20%ile	0.231	0.096	0.052	0.034	0.033	0.030	0.058	0.172	0.340	0.661	0.586	0.424
10%ile	0.146	0.069	0.034	0.026	0.025	0.026	0.039	0.056	0.208	0.418	0.414	0.258
1%ile	0.085	0.050	0.026	0.022	0.021	0.019	0.023	0.037	0.068	0.123	0.184	0.146

Table 3.18. Simulated monthly flows (m^3/s) under Reference Condition

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.168	0.201	0.317	0.146	0.322	0.119	0.077	0.056	10.482	3.424	0.982	1.902
1921	0.638	0.081	0.299	1.908	0.699	0.825	0.347	0.153	1.150	0.515	0.657	0.355
1922	0.209	4.313	1.370	0.243	0.103	0.034	4.074	5.003	3.368	2.408	1.281	0.880
1923	0.549	1.308	0.414	0.045	0.054	0.161	0.123	0.056	2.018	0.956	5.223	2.319
1924	0.523	3.364	1.075	0.123	0.062	0.037	0.073	0.052	3.904	1.605	1.355	0.594
1925	0.799	0.397	0.071	0.034	0.037	0.060	0.054	0.433	0.795	5.880	2.677	0.633
1926	9.969	3.434	0.071	0.049	0.153	0.075	0.069	1.098	0.502	0.179	1.210	0.563
1927	0.123	0.386	0.295	0.138	0.050	0.108	0.062	0.034	0.883	0.373	0.624	1.265
1928	0.452	0.598	0.235	0.030	0.033	0.209	0.258	0.329	0.285	3.543	1.482	0.285
1929	0.146	0.355	0.280	0.108	0.351	0.762	0.490	0.986	0.532	0.418	1.602	2.431
1930	0.900	0.513	0.161	0.045	0.033	0.056	3.098	1.180	0.208	1.400	2.203	1.042
1931	2.487	0.876	0.086	0.056	0.550	0.198	0.042	1.322	1.505	1.030	0.601	8.438
1932	2.867	0.131	0.071	0.037	0.037	0.056	0.062	0.403	3.052	1.807	2.027	0.853
1933	0.343	0.201	0.060	0.037	0.037	0.045	0.351	0.721	0.421	1.083	3.864	2.176
1934	0.650	0.228	0.056	0.037	0.033	0.026	1.142	1.788	1.273	18.750	31.590	9.005
1935	0.444	0.664	0.231	0.474	0.211	0.037	0.347	0.900	0.475	0.508	0.571	0.779
1936	0.373	1.941	1.098	0.198	0.041	0.093	0.069	0.045	3.434	6.467	2.001	1.852
1937	0.784	0.305	0.105	0.037	0.037	0.273	0.220	1.113	0.826	1.206	1.971	5.324
1938	1.874	0.258	0.067	0.037	0.227	0.362	0.370	0.273	0.143	1.684	4.749	1.678
1939	0.758	0.336	0.060	0.037	2.096	0.676	2.924	1.083	2.515	1.269	0.347	0.235
1940	0.426	1.790	0.579	0.575	0.244	0.034	3.430	5.111	5.768	2.621	1.766	4.016
1941	1.576	0.394	0.108	0.049	0.041	0.034	0.039	2.341	1.717	0.504	0.414	0.637
1942	0.291	0.069	0.657	4.805	1.703	0.605	0.671	0.930	0.444	0.758	1.202	0.687
1943	0.388	5.961	1.889	0.060	0.045	0.034	0.058	3.345	8.472	2.595	4.630	9.032
1944	2.524	0.104	0.119	0.056	0.041	0.034	0.490	12.463	10.509	6.369	7.191	2.215
1945	5.921	2.168	0.093	0.056	0.050	0.784	0.324	0.172	0.340	0.411	0.463	1.208
1946	0.642	0.212	0.052	0.034	0.033	0.433	0.467	0.937	1.073	6.433	2.404	0.806
1947	0.582	0.270	0.067	0.037	0.037	0.956	0.590	0.246	0.664	1.243	0.582	0.764
1948	9.170	3.090	0.067	0.049	0.041	0.034	1.678	1.983	0.725	0.620	1.236	0.617
1949	0.205	1.798	0.601	0.045	0.037	0.030	0.899	0.351	0.135	3.543	1.337	1.285
1950	0.691	2.886	1.057	2.826	1.046	0.052	1.111	0.698	9.996	8.233	5.959	7.735
1951	2.169	0.139	0.060	0.045	0.041	0.037	0.058	0.836	0.995	1.826	6.747	3.086
1952	1.161	4.279	1.310	0.060	0.054	0.037	1.686	0.851	0.455	2.531	1.090	0.282
1953	0.224	0.559	0.187	0.037	0.050	0.093	0.340	9.401	4.344	6.776	10.674	3.152
1954	0.250	0.123	0.060	0.045	3.315	1.012	0.143	0.093	2.735	3.491	7.120	2.434
1955	1.161	0.459	0.060	0.041	0.041	0.049	0.123	2.972	3.021	1.538	1.990	0.930
1956	0.467	0.174	0.142	0.060	0.194	0.172	0.120	5.888	10.394	5.078	7.198	3.218
1957	5.130	1.701	0.063	0.045	0.041	0.418	1.173	5.869	2.620	0.418	5.025	1.883
1958	0.597	0.228	0.056	0.041	0.037	0.034	1.362	2.905	1.030	0.683	5.007	2.292
1959	1.232	0.421	0.063	0.045	0.037	0.075	0.054	0.153	0.899	1.098	0.508	0.328
1960	0.161	0.054	0.075	0.317	0.128	0.026	0.147	0.317	0.224	1.045	4.040	2.407
1961	0.650	0.131	0.045	0.246	0.116	0.452	0.891	0.433	3.785	1.598	8.397	3.048
1962	3.002	1.173	0.071	0.060	0.037	0.034	0.058	0.056	0.490	2.203	5.205	1.744
1963	0.146	0.274	0.239	0.075	0.041	0.086	0.085	0.127	3.669	2.599	3.215	1.373

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	0.287	0.158	0.052	0.037	0.037	0.045	0.073	0.586	0.278	0.702	0.429	0.170
1965	0.414	0.197	0.086	0.034	0.025	0.030	0.143	0.086	0.054	0.340	1.281	1.362
1966	0.426	0.062	0.034	0.026	0.025	0.045	6.644	2.337	2.168	1.198	1.303	0.860
1967	0.485	0.239	0.060	0.034	0.033	0.026	0.039	0.586	2.014	1.072	1.172	0.552
1968	0.422	0.235	0.052	0.071	0.074	0.056	1.181	0.444	1.744	0.736	0.265	0.201
1969	0.231	0.096	0.034	0.026	0.128	0.056	0.023	0.183	1.960	2.035	3.991	1.647
1970	0.258	0.089	0.052	0.037	0.037	0.034	0.104	0.265	0.629	3.099	6.903	2.473
1971	0.821	0.305	0.261	0.105	0.169	0.116	2.188	1.396	1.289	0.896	5.933	2.411
1972	0.273	0.085	0.049	0.034	0.037	0.026	0.039	0.366	0.216	1.505	0.792	0.532
1973	0.239	0.073	0.037	0.030	0.025	0.045	0.035	1.990	0.849	0.332	10.559	5.143
1974	1.310	0.336	0.052	0.082	0.050	0.030	0.031	1.833	0.907	1.923	4.865	1.701
1975	0.519	0.201	0.052	0.037	0.037	0.045	0.899	0.448	7.172	4.282	1.688	1.003
1976	0.388	1.887	0.702	0.052	0.405	0.306	0.166	2.655	2.836	7.254	3.207	1.007
1977	0.351	0.270	0.844	0.287	0.041	0.037	0.517	0.265	0.239	0.836	2.378	1.134
1978	0.620	0.208	0.052	0.056	3.046	0.922	0.046	1.676	0.918	1.273	2.117	0.992
1979	0.765	0.266	0.049	0.037	0.033	0.026	0.031	0.381	1.782	0.661	0.280	0.181
1980	0.112	0.907	0.314	3.386	1.252	0.538	1.701	0.579	0.239	2.722	4.913	2.234
1981	0.683	0.417	0.116	0.060	0.037	0.034	2.662	0.907	0.992	0.568	0.347	0.197
1982	0.093	0.054	0.034	0.022	1.294	0.411	0.343	3.674	4.016	5.261	2.057	2.037
1983	0.747	0.158	0.060	0.037	0.037	0.030	0.089	3.752	1.570	0.635	0.526	0.679
1984	1.456	33.484	10.723	0.217	0.360	0.497	1.080	0.385	0.123	8.501	3.625	0.486
1985	1.157	0.451	0.063	0.041	0.194	0.377	0.174	0.060	0.756	1.355	12.194	4.437
1986	0.403	0.143	0.052	0.041	0.079	0.037	2.226	1.508	3.279	1.333	2.009	2.404
1987	0.724	0.093	0.052	0.037	0.037	0.030	0.478	0.235	2.585	1.344	2.968	1.624
1988	1.012	0.347	0.056	0.037	0.037	5.178	4.444	1.172	1.115	5.111	4.234	3.083
1989	1.953	0.548	0.063	0.049	0.041	0.037	4.460	2.550	7.836	2.599	0.549	0.258
1990	0.142	0.170	0.116	0.049	0.037	0.026	0.062	0.620	1.308	7.721	2.658	0.424
1991	1.781	0.644	0.052	0.037	0.037	0.034	0.332	1.053	1.628	1.381	1.512	2.018
1992	1.710	0.505	0.056	0.037	0.355	0.131	12.878	4.443	4.001	6.664	2.315	0.444
1993	0.157	0.069	0.131	0.067	0.033	0.041	1.852	0.795	8.480	3.110	0.586	0.347
1994	0.161	0.069	0.217	0.090	0.033	0.187	0.104	1.885	1.327	1.064	1.912	0.810
1995	0.287	0.382	1.030	0.310	0.037	0.086	0.050	0.045	0.606	3.816	1.430	0.856
1996	3.973	3.488	0.918	0.090	0.037	0.034	0.637	2.733	2.809	0.859	0.455	0.266
1997	0.090	0.189	0.075	0.026	0.025	0.034	0.417	4.566	1.813	0.426	0.392	0.235
1998	0.086	0.687	3.401	0.993	0.037	0.030	0.667	0.306	0.123	0.086	0.063	2.380
1999	0.810	0.050	0.030	0.093	0.050	0.209	0.093	0.045	0.069	1.658	0.732	0.922
2000	0.355	0.050	0.026	0.022	0.021	0.019	0.050	0.157	0.089	1.897	1.508	0.513
2001	0.448	0.135	0.030	0.997	0.331	0.026	0.039	0.403	0.455	1.900	1.004	0.525
2002	0.243	0.058	0.030	0.026	0.021	6.063	2.091	0.627	0.313	0.127	7.512	2.843
2003	0.224	0.058	0.037	0.026	0.025	0.022	0.066	0.049	0.120	0.284	0.198	0.143
2004	3.663	1.215	0.034	0.590	0.182	0.026	5.428	2.024	3.947	1.378	0.347	0.220
2005	0.082	0.069	0.037	0.022	0.021	0.019	0.039	0.422	0.285	4.835	4.167	1.107
2006	0.269	0.085	0.034	0.026	0.025	0.026	0.073	0.653	0.918	2.707	1.691	0.532
2007	0.396	2.114	0.650	0.037	0.045	0.037	0.031	0.037	0.158	0.982	0.594	1.381
2008	0.568	3.005	0.900	0.034	0.029	0.026	0.027	0.056	2.218	2.494	0.918	0.367
2009	2.662	0.899	0.037	0.026	0.029	0.022	0.023	0.213	0.787	0.750	0.325	0.147
2010	0.134	0.062	0.026	0.019	0.021	0.019	0.066	0.321	0.525	0.325	0.676	0.340

State 1	<0.03	State 2	0.03-3.0	State 3	>3.0



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL	Check
State 1	0.0	0.0	5.5	14.3	13.2	23.1	3.3	0.0	0.0	0.0	0.0	0.0	4.9	4.9
State 2	92.3	90.1	92.3	83.5	84.6	74.7	87.9	87.9	76.9	74.7	68.1	85.7	83.2	83.2
State 3	7.7	9.9	2.2	2.2	2.2	2.2	8.8	12.1	23.1	25.3	31.9	14.3	11.8	11.8

Figure 3.28. Monthly occurrences of the various abiotic states under the Reference condition

3.4.5 Hydrodynamic health

Table 3.19. Calculation of the hydrodynamics score, giving examples in italics.

Variable	Score	Motivation	Conf
a. Mouth condition and abiotic states	65	**Months in which mouth closure could occur increased from less than 5% under Reference to 39% under Present State.** Under natural conditions closure would only have been for brief periods (days to a few weeks) at a time during drought periods. Under the present state mouth closure is a persistent state lasting for months at a time. Artificial breaching at low levels disguises the frequency at which this would occur. Note: score calculated as Bray-Curtis similarity score of the % occurrence of three types of abiotic states.	VL
b. Stratification		Not scored – too little data	
c. Water retention time		Not scored – too little data	
d. Water level		Not scored – too little data	
Hydrodynamics and mouth conditions score	65	The first score was considered as an adequate representation of all of the above	VL

3.5 Water quality

3.5.1 Baseline description and reference condition

For the purposes of this study, the Uilkraals Estuary was sub-divided into 3 distinct zones (Figure 3.29):

A. Lower estuary (20% of water volume when open)
B. Middle estuary (50% of water volume when open)
C. Upper estuary (30% of water volume when open)

Figure 3.29. Zones in the Uilkraals Estuary

There were no data available that described the water quality in the Uilkraals Estuary under Reference condition. Reference condition therefore had to be derived from other available data sources and expert opinion. Also, data for the Present state was limited to a few surveys. Refer to Table 3.14 for description of the flow ranges and physical characteristics of various abiotic states.

Limited data on salinity (Figure 3.30, Anchor Environmental, unpublished data) indicated that the estuary tends to be hypersaline under closed conditions when inflow is very low (April 2011), but that it turns brackish once the system starts to fill up before a breaching (August 2011). Data from Heydorn & Bickerton (1982) were used as indicative of the open tidal conditions.

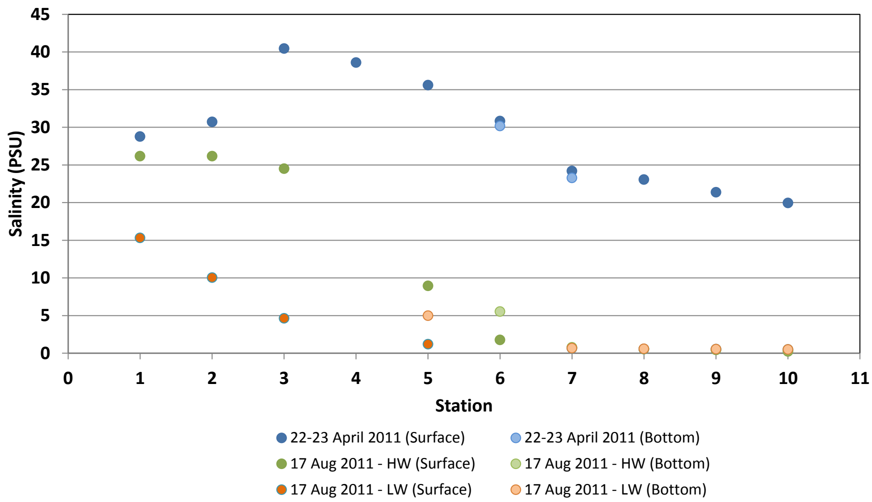


Figure 3.30. Salinity concentrations measured in the Uilkraals Estuary on 22 April 2011 (closed) and August 2011 (open, high tide). Stations indicated in Figure 3.29.

Very limited data on turbidity/transparency (Anchor Environmental, unpublished data) indicated that although the estuary is a blackwater system, transparency averaged 1 m. The system is also shallow in most parts, thus clear to the bottom. It is expected that transparency will be reduced during periods of high river inflow (State 3) (0.5 m).

Based on limited dissolved oxygen data available for the estuary, e.g. Heydorn & Bickerton, 1982; Anchor Environmental, unpublished data) the estuary is generally well-oxygenated (>6 mg/l). However, from aerial photos and visual observations it appears that there are wastewater (mainly sewage and organic matter) from diffuse sources, e.g. seepage from caravan park, wastewater treatment facility and cattle grazing in the upper reaches entering the estuary under the present state potentially lowers DO concentrations under States 2 and 1 in the narrow upper reaches (4 mg/l). During the closed state, stagnant conditions in the narrow upper reaches can possibly result in even lower DO (4 mg/l under Reference and 2 mg/l under Present and Future Scenarios).

The only measured data on inorganic nutrient concentrations (present state) was measured in April and August 2011 (Figure 3.31). During the closed state (April 2012), nutrient enrichment from such sources is evident in high DIN (70% ammonia) and DIP. Based on these results it is assumed that during the closed state (State 1) average DIN and DIP concentrations in the estuary are about 300 µg/l and 100 µg/l, respectively under the present state. During the open state (Aug 2011) DIN and DIP concentrations tended to be lower compared with the closed state (**Error! Reference source not found.**). This is attributed to good flushing driven by stronger river inflow and tidal exchange during the open state. Based on these results it is assumed that during the open states (States 2 and 3) average DIN and DIP concentrations in the estuary are estimated at 100 µg/l and 50 µg/l, respectively under the present state. Occasional upwelling can introduce elevated concentrations, but for this assessment nutrient influx from the sea was assumed to be low.

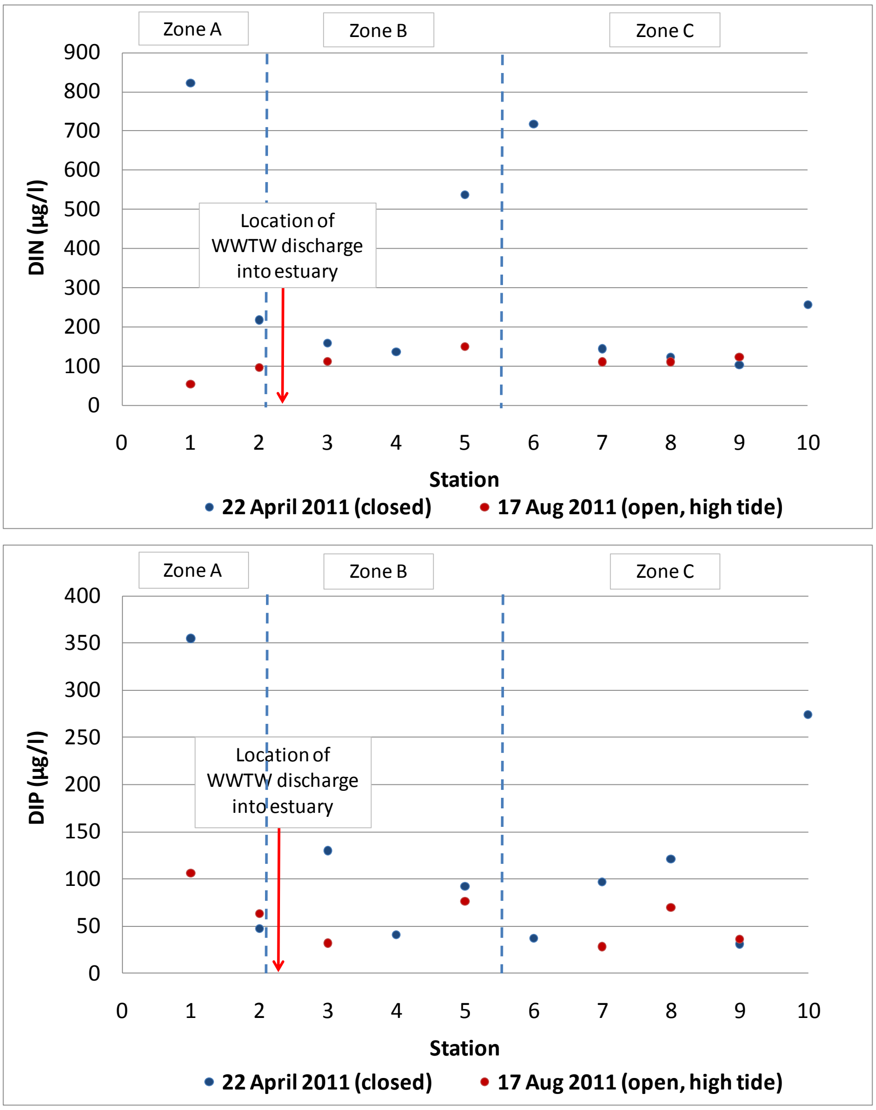


Figure 3.31. DIN and DIP concentrations measured in the Uilkraals Estuary on 22 April 2011 (closed) and August 2011 (open, high tide). Stations are indicated in Figure 3.29.

Results from the Palmiet Estuary EWR study (also a black water system in the area) were used to estimate the Reference condition for the Uilkraals (DWA 2010). Based on the Palmiet results it is estimated that under Reference condition DIN and DIP concentrations in river inflow would have been low typical of blackwater systems – 50 µg/l and 10 µg/l, respectively.

DRS are naturally high in river water, compared to the sea. Therefore, high levels in freshwater inflow (reflected in concentrations in upper reaches) are not as a result of anthropogenic enrichment. It is expected that conditions would have been similar for the Reference condition as for Present

In addition to the above, aerial photos suggest that wastewater (mainly sewage and organic matter) from diffuse sources entering the estuary (e.g. wastewater treatment facility and seepage from the caravan park), as well as cattle grazing in the upper reaches are the key sources of nutrient enrichment in the system under the present state.

A summary of the typical water quality characteristics of different abiotic states in the Uilkraals Estuary is provided in Table 3.20.

Table 3.20. Summary of hydrodynamic and water quality characteristics of different abiotic states in the Uilkraals Estuary (differences in state between reference condition and present state and future scenarios – due to anthropogenic influences other than flow - are indicated)

PARAMETER		State 1: Closed, brackish and inundated			State 2: Open, tidally dominated			State 3: Open, fluvially dominated		
Stratification		Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
		Well mixed	Well mixed	Weak Stratification	Well mixed	Well mixed	Weak Stratification	Stratified on high tide	Well mixed	Well mixed
Salinity		Closed, brackish & inundated			Reference			Reference		
	Low tide	Only in Present			15	5	1	0	0	0
	High tide	20	15	10	35	30	1	25	10	0
	Average	Under prolonged closed conditions State 3 can progress into hypersaline & very exposed conditions			25	20	1	10	5	0
					Present			Present		
	Low tide				20	5	1	0	0	0
	High tide	Only in Present			35	20	1	25	5	0
	Average	35	40	25	30	15	1	10	1	0
DO (mgl/l)		Reference			Reference			Reference		
		6	6	4	6	6	6	6	6	6
		Present & Future 1/2			Present & Future			Present & Future		
		4	4	2	6	6	4	6	6	6
		Future 3								
		5	5	4						
Transparency (Secchi depth in m)		1	1	1	1	1	1	0.5	0.5	0.5
Dissolved inorganic nitrogen (DIN) (µg/l)		Reference			Reference			Reference		
		50	50	50	50	50	50	50	50	50
		Present & Future 1/2			Present & Future			Present & Future		
		300	300	300	50	100	100	50	100	100
		Future 3								
		200	200	200						
Dissolved inorganic phosphate (DIP) (µg/l)		Reference			Reference			Reference		
		10	10	10	10	10	10	10	10	10
		Only Present & Future 1/2			Present & Future			Present & Future		
		100	100	100	10	50	50	10	50	50
		Future 3								
		70	70	70						
Dissolved reactive silicate (DRS) (µg/l)		500	500	50	200	500	1000	500	1000	1000

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3.5.2 Reference vs Present water quality

Overall changes in water quality parameters are estimated in Table 3.21.

Table 3.21. Summary of changes in water quality from Reference state. Estimated concentrations/measures under Reference and Present are summarised for the three estuary zones

Parameter	Description of change from Reference	Zone	Ref	Pres
Salinity (µg/l)	Salinities have increased from reference due to decrease in baseflows.	Lower	23	30
		Middle	17	24
		Upper	1	10
DIN (µg/l)	Due to increased nutrient input from diffuse sources, e.g. seepage from caravan park, wastewater treatment facility and cattle grazing, concentrations in the estuary increased under Present state (and future scenarios) compared with reference.	Lower	50	148
		Middle	50	179
		Upper	50	179
DIP (µg/l)	Due to increased nutrient input from diffuse sources, e.g. seepage from caravan park, wastewater treatment facility and cattle grazing, concentrations in the estuary increased under Present state (and future scenarios) compared with reference.	Lower	10	45
		Middle	10	70
		Upper	10	70
Transparency (Secchi depth in m)	Only State 3 Introduces lower transparency into the system. Due to only limited change in the occurrence of this State, transparency in the system did not change markedly.	Lower	1	1
		Middle	1	1
		Upper	1	1
DO (µg/l)	Due to increased organic input from diffuse sources, e.g. seepage from caravan park, wastewater treatment facility and cattle grazing, DO concentrations in the estuary decrease from the Reference to Present State (and future scenarios). Also the occurrence of State 3 (closed) increased under the present state (and future scenarios) resulting in more stagnant conditions.	Lower	6	5
		Middle	6	5
		Upper	6	4
Toxic substances	Agricultural development in the catchment may have introduced some pesticides and herbicides into the estuary. Assume similarity to reference as 90% for present and all future scenarios.			

3.5.3 Scoring present water quality

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

- Define **zones** along the length of the estuary **(Z)** (i.e. Zones A, B and C)
- **Volume fraction** of each zone **(V)** (i.e. A = 0.2; B = 0.5; C = 0.3)
- Different **abiotic states (S)** (i.e. States 1 to 3)
- Define the **flow scenarios** (i.e. Reference, Present, Future scenarios)
- Determine the **% occurrence** of abiotic states for each scenario
- Define **WQ concentration range (C)** (e.g. 6 mg/l; 4 mg/l; 2 mg/l)

Similarity of salinity in Present or any Future Scenarios relative to Reference was calculated as follows:

- Calculate Average concentration for each Zone for Reference and Present/Future Scenarios, respectively:
- Average Conc (Z_A) = [({∑% occurrence of states in C_1}*C_1)+ ({∑% occurrence of states in C_2}*C_2)+({∑% occurrence of states in C_n}*C_n)] divided by 100
- Calculate similarity between Average Conc's Reference and Present/Future Scenario for each Zone using the Czekanowski's similarity index: ∑(min(ref,pres) (∑ref + ∑pres)/2

For the final scores, a weighted average of the similarity scores of different zones was computed using the volume fractions.

Table 3.22. Summary of changes and calculation of the water quality health score.

	Variable	Summary of change	Score	% non-flow	Adjusted score[1]
1	**Salinity**				
	Similarity in salinity	⇧ due to decrease in flow	66	0	66
2	**General water quality in the estuary**				
a	N and P concentrations	⇧ due to nutrient enrichment from diffuse sources mostly during State 1 (closed)	36	90	94
b	Water clarity (measured as suspended solids/turbidity/transparency)	No marked change in occurrence of State 3 (when transparency is reduced in estuary)	99	0	99
c	Dissolved oxygen (mg/l) concentrations	⇩ due to organic enrichment from diffuse sources, mostly during State 1 (closed)	91	90	99
d	Toxic substances	⇧ accumulation	90	100	100
Water quality health score[2]			**64**		**83**
Confidence			**L**		

[1] net of non-flow impacts

[2] $Score = \frac{0.6*S+0.4*(\min(a\ to\ d)+mean(a\ to\ d))}{2}$

3.6 Microalgae

3.6.1 Microalgae groups

Due to lack of data, only two groupings of microalgae were considered in this study (Table 3.23).

Table 3.23. Groupings of microalgae considered in this study with their defining features

Microalgal groups	Defining features, typical/dominant species
Benthic microalgae	Benthic microalgae are potentially abundant in this shallow Uilkraals system covering up to 46 ha. The MPB community generally consists of euglenophytes, cyanophytes and bacillariophytes (diatoms).
Phytoplankton	Flagellates, diatoms, dinoflagellates, cyanophytes, chlorophytes, euglenophytes and coccolithophorids are the dominant phytoplankton groups. Phytoplanton community composition has not been measured in the Uilkraals Estuary. Two surveys showed that phytoplankton biomass was low.

3.6.2 Baseline description

Heydorn and Bickerton (1982) suggested that the phytoplankton in the estuary were mostly marine phytoplankton carried into the estuary due to incoming tides. Open water surface area representing phytoplankton habitat was 21 ha but fluctuates with changes in water level. Water volume has been estimated as 37 644 m^3 when the estuary is closed and empty to 535 459 m^3 when the estuary is open at mid tide. Anchor Environmental Consultants measured phytoplankton biomass on 22 April 2011 along the length of the estuary. Chlorophyll-a was low and ranged from 2.9 to 5.7 ug l^{-1}. On the 17 August 2011 no chlorophyll-a was recorded at most sites, 2.4 ug l^{-1} was measured at Sites 2 and 8 and 1.2 ug l^{-1} at Site 10. All values were low indicating that microphytobenthos (MPB) are probably more important than phytoplankton as primary producers in this shallow water system. Indeed some of the chlorophyll-a measured in the water column could be dislodged MPB, an analysis of the species composition can be used to verify this.

3.6.3 Description of factors influencing microalgae

The factors influencing the different microalgal groups are summarised in Table 3.24. Based on these considerations, the expected influence of the different abiotic states on microalgae is described in Table 3.25.

Table 3.24. Effect of abiotic characteristics and processes, as well as other biotic components on microalgae groupings

	Phytoplankton					
	Cyano-phytes	**Dino-flagellates**	**Chloro-phytes**	**Diatoms**	**Flagellates**	**MPB**
Temperature	Lower chl *a*	higher chl *a* in spring	higher chl *a* in summer	higher chl *a* in spring	higher chl *a* in spring	higher chl *a*
% Fines (<63 µm)	higher chl *a*	higher chl *a*	higher chl *a*	higher chl *a*	higher chl *a*	higher chl *a*
Salinity	Low chl *a* with increasing salinity	Low chl *a* with increasing salinity	Low chl *a* with increasing salinity	Low chl *a* with increasing salinity	Low chl *a* with increasing salinity	Low chl *a* with increasing salinity
External P input	higher chl *a*	higher chl *a*	higher chl *a*	higher chl *a*	higher chl *a*	higher chl *a*
Grazing	lower chl *a*	lower chl *a*	lower chl *a*	lower chl *a*	lower chl *a*	lower chl *a*
Oxygen	Increase in chl *a*	Increase in chl *a*	Increase in chl *a*	Increase in chl *a*	Increase in chl *a*	Increase in chl *a*
Stratification						High productivity
External N input	higher chl *a*	higher chl *a*	higher chl *a*	higher chl *a*	higher chl *a*	higher chl *a*
Turbidity	higher chl *a*	higher chl *a*	lower chl *a*	lower chl *a*	higher chl *a*	higher chl *a*
Organic content	Incr chl *a*	Incr chl *a*	Incr chl *a*	Incr chl *a*	Incr chl *a*	Incr chl *a*

Table 3.25. Summary of phytoplankton biomass (water column chlorophyll a) of different abiotic states in the Uilkraals Estuary.

STATE	Predicted water column chlorophyll-a (phytoplankton biomass)
State 1: Closed	Phytoplankton biomass can increase directly after mouth closure due to increased water retention. After 6 weeks of closed mouth conditions macroalgae would outcompete the phytoplankton and become the dominant primary producer. Clear stable water conditions would result in high microphytobenthos biomass.
State 2: Open, tidally dominated	Tidal conditions and low water retention would prevent high phytoplankton biomass particularly in the lower reaches of the estuary. Microphytobenthos could potentially be high in the internal areas particularly near the nutrient enriched sites.
State 3: Open, fluvially dominated	Phytoplankton biomass would increase in response to freshwater inflow. Species composition and abundance is likely to shift from marine to freshwater dominated. Exposure of previously inundated intertidal sediment under closed mouth conditions may increase the distribution and abundance of microphytobenthos. However microphytobenthos would not be high under high flow conditions.

3.6.4 Reference condition

There were no available data on the different phytoplankton groups in the Uilkraals Estuary and therefore for the purposes of this study changes are described for phytoplankton and microphytobenthos. However if data were available changes could be described for the different groups i.e. cyanophytes, dinoflagellates, chlorophytes, diatoms and flagellates. Changes are summarised in Table 3.26.

Table 3.26. Summary of how the microalgae in the Present condition have changed relative to the Reference condition.

Drivers	Changes
⇧State 1 (closed mouth)	⇩phytoplankton richness ⇧ subtidal benthic microalgae biomass ⇩intertidal benthic microalgae biomass
⇧Salinity (decrease in base flow)	⇩species richness of microalgae
⇧Nutrients (WWTW input)	⇩species richness of microalgae ⇧ biomass
TOTAL CHANGE	⇩phytoplankton & benthic microalgae richness⇧ subtidal benthic microalgae biomass ⇩intertidal benthic microalgae biomass

3.6.5 Health of the microalgae component

Health scores are summarised in Table 3.27. 20% of the impact on microalgae was thought to be non-flow related.

Table 3.27. Similarity scores of microalgae in the Present condition relative to the Reference condition.

Variable	Change from natural	Score	Conf.
1. Species richness	Salinity has increased from the reference condition due to decrease in baseflows. There has been an increase in nutrient concentrations and closed mouth conditions which would decrease species richness. The loss of intertidal habitat would decrease microphytobethos species richness in the intertidal zone.	70	Low
2. Abundance	An Increase in mouth closure and nutrient rich conditions would promote microphytobenthos growth particularly in shallow sheltered areas of the estuary. Loss of intertidal habitat would represent a loss of habitat for benthic microalgae. The abundance score was calculated using the DIN concentration, change in phytoplankton biomass (chlorophyll-a concentration) and similarity index.	55	Low
3. Community composition	Blue-green algae would outcompete other algal groups under nutrient rich, freshwater conditions. Mouth closure would result in a loss of intertidal benthic microalgal communities but a gain in subtidal habitat.	65	Low
Microalgal health score		**55**	**Low**
% non-flow related impacts - Pollution		20%	
Adjusted score		67	

3.7 Macrophytes

3.7.1 Macrophyte groups

The main habitats and macrophytes groups present in the Uilkraals Estuary are described in Table 3.28.

Table 3.28. Macrophyte habitats and functional groups recorded in the estuary (spp. examples in italics).

Habitat type	Defining features, typical/dominant species
Open surface water area	Serves as habitat for phytoplankton and overlapping habitat for macroalgae.
Intertidal sand and mudflats	Intertidal zone consists of sand banks that are regularly flooded by tidal exchange, particularly in the lower reaches. The chenopod *Salicornia meyeriana* Moss occurs in the middle intertidal zone. This zone was characterised as sand banks that are regularly flooded. This area also has shallow depressions which are poorly drained and can be inundated for prolonged periods.
Submerged macrophyte beds	Only one submerged macrophyte species has been recorded in the system, *Ruppia cirrhosa* L which has a wide salinity tolerance range but is sensitive to desiccation. When exposed the beds will die-back rapidly but will develop from a large seed bank when areas are submerged for longer than a few weeks.
Macroalgae (50 % of submerged area)	Macroalgae present are the opportunistic filamentous greens, e.g. *Cladophora glomerata* (Linnaeus) Kützing, *Ulva capensis J.E*. Areschoug and *Ulva intestinalis* L. They are euryhaline species usually widely distributed throughout the estuary.
Intertidal salt marsh	The sandy substrate of the salt marsh of the Uilkraals Estuary is unique. Mucina *et al.* (2003) compared it to the inland temporarily flooded sandy bottom salt marsh habitats of the Agulhas plain. The intertidal zone consists of sand banks that are regularly flooded by tidal exchange and can be divided into a lower intertidal zone and a middle intertidal zone. The lower intertidal zone has high abundance of *Salicornia meyeriana* Moss and to a lesser extent *Triglochin bulbosa* L. There are also lower intertidal species *Sarcocornia tegetaria* S. Steffen, Mucina & G. Kadereit, *Triglochin striata* Ruiz & Pav. as well as *Sarcocornia decumbens* (Tölken) A.J. Scott as a middle intertidal zone species (Mucina *et al*. 2003). The middle intertidal zone is species-rich and occurs on hummocks. This includes *Cotula coronopifolia L., Puccinella angusta* (Nees) C. Presl, *Sporobolus virginicus* (L.) Kunth, *Plantago crassifolia* Forssk. and *Spergularia media* (L.) C.Presl ex Griseb. This indicates a brackish habitat. Unique communities are composed of species such as *Spergularia media* (L.) C.Presl ex Griseb, *Triglochin elongata* Buchenau, *Bassia diffusa* (Thunb.) Kuntze, and *Sarcocornia littorea* (Moss) A.J. Scott are also found. The sandy low nutrient habitat may encourage adaptation and diversity.

Habitat type	Defining features, typical/dominant species
Supratidal salt marsh	The supratidal marsh covers the largest area of salt marsh and is outside the direct influence of the tidal regime (Mucina *et al*. 2003). The dominant macrophyte in this habitat is *Sarcocornia capensis* (Moss) A.J. Scott with other species being found in areas that are waterlogged or exposed to drying-out. The supratidal salt marsh is the richest habitat in the Uilkraals Estuary. However, Mucina *et al.* (2003) also noted that there exists communities such as the '*Crassulo glomeratae-Sarcocornietum capensis*' which may not be a member of estuarine systems of other marshes of the Western and Eastern Cape. For this reason Adams *et al.* (2010) classified this community as 'Supratidal Fringe'; a transition between terrestrial and salt marsh vegetation. The species included in this habitat contain a mixture of salt marsh element with a number of short-lived herbs and grasses such as *Crassula glomerata* P. J. Bergius, *Bromus pectinatus* Thunb, *Tribolium hispidum* (thunb.) Desv., *Silene clandestin*a Jaq., *Senecio elegans* L., *Ruschia lineolata* (Haw.) Schwantes, *Romulea tabularis* Eckl. Ex Beg, *Pteronia uncinata* DC, *Nidorella foetida* (L.) DC, *Cerastium capense* Sond, *Apium prostratum* Vent.
Reeds and sedges	The following species have been recorded most of which belong to the families Cyperaceae and Juncaceae: *Carex clavata* Thunb., *Carex ecklonii* Nees., *Elegia stipularis* Mast, *Ficinia pygmaea* Boeck., *Isolepis verrucolsa* (Steud.) Nees, *Cyperus laevigatus* L., *Juncus acutus* L., *Juncus kraussii* Hochst., *Juncus scabrisculus* Kunth, *scirpoides nodosus* (Rottb.) sojak, *Scirpus littoralis* Schrad. Mucina *et al.* (2003) explained that freshwater seepage from groundwater forms a unique microhabitat for the growth of reeds and sedges in the salt marsh system. This community is found closer mouth of the estuary and further upstream in brackish water.

3.7.2 Baseline description: Species diversity, richness and rarity

The present area of the different vegetation types and their distribution of within the 5m contour around the estuary is given in Table 3.29 and Figure 3.32.

Table 3.29. Area of each habitat type

Habitat type	Area (ha)
Open surface water area	21
Intertidal sand and mudflats	46
Submerged macrophyte beds	1.4
Macroalgae (50 % of submerged area)	0.5
Intertidal and supratidal salt marsh	47
Reeds and sedges	5.6
TOTAL	**121.5**

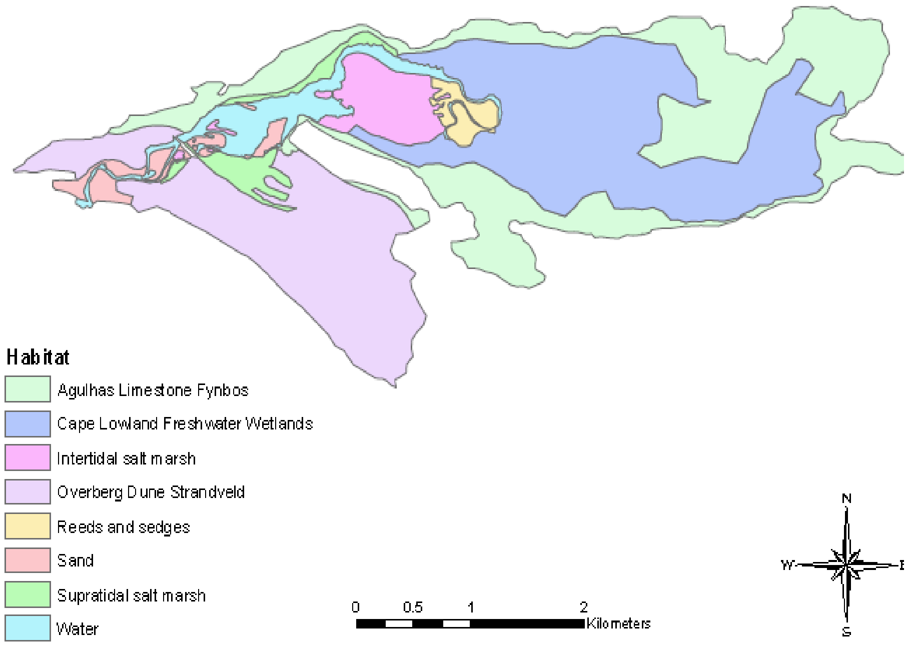


Figure 3.32. Vegetation map of the Uilkraals Estuary mapped from 2008 Spot5 image.

Heydorn & Bickerton (1982) were the first to describe the vegetation of the estuary. An important study by Mucina *et al.* (2003) on the salt marsh of the Uilkraals Estuary indicated a number of unique characteristics. The Uilkraals Estuary lies in the Cape Agulhas region that is considered as a phylogeographic break or transitioning zone between the cool temperate and warm-temperate zone (Teske *et al*. 2011). At these sites, several species have phylogeographic breaks, with distinct lineages that are endemic to this transition zone. This could explain the high species richness and number of endemic macrophytes found in the Uilkraals Estuary (Adams *et al.* 2010). Approximately 60 different macrophyte species are distributed in five different estuarine habitats: Intertidal and Supratidal salt marsh, Macroalgae, Submerged macrophytes, Reeds and Sedges. The estuary is therefore important in biodiversity conservation.

3.7.3 Factors affecting the abundance of different macrophytes groups

The effect of abiotic characteristics and processes, as well as other biotic components on macrophyte habitats is described in Table 3.30.

Table 3.30. Effect of abiotic characteristics and processes, as well as other biotic components on macrophyte habitats

Process	Macrophytes
Mouth condition (provide temporal implications where applicable)	*Macroalgae* Under the current mouth condition it is expected that macroalgae will proliferate. Extensive growth can rot causing unpleasant odours in the estuary. *Reeds and sedges* A reduction in water depth may result in a change of submerged vegetation to one of reeds and sedges. *Salt marsh* Intertidal salt marshes grow better under regular tidal inundation. However most of the salt marsh area in Uilkraals is supratidal. The present state of prolonged mouth closure could result in the die back of intertidal salt marsh species. Under conditions where habitats are seasonally inundated, salt marsh species survive as short-growing emergent macrophytes. The supratidal salt marsh and floodplain may become flooded. Prolonged inundation slows flowering and subsequent seed production. *Submerged macrophytes* Currents less than 0.1 m s^{-1} favour the growth and establishment of submerged macrophytes such as *R. cirrhosa.*
Retention times of water masses	*Macroalgae* Retention times of water masses during low flow conditions will lead to an increase in the abundance of macroalgae. *Salt marsh* Under prolonged mouth closure organic matter from dense stands of emergent macrophytes may lead to anoxic conditions developing in the upper reaches during prolonged periods of low river flow and mouth closure. Greater water retention time provides better opportunities for nutrient uptake by macrophytes. Reduced water flow as a result of man-made structures creates quiet backwater areas where macroalgae proliferate. Circulation/water movement is necessary to maintain the salt marsh dynamics.
Flow velocities (e.g. tidal velocities or river inflow velocities)	Tidal flushing is important for salt marsh nutrient exchanges and for maintaining the zonation and diversity of salt marsh plants. High flow during floods is important in flushing out salts from the marshes. Reduced flow velocity can increase macrophytic growth, e.g. macroalgae submerged macrophytes, *R. cirrhosa* and reeds and sedges.
Total volume and/or estimated volume of different salinity ranges	Submerged macrophytes Rapid changes in estuarine water depth can leave plants exposed and dry. Exposure for one hour will result in a loss of *Ruppia* stands.
Floods	*Macroalgae* These proliferate during the closed mouth phase and are washed out to sea during the open phase. *Salt marsh* Freshwater input for too long may eliminate the salt marsh community. However, floods to the estuary are important in lowering the salinity of the water column, which then influences groundwater salinity. *Submerged macrophytes* Turbid events (floods or storm events) may be tolerated for short periods, although they may have the potential to affect the distribution and abundance of *R. cirrhosa*.
Salinity	*Macroalgae* Increases in salinity are unlikely to affect the composition or biomass of the macroalgae as they can tolerate a wide range of conditions. *Reeds and sedges* These plants are sensitive to increases in salinity but can survive if

Process	Macrophytes
	their roots and rhizomes are located in salinity less than 20 ppt. However if freshwater seepage is reduced then it may lead to die back. *Salt marsh* Freshwater inflow dilutes salts, preventing hypersaline conditions in salt marshes. Rainfall and evaporation on the marsh, groundwater seepage from adjacent land and the salinity of the tidal water that inundates the marsh control the sediment salinity. Hypersaline sediments caused by evaporation and infrequent flooding is probably responsible for the high abundance of *S. capensis* in the supratidal areas. This indicates evaporation and accumulation of salts in the supratidal marsh. High ground water level and freshwater flooding would be important in influencing the marsh. Disturbance to the supratidal and floodplain habitat will result in large areas of barren land as has happened at the Orange River mouth if conditions become too saline or dry.
Turbidity	*Submerged macrophyte* beds grow and expand during closed mouth conditions when the light is favourable due to low freshwater and sediment input. The input of silt and associated high turbidity limit submerged macrophyte distribution.
Dissolved oxygen	Accumulations of *macroalgae* can reduce the water quality of estuaries, not only by depleting the oxygen in the water column upon decomposition but also causing anoxic sediment conditions when large mats rest on the sediment under low flow conditions.
Nutrients	*Macroalgae* Under closed mouth conditions light penetration reaches the bottom sediments and seepage from groundwater may supply the nutrients, creating conditions in which macroalgae thrive. Inorganic nutrients (especially N and P) are known to stimulate the abundance of ephemeral and epiphytic macroalgae in shallow coastal waters such as the Uilkraals Estuary. *Ulva* and *Cladophora* often form accumulations due to their filamentous nature and higher nutrient uptake rates than algae with thicker thalli. These accumulations can reduce the water quality of estuaries, not only by depleting the oxygen in the water column upon decomposition but also causing anoxic sediment conditions when large mats rest on the sediment under low flow conditions.
Sediment characteristics (including sedimentation)	*Macroalgae* Under the closed mouth phase, estuarine water levels increase and sediment disturbance from wind and water generated turbulence are minimal, thus offering a stable environment for micro and macroalgal growth. *Reeds and sedges* Increased sedimentation and a reduction in water depth may result in a change of submerged vegetation to one of reeds and sedges if salinity is lower than 20 ppt. *Salt marsh* The unique sediment characteristics of the Uilkraals system are one of the most important factors controlling the distribution and diversity of macrophytes. The salt marsh is mostly comprised of sand in the middle reaches where the largest salt marsh area is found. *Submerged macrophytes* The degree of sedimentation is important in the germination of *Ruppia* seeds. Most *Ruppia* seeds occur in the top 5 cm of sediment and can survive in sediment for up to three years and germinate as long as they are not buried by more than 10 cm of sediment.
Other biotic components	Nutrient pulses and point source inputs will increase macrophyte growth. Macroalgal blooms can occur due to the decomposition of inundated salt marsh species or from localised nutrient inputs such as septic tanks from surrounding developments.

The closing of the estuary mouth may possibly alter the macrophyte species composition and habitats in the estuary and must be carefully monitored. The diversity of macrophytes in the upper floodplain reaches and the relationship with topographical gradients and substrate type needs further investigation. According to Mucina *et al*. (2003) the estuary's sand flats consist of greyish-white sands that are derived from the nutrient poor sandstones and lime rich sand deposits. An opposing impact to that of closed mouth high water level conditions is that decreased base flow may cause large areas of this marsh to desiccate and die. The middle-upper reaches also appear to become disconnected during low flow conditions partially attributable to bridge construction, sedimentation and decrease in tidal flows. The importance of freshwater seepage and groundwater input to the large marsh area also needs further investigation. An analysis of early aerial photographs indicates that the floodplain marsh area in Zone C was more sparsely vegetated than it is now. This could have been due to windblown sediment from the mobile dune field to the south. Indeed the hummock like structure of the marsh indicates that this area was influenced by wind. Since the dunes were stabilized the area has now been colonized by plants. This was assigned a 20% change and identified as a non-flow related impact on the system. Our understanding of the impacts of different abiotic states on the macrophytes groups is summarised in Table 3.31:

Table 3.31. Responses of different groups of macrophytes to estuary state.

	State 1 **Closed**	**State 2** **Open, tidally dominated**	**State 3** **Open, fluvially dominated**
Salt marsh	The intertidal area in the middle reaches of the estuary has shallow depressions which are poorly drained and may be inundated for prolonged periods when the mouth is closed. This could result in the die back and reduction in productivity of the intertidal succulent *Salicornia meyeriana*. In the supratidal habitat there are a number of species in areas that are waterlogged or exposed to drying-out. Continual mouth closure would cause die-back and decrease cover of the plants (e.g. succulents such as *S. capenis*) after 3 months. This would decrease macrophyte diversity.	Regularly flooding by tidal exchange is important. This is critical in the maintenance of the diversity of species and the uniqueness of the intertidal vegetation, particularly in the lower reaches of the intertidal salt marsh.	The intertidal zone in the lower reaches is composed of sand and sparse growing forbs and bulbs such as *Triglochin* spp. Changes in sediment types could alter the species composition. The species *Triglochin elongata* is found in sandy areas. Changes to a finer sediment type could result in the local extinction of the species.
Reeds and sedges	Reeds and sedges are not directly affected by mouth state as they are only found at sites of freshwater seepage. However if submerged for longer than 3 months they would die-back.	Reeds and sedges are not directly affected by mouth state as they commonly occur at sites of freshwater seepage	Increased freshwater flushing to the system and an increase in the deposition of fine sediments could lead to the expansion of reeds such as *Phragmites australis.*
Submerged macro-phytes	An increase in water level and stable high water level conditions would promote the growth of the submerged macrophytes. However high nutrient input could result in macroalgae outcompeting *R. cirrhosa.*	Submerged macrophytes such as *R. cirrhosa* have a wide salinity tolerance range, therefore salinity fluctuations are unlikely to influence this species.	Should the river inflow bring more suspended matter into the system there is likely to be an increase in turbidity which would reduce cover and biomass.

	State 1 Closed	State 2 Open, tidally dominated	State 3 Open, fluvially dominated
		However this plant is sensitive to desiccation and would die when exposed.	
Macroalgae	Closed mouth nutrient rich conditions would promote the growth of macroalgae as has been observed in the system recently.	Increase in marine dominated species that are washed into the estuarine waters.	High flow conditions will result in a decrease in macroalgal biomass but an increase in species richness as more freshwater and nutrients flow into the estuary.

3.7.4 Reference condition

Low flow has resulted in mouth closure which is the most significant impact in the estuary. This combined with an increase in nutrient input has increased macroalgae growth particularly during closed mouth conditions. When the water level drops thick mats remain on the salt marsh which inhibits germination and growth. Also the increase in biomass and organic load could result in anoxic conditions during decomposition. Most of the salt marsh in the Uilkraals Estuary is supratidal. This habitat is particularly sensitive to high water level and waterlogging during closed mouth high water level conditions. High water level for greater than 6 months can result in die-back, the succulent species are usually the first to die. The cause for concern in the Uilkraals Estuary is that there are a number of rare and endemic species present which is possibly related to the biogeographic position but also the unique topography and substrate conditions. The increase in salinity would reduce germination of salt marsh seedlings in spring / summer. There is a large change in the DIN/DIP concentrations from the reference condition. This would stimulate the growth of all primary producers, particularly reeds, sedges and macroalgae. Changes and scores are summarised in Table 3.32 and Table 3.33.

Table 3.32. Summary of how the macrophytes in the Present condition have changed relative to the Reference condition.

Drivers	Changes
⇧State 1 (closed mouth)	⇧ 20% macroalgae, ⇩20% salt marsh (small loss due to development & disturbance but mainly closed mouth)
⇧Salinity (decrease in base flow)	⇩ 20% salt marsh, reed & sedge species richness
⇧Nutrients (WWTW input)	⇧ 20% macroalgae, 5% submerged, 5%reeds
⇩Decrease in wind-blown sand & flow	⇧ salt marsh
TOTAL CHANGE	⇧ macroalgae, ⇧ submerged, ⇧reeds, ⇩ salt marsh

3.7.5 Health of the macrophytes

Health scores are summarised in Table 3.33.

Table 3.33. Similarity scores of macrophytes in the Present condition relative to the Reference condition.

Variable	Change from natural	Score	Confidence
1. Species richness	Increase in flooding and water level because of mouth closure and an increase in salinity would result in a loss of sensitive species characteristic of the supratidal salt marsh hummocks and reed & sedge habitats. This would also pose a threat to the richness of this habitat. Change in nutrient status of the sandy nutrient poor substrate conditions of the salt marsh could also result in loss of specialist species adapted to these conditions. This is a rare type of salt marsh in South Africa.	60	Low
2. Abundance	Closed mouth conditions results in loss of intertidal salt marsh. There has also been a small loss of macrophytes habitat due to development and building of the road bridge. Increase in nutrient conditions from the reference condition result in an increase in macroalgae particularly during closed mouth conditions.	86	Medium
3. Community composition	Loss of intertidal salt marsh as a result of mouth closure and high water levels. Macroalgae would increase due to nutrient enrichment and could displace the submerged macrophytes. Mats of macroalgae cover the salt marsh when the water level drops causing die-back and bare patches.	54	Medium
Macrophyte health score		**54**	
% of impact non-flow related - Bridge, diminished source of sand blowing onto estuary		20%	
Adjusted score		68	

3.8 Invertebrates

3.8.1 Invertebrate groups

Estuarine benthic invertebrates show affinities to a suite of biotic and abiotic parameters (mainly vegetation, salinity and sediment properties) which determine their relative abundance and distribution throughout the system. In order to predict a response in the invertebrate community structure to changes in these parameters, the estuarine invertebrate macrofauna need to be classified according to their relative affinity for these parameters. The classification used in this study is shown in Table 3.34 where the parameters influencing different species or taxonomic groups y are shown.

Table 3.34. Classification of South African estuarine invertebrate fauna and the parameters influencing their abundance and distribution. POM = particulate organic matter, MPB = Microphytobenthos

#	Description	Influencing factors
1	Polychaetes - estuarine resident (e.g. *Ceratoneries keiskamma*)	Medium to fine sediments; detritus; prey
2	Polychaetes - marine (e.g. *Arenicola*)	Med to coarse sediments; detritus; open mouth; saline water
3	Amphipods	Finer sand/mud; shelter; detritus; POM; reduced salinity
4	Isopods	Coarse sediments; higher salinity; dead matter
5	Gastropods - marine dominated species (detritivores, scavengers & predators e.g. *Bullia*)	Detritus; open mouth; MPB; higher salinity
6	Gastropods - resident sediment living grazers, detritivores & predators (e.g. *Hydrobia*; *Natica*)	Shelter from wave action; submerged macrophytes; MPB; detritus
7	Gastropods - grazers associated with macrophytes	Shelter from wave action; submerged macrophytes; MPB
8	Bivalves - estuarine resident	Med-fine sediments; submerged macrophytes; POM
9	Bivalves - marine (e.g. *Donax*/*Tellina*)	Med-coarse sediments; open mouth; POM
10	Crabs - resident estuarine (e.g. *Spiroplax)*	Med-fine sediments; (presence of prawns for *Spiroplax*)
11	Crabs - marine (e.g. *Hymenosoma*)	Open mouth; saline
12	Carids - marine (e.g. *Palaemon*)	Med-fine sediments; detritus; open mouth; high salinity
13	Carids - resident (e.g. *Betaeus*)	Med-fine sediments; detritus; submerged macrophytes; prawns (*Betaeus*)
14	Saltmarsh inverts	Saltmarsh
15	Insect larvae	Lower salinities
16	Mudprawns (e.g. *Upogebia*)	Fine sand/mud; open mouth; POM
17	Sandprawns (e.g. *Callianassa*)	Sand; not extended fresh water (>17ppt to breed); POM
18	Zooplankton - marine	Phytoplankton; open mouth
19	Zooplankton – estuarine resident	Phytoplankton

3.8.2 Baseline description

Very little research on the invertebrate community of the Uilkraals Estuary has been undertaken and almost no quantitative data exists. Heydorn & Bickerton (1982) provide a brief anecdotal account on the presence of the following seven species: *Arenicola loveni*, *Callianassa kraussi, Upogebia africana, Hymenosoma obiculare, Diogenes brevirostris, Cyclograpsus punctatu* and *Palaemon pacificus.* The bloodworm, *Arenicola loveni*, which was previously abundant in the lower reaches of the estuary, is now absent as a result of reduced tidal water exchange and the effects of freshwater flooding caused by the construction of the road bridge in 1973 (Gaigher 1984). The construction of the bridge together with drought conditions in recent years, have changed the estuary from a predominantly open-mouth tidal system to a temporary open/closed system. It is predicted that corresponding changes in the invertebrate community structure have occurred, but this is hard to quantify due to the aforementioned lack of baseline research on the system. We have therefore inferred the reference condition of the Uilkraals based on the results of the present survey including several species present in the Heuningnes system which are expected to be present in a reference scenario (i.e. without any human impact on the system).

There are no data on zooplankton but under closed mouth conditions, marine species would be restricted from entering the estuary. Thus our assessment concentrates on subtidal and intertidal benthic invertebrates. Three replicate core and grab samples were collected from the intertidal and subtidal zones at five sites, respectively, in the estuary (Figure 3.33). A list of the species collected during this study is given in Table 3.35.

Figure 3.33. Invertebrate sampling stations in the Uilkraals estuary.

Table 3.35. Species collected in the present survey and their classification.

Species	Category	Taxon	Trophic functional group
Capitellid worm	1	Polychaeta	Detritivore
Ceratonereis keiskamma	1	Polychaeta	Detritivore
Terrebellid/Ampharetid	1	Polychaeta	Detritivore
Melita zeylanica	3	Amphipoda	Detritivore
Monocorophium acherusicum	3	Amphipoda	Filter Feeder
Corophium sp.	3	Amphipoda	Detritivore
Eurydice kensleyi	4	Isopoda	Scavenger
Hydrobia spp.	6	Mollusca	Detritivore
Spiroplax spiralis	10	Brachyura	Detritivore
Diogenes brevirostris	11	Anomura	Scavenger/Filter Feeder
Hymenosoma obiculare	11	Brachyura	Predator
Betaeus jucundus	13	Caridea	Detritivore
Telmatogeton minor	15	Insecta	Scavenger
Upogebia africana	16	Anomura	Detritivore
Callianassa kraussi	17	Anomura	Detritivore

Lower reaches of estuaries usually have sandy bottoms and are more saline whereas the middle and upper reaches are characterised by finer sediment and are less saline (Day 1951). Teske & Wooldridge (2003) have shown that the nature of sediment particle size is more important than salinity in limiting the distribution of macrobenthos within several South African estuaries. Apart from site 8.3, results in **Error! Reference source not found.** show a uniform distribution of fine sediment from site 1 near the mouth to site 9/10 in the upper reaches, which is indicative of a prolonged closed mouth condition observed during the April survey.

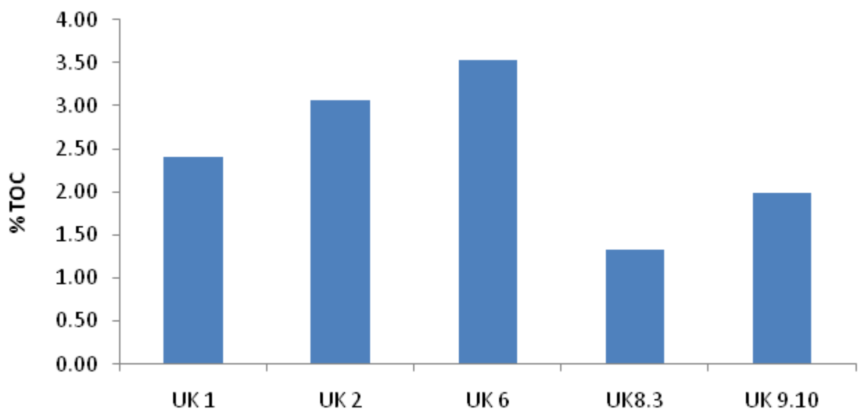


Figure 3.34. Percentage total organic carbon content (April survey).

Comment [BC1]: Add sites where they were collected and maybe abundance as well

Comment [NT2]: This species is most likely to be *Corophium sp. Probably C. triaenonyx – common in estuaries in SA.*

Comment [NT3]: Please ensure that it is not E. longicornis, a typical sand dweller sometimes associated with lower estuary

Comment [NT4]: Is it not Thaumastoplax spiralis?

Comment [NT5]: Thaumastoplax spiralis?

Comment [NT6]: Results on which species contributed most to the observed are not clear (taxonomic grouping encompasses everything). It is important to include this as it gives characteristic species of each zone against which temporal changes can be compared assessed.

Comment [BC7]: Aiden to fix graphs – remove .3 and .10

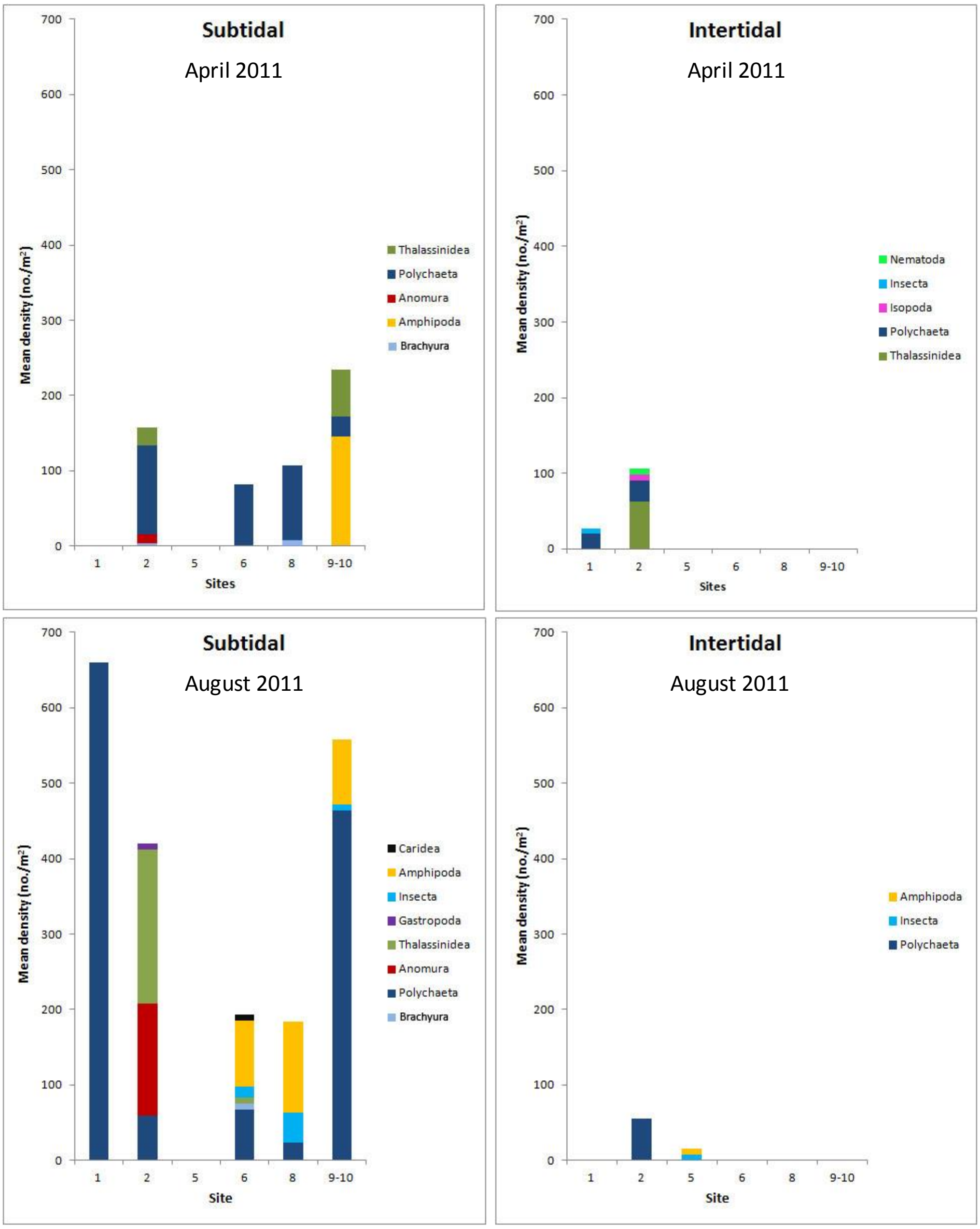


Figure 3.35. Mean ab~~d~~undance of the invertebrate macrofauna sampled in the Uilkraals Estuary in April and August for both subtidal and intertidal zones. The fauna have been placed in higher order taxonomic groups in order to provide an indication of diversity.

Comment [NT8]: *U. africana* and C. *kraussi* are under Anomura which is the taxonomic grouping.
Use mollusca instead of gastropoda

Based on these results and the lack of tidal water exchange we would expect sediment particle size and TOC to have less of an influence on the distribution of the macrobenthos than they would otherwise normally have in a predominantly open mouth system i.e. invertebrate community structure would not vary from the lower reaches to the upper reaches as one would expect it to under "normal" conditions.

Mean abundance and proportions of the different invertebrate macrofaunal taxonomic groups at each site are shown in Figure 3.35. Most notable is the significantly lower abundance of individuals in the intertidal zone in comparison to the greater abundance of individuals in the subtidal zone for both sampling periods. This is a known trend (Branch, 1981), which has been further compounded by the presence of a thick matt of dead filamentous macroalgae which covered the intertidal mudflats and sand banks during the April field trip. The dead macroalgae depleted the underlying fauna of oxygen leaving the mud beneath it black, anoxic and void of macrofauna. It is also apparent from the results that diversity and abundance were far greater during the August trip when the mouth was open in comparison to the April trip when the mouth was closed. Apart from the Amphipoda and Anomura, most taxa showed no affinity to zones of their position in the estuary during the April survey. However, in August when the mouth was open, prawns were not found above site 2 and the polychaetes in the lower reaches were dominated by a Capitellid species which was not found above site 6.

3.8.3 Factors affecting the invertebrate fauna

The main factors affecting the abundance of the different invertebrate groups found in the Uilkraals estuary are summarised in Table 3.24.

Figure 3.36. Effect of abiotic characteristics and processes, as well as other biotic components on invertebrate groupings

Factor	Affected categories
Mouth condition (provide temporal implications where applicable)	Closed mouth leads to decrease in species richness (absence of marine associated species). Reductions in tidal exchange due to a constricted mouth (bridge construction and siltation) have allowed estuarine resident species to proliferate (category 1, 3, 15, 19). Open mouth linked to increased salinity values and opportunity for euryhaline species (category 2, 4, 5, 9, 11, 12, 13, 16, 17, 18) to increase in biomass and abundance if salinity increases from a low base (<10). An open mouth is also important for the input of larvae into the estuary from the marine environment for recruitment and vice versa.
Retention times of water masses	An increase in retention times of water masses will increase the abundance of macroalgae which, in turn, leads to a decrease in abundance of intertidal invertebrate macrofauna (observed in April survey). Furthermore, increased retention times would favour estuarine resident subtidal macrofauna tolerant of reduced salinity (category 1, 3, 6, 7, 8, 15, 19).
Flow velocities (e.g. tidal velocities or river inflow velocities)	Increased flow velocities would scour and flush the system of fine sediment leaving a greater proportion of coarse sediment towards the lower reaches which is less preferential to burrowing species – essentially most of the species recorded in this study. Phytoplankton levels would decrease in response to high flow velocities, thereby limiting the amount of food available to zooplankton.

Factor	Affected categories
Total volume and/or estimated volume of different salinity ranges	A change in total volume or estimated volume of different salinity ranges would result in a corresponding change in habitat accessible to the invertebrate macrofauna, particularly if the mesohaline area increases (salinity values above 17-20 particularly benefits categories 16 and 17). Associated species would respond accordingly – i.e. marine dominated species would increase with a greater marine volume component and estuarine resident species would retreat to the upper reaches, where there is less habitat available and vice versa.
Floods	A severe flood would scour the system, flushing most macrobenthic invertebrates out to sea and inundating the system with a high sediment load. Therefore an initial decrease in abundance of all invertebrates would be expected followed by a steady increase as the fauna recovers and exploits the newly available nutrients, detritus and particulate organic matter.
Salinities	A decrease in salinity would have a greater negative impact as most of the invertebrates associated with the Uilkraals are adapted to life in a tidal system where the salinity is almost that of sea water. However, categories 1, 3 and 4 have a wide salinity range and are able to tolerate low salinity values (<10) but abundances would be affected by the duration of low salinity regimes. If salinity falls too low breeding ceases until conditions become more favourable again. Because the system is historically tidal, higher salinities would favour most species which occur there.
Turbidity	Little to no effect on benthic forms
Dissolved oxygen	Oxygen levels below ~50% surface saturation will have a negative effect on populations of zooplankton (category 18, 19). Oxygen levels below ~50% surface saturation will have a negative effect on populations of all other invertebrate species, however, the polychaete *Capitella capitata* (category 1) will tolerate extremely low values. Category 8 and 9 are able to withstand temporary periods of hypoxia.
Subtidal, intertidal and supratidal habitat	Different benthic invertebrate macrofauna show differening affinities for intertidal and subtidal habitats and changes in the availability of these two habitat types will influence the relative abundance of these taxa. No benthic invertebrate macrofauna have been recorded in the supratidal habitat of the Uilkraals.
Sediment characteristics (including sedimentation)	Species composition likely to change if particle size composition of sediments change. Open mouth states favour upstream intrusion of marine sandy sediment which favours sand-dwellers. The dominant species *Callianassa kraussi* (category 17) requires a sandy substrate and this generally occurs in the lower third of the estuary. On the other hand, *Upogebia* (category 16) requires finer muddier substrata, therefore changes to sediment type will limit abundance and distribution of these categories. Increased sedimentation would temporarily smother subtidal and intertidal habitats.
Phytoplankton biomass	An increase in phytoplankton would result in an increase in zooplankton (categories 18 and 19).
Benthic micro-algae biomass	Increased benthic microalgal biomass will favour burrowing forms such as categories 3 and 4.
Zooplankton biomass	During closed mouth phase zooplankton biomass will be low. Subsequent increases in biomass will coincide with open mouth phases which favours tidal exchange enabling marine species to enter the estuary. Since zooplankton rely on water column for movement, tidal intrusion will enhance colonisation of upper sites, Salinity increases upstream will also favour euryhaline species.

Factor	Affected categories
Aquatic macrophyte cover	*Callianassa kraussi* abundance and biomass will decrease and favour other species such as *Exosphaeroma hylocoetes, Cyathura estuaria, Arcuatula capensis* who all favour vegetated areas. Generally, a major shift in the overall estuary community structure. Highly detrimental in extreme cases to all intertidal benthic invertebrate macrofauna – macroalgal cover results in hypoxic conditions in the underlying sediment resulting in mass mortality.
Fish biomass	Increased predation on invertebrates if fish biomass increases

3.8.4 Reference condition

Under reference conditions, the system was strongly tidal with extensive intertidal sand and mud flats, which would have provided ideal habitat for both estuarine and marine species such as *Callianassa kraussi, Upogebia africana* and in particular *Arenicola loveni* towards the lower reaches. With the mouth permanently open, *Upogebia africana* would constitute a greater proportion of the prawn population in comparison to the present temporary open mouth condition where *Callianassa kraussi* is by far the dominant prawn species. It would be expected that additional marine and estuarine species would be present in similar permanently open-mouth systems like the nearby Heuningnes Estuary. Such species would be represented by the following taxa: polychaetes (e.g. *Ceratonereis erythraeensis*, *Lumbrinereis brevicirra*, *Nephtys capensis*), isopods (e.g. *Pontogeloides latipes*), gastropods (e.g. *Natica spp.*), brachyurans (e.g. *Paratylodiplax spp.*), carids (e.g. *Palaemon pacificus*) and various species of marine associated zooplankton. A greater tidal range would exist in the lower reaches of the system with saltwater penetrating further upward in comparison to the present scenario. This would influence the distribution of estuarine, brackish and freshwater taxa in a similar fashion – pushing them up towards the middle reaches of the system.

3.8.5 Health of the invertebrate component

Health scores for the invertebrate component are provided in Table 3.36.

Table 3.36. Similarity scores of Invertebrates in the Present condition relative to the Reference condition.

Variable	Change from natural	Score	Confidence
1. Species richness		45	L
2. Abundance		53	L
3. Community composition		51	L
Invertebrate score		**47**	
Degree to which deviation from natural is due to non-flow related impacts		10	
Adjusted score		53	

3.9 Fish

3.9.1 Fish groups

Estuaries provide an extremely important habitat for fish in southern Africa. The vast majority of coastal habitat in southern Africa is directly exposed to the open ocean, and as such is subject to intensive wave action throughout the year (Field & Griffiths 1991). Estuaries in southern Africa are thus disproportionately important relative to other parts of the world, in that they constitute the bulk of the sheltered, shallow water inshore habitat in the region. Juveniles of many marine fish species in southern Africa have adapted to take advantage of this situation, and have developed the necessary adaptations to enable them to persist in estuaries for at least part of their life cycles. There are at least 100 species that show a clear association with estuaries in South Africa (Whitfield 1998). Most of these are juveniles of marine species that enter estuaries as juveniles, remain there for a year or more before returning to the marine environment as adults or sub-adults where they spawn, completing the cycles. Several other species also use estuaries in southern Africa, including some that are able to complete their entire life cycles in these systems, and a range of salt tolerant freshwater species and euryhaline marine species. Whitfield (1994) has developed a detailed classification system of estuary associated fishes in southern Africa. He recognized five major categories of estuary associated fish species and several subcategories (Table 3.37).

Table 3.37. Classification of South African fish fauna according to their dependence on estuaries (Whitfield 1994)

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

Fish species in categories I, II, and V as defined by Whitfield (1994) are all wholly or largely dependent on estuaries for their survival and are hence the most important from an estuary conservation perspective. These species need to receive most attention from a management perspective.

3.9.2 Baseline description

The Uilkraals Estuary is categorised as a cool-temperate temporarily open-closed estuary, therefore its icthyofaunal composition is likely to be consistent with other estuaries in the same category. Fish in estuaries respond to their environment in a consistent manner and estuaries with similar habitats and environmental regimes support similar species assemblages (Whitfield 1998).

A few surveys have been undertaken of fish of the Uilkraals estuary in the last two decades (1994, 1996 and 2011), and some anecdotal reports exist on the fish fauna of the estuary prior to this time. Harrison (1999) sampled the estuary using beach- seine and gill nets in 1994, and reported the presence of only four species in the system (Table 3.38). Clark & Turpie (Unpublished) reported 12 species in 1996, and in this study, 12 species were recorded in April 2011 and four species in August 2011 (Table 3.38). The reason for the low numbers of species reported by Harrison (1994) is not clear and may be related to low sampling effort and seasonal influences. Low numbers of species recorded by Clark in the August 2011 survey is most likely a function of the fact that this survey was undertaken during very low water conditions in winter, soon after a flood that would have flushed most of the fish out of the system.

The similarity in the season of the March 1996 and April 2011 surveys undertaken by Clark, allows for certain inferences to be drawn regarding the impact of recent changes in mouth state on fish fauna of the system, given that the mouth was closed in April 2011. The greatest changes were reflected in the change in abundance of Category Ia species (resident species that breed only in estuaries), Ib species (species that breed in estuaries and the sea), and in the marine migrants species (Category IIa and b, and II). The relative proportion of Category Ia species had increased dramatically since 1996 (up from 0.7 to 41.3% of fish numbers), while Category Ib species had decreased in an equally dramatic manner (from 79 to 19% of fish numbers). This could be explained by the fact that open, marine dominated systems more favourable for Category Ib species, whereas closed, freshwater water-dominated conditions are more favourable for Category Ia species. The differences observed may also have reflected changes in the trophic status of the estuary and hence food availability for these two groups, but because of the paucity of data on microalgae and invertebrates (particularly zooplankton), this could not be confirmed. While little change was evident in the relative contribution by marine migrant species between the 1996 and 2011 (mostly a function of their low abundance relative to the estuarine resident species), reductions in their absolute abundance (e.g. of harders *Liza richardsonii* and white stumpnose *Rhabdosargus globiceps* both of which have declined in abundance by more than 70%) and in the number of species present (loss of at least two species - evil eye blassop *Amblyrhynchotes hokenii* and sand shark *Rhinobatos blochii)* were evident and are also most likely a result of reduced tidal exchange and marine influences in the estuary. Anecdotal reports by Heydorn & Bickerton (1982), amongst others (e.g. G F van Wyk, G. Brett), confirm that a number of other marine species, such as white steenbras *Lithognathus lithognathus* and leervis *Lichia amia,* that were once abundant in the estuary but now no longer occur in the system, are indicative of longer term changes in the estuary, *viz*. progressive reduction of tidal exchange and marine influence over time.

Table 3.38. Species composition and abundance of fish in seine net surveys of the Uilkraals estuary in 1994, 1996 and 2011.

		1994	Apr 1996		Mar 2011		Aug 2011	
Species	**Category**	**No./ haul**	**No./ haul**	**kg/ha**	**No./ haul**	**g/ haul**	**No./ haul**	**g/ haul**
Caffrogobius multifasciatus	Ia				6.2	15.8	0.3	3.7
Gilchristella aestuaria	Ia		114.9	31.7	999.1	578.4	58.2	21.9
Atherina beviceps	Ib	18.5	61.8	17.0	301.2	167.6		
Caffrobius nudiceps	Ib		6.7	11.0	1.2	2.4		
Psammogobius knysnaensis	Ib	1.0	13 284.2	700.7	149.5	81.3	9.0	8.1
Mugil cephalus	IIa	0.3	36.7	303.3	1.2	26.0		
Liza dumerilii	IIb		3.3	496.7	66.0	1068.0		
Liza tricsuspidens	IIb				0.4	90.0		
Solea bleekeri	IIb		6.7	33.3	0.4	3.2		
Heteromycteris capensis	IIb		213.3	233.3				
Liza richardsonii	IIc	139.5	3 036.7	42492.0	875.4	7033.0	2.3	0.9
Rhabdosargus globiceps	IIc		110.0	52.7	31.2	703.2		
Amblyrhynchotes hokenii	III		33.3	70.3				
Rhinobatos blochii	III		20.0	58020.0				
Galaxias zebratus	IVa				2.6	0.8		

3.9.3 Factors affecting the fish community

Table 3.39 provides a summary of the fish responses to abiotic processes and other biotic responses.

Table 3.39. Summary of fish responses to abiotic processes and biotic components.

Factor	**Ia. Estuarine residents (breed only in estuaries)**	**Ib. Estuarine residents (breed in estuaries and the sea)**	**IIa. Estuary dependent marine species**	**IIb and c. Estuary associated species**	**III. Marine migrants**	**IV. Freshwater species**
Mouth condition	Resident species proliferate under closed mouth conditions		Abundance and richness of marine migrant communities declines as frequency and duration of mouth closure increases			
Retention times of water masses	Food (zooplankton) abundance for all groups increases with increased retention times, also favour resident and freshwater species over marine migrants					
Flow velocities (e.g. tidal velocities or river inflow velocities)	Resident species move upstream when flow velocities increase	Migrant species exploit tidal currents when migrating into the estuary				

Factor	Ia. Estuarine residents (breed only in estuaries)	Ib. Estuarine residents (breed in estuaries and the sea)	IIa. Estuary dependent marine species	IIb and c. Estuary associated species	III. Marine migrants	IV. Freshwater species
Total volume and/or estimated volume of different salinity ranges	Increased volume translates to an increase in available habitat for all species, especially those that spend most of their time in the water column. Brakish water habitat good for resident and estuary associated marine migrants while marine water is good for marine species					
Floods	Resident species move upstream at the onset of floods	Juvenile marine and catadramous species use floods as a cue for locating and migrating into estuaries, find refuge in the marginal areas during floods, adults and sub-adults exit during floods				High flow velocities may flush some individuals downstream into the estuary
Salinities	Resident and estuary associated marine species tolerant of salinities in the range 0-35 PSU				Tend to stay as close to 35 psu as possible. Stressed under 20 psu.	Highly variable most prefer much < 10 PSU
Turbidity			Little discernible response to turbidity.	Turbidity preferences vary among species	Generally prefer low turbidity	Indigenous Galaxias likes clear blackwater.
Dissolved oxygen	Most resident and estuary associated marine species become stressed when oxygen drops below 4 mg.l^{-1}. Gobies (particularly *Caffrogobius* spp.) tend to be more tolerant of low oxygen than other species.				Little tolerance to low oxygen levels/hypoxia and unable to practice surface breathing.	Indigenous species (Galaxias) highly tolerant of low oxygen
Subtidal, intertidal and supratidal habitat	All the fish are confined to the subtidal at low tide but forage in the intertidal during high tide. Intertidal reaches are nonetheless extremely important foraging areas for most fish species. Shallow marginal areas tend to be warmer than deeper channel areas and are thus favourable for metabolic processes. Juveniles and small adults also use shallow water as a predation refuge.					Freshwater species seldom occur in tidal reaches of estuaries
Other abiotic components	Low temperatures increase tolerance to hypoxia and low salinities. Most species tolerant of low pH					
Sediment characteristics (including sedimentation)	Individual species preferences are highly variable and related to preferred food sources					
Phytoplankton biomass	Filter feeding species benefit from high phytoplankton biomass (increased food) but harmful algal blooms may clog gills or be toxic to fish. High phytoplankton production contributes to turbidity in estuaries and probably favours those species with higher turbidity preferences.					

Factor	Ia. Estuarine residents (breed only in estuaries)	Ib. Estuarine residents (breed in estuaries and the sea)	IIa. Estuary dependent marine species	IIb and c. Estuary associated species	III. Marine migrants	IV. Freshwater species
Benthic micro-algae biomass	Detritivores especially mullet benefit from high microalgae biomass , but benthic microalgae mats may cover intertidal sand/mud flats and reduce available foraging area in estuaries. High benthic microalgae biomass can cause hypoxia especially at night.					
Zooplankton biomass	Filter and particulate feeders benefit from increased zooplankton biomass. Many species are able to switch between filter and particulate feeding modes to take advantage of dominant food sources					
Aquatic macrophyte cover	Juveniles of most fish species find refuge in the macrophytes during the daytime but move into open water during the night as oxygen levels drop.					
Benthic invertebrate biomass	Many estuary associated fish species feed on benthic invertebrates and will thus benefit from increases in benthic invertebrate biomass					
Fish biomass	No piscivorous species in these categories		Piscivorous fish e.g. *Lichia amia* & *Pomatomus saltatrix* benefit from high biomass of estuarine resident and small marine migrants in the estuary.			No piscivorous freshwater fish species present

3.9.4 Reference condition

Under reference conditions, the estuary was probably very strongly tidal and had extensive sandy intertidal areas that provided ideal foraging and nursery areas for adults and juveniles of a wide range of marine migrant species (both estuary-associated marine species as well as marine 'vagrants' – e.g. white steenbras *Lithognathus lithognathus*, leervis *Lichia amia*, white stumpnose *Rhabdosargus globiceps*, sand shark *Rhinobatos blochii*). These species, together with sand (as opposed to mud) associated estuarine resident species such as the Cape sole *Heteromycteris capensis* and knysna sand goby *Psammogobius knysnaensis* most likely dominated the ichtyofauna of the estuary under these conditions. Mud associated resident species would most likely have been largely confined to the narrower channels in the upper reaches of the estuary. The silverside *Atherina breviceps* and various species of mullet (*Liza richardsonii, L. tricuspidens, L. dumerilii,* and *Mugil cephalus*) would have been very important in the system while *Gilchristella aestuaria* (currently the most abundant species) would have been less important. Eels *Anguilla mossambica* and *A. marmorata* although they have not been recorded in the system in recent times, probably still move through the estuary on their way upstream but nowhere near in the numbers that were historically present.

3.9.5 Health of the fish component

Scores are provided in Table 3.40.

Table 3.40. Similarity scores of fish in the Present condition relative to the Reference condition.

Variable	Change from natural	Score	Confidence
1. Species richness	Significant reduction in numbers of marine migrant species in the estuary under present state (estuary associated marine species as well as marine vagrants)	64	M
2. Abundance	Significant reduction in abundance and biomass of fish in the estuary due to mostly associated with reduced numbers of marine migrant species in the estuary under present state (estuary associated marine species as well as marine vagrants)	46	L
3. Community composition	Significant change in community composition from a fish community that was almost certainly dominated (>75% contribution) by marine migrants species to one that is now dominated by estuarine resident species	62	L
Fish score		**52**	
% due to non-flow related impacts Mainly due to reductions in overall marine populations; a small amount of fishing.		30%	
Adjusted score		66	

3.10 Birds

3.10.1 Available information

Only a few counts of birds have been conducted at the Uilkraals estuary (Table 3.41), most of which have been in summer, and some of which have been partial counts, either in terms of estuary coverage or the types of birds counted.

Table 3.41. Summary of bird count information at Uilkraals Estuary.

Date	Type of count	Number of species	Total abundance	Wader abundance	Reference
January 1976	Waders	32	Not counted	774	Summers *et al.* 1976
January 1976	Full	17	4864	720	Summers unpublished data
December 1979	Full	26	5879	584	Heydorn & Bickerton 1982
January 1981	Full	22	6746	880	Ryan *et al.* 1988
February 1996	Full	30	2180	1041	Barnes 1996
February 2010 *	Lower 3km	22	435	60	Anchor Environmental 2011
April 2011*	Full	26	275	93	This study
August 2011	Full	33	657	161	This study

* The estuary was closed during these counts

3.10.2 Bird groups

For the purposes of this study, the birds found on the estuary have been grouped into nine groups (Table 3.42). Gulls and terns (mainly gulls) dominate the avifauna at present, with waders and waterfowl being the next two most common groups (Figure 3.37). Numbers of piscivorous birds actually feeding in the estuary (i.e. excluding gulls and terns) are low.

Table 3.42. Major bird groups found in the Uilkraals Estuary, and their defining features.

Bird groups	Defining features, typical/dominant species
Piscivorous cormorants	The estuary supports a few species of pursuit swimming piscivores which catch their prey by following it under water and therefore prefer deeper water habitat. These include Reed Cormorant, Cape Cormorant, White-breasted Cormorant and African Darter.
Piscivorous wading birds	This group comprises the egrets, herons, ibises and spoonbill. Loosely termed piscivores, their diet varies in plasticity, with fish usually dominating, but often also includes other vertebrates, such as frogs, and invertebrates. The ibises were included in this group, though their diet mainly comprises invertebrates and is fairly plastic. They tend to be tolerant of a wide range of salinities. Wading piscivores prefer shallow water up to a certain species dependant wading depth.

Bird groups	Defining features, typical/dominant species
Herbivorous waterfowl	This group is dominated by species that tend to occur in lower salinity or freshwater habitats and are associated with the presence of aquatic plants such as *Potamageton* and *Phragmites*. The group includes some of the ducks (e.g. Southern Pochard), and all the rallids (e.g. Redknobbed Coot, African Purple Swamphen). Some herbivorous waterfowl such as Egyptian Goose probably feed in terrestrial areas away from the estuary and floodplain as well as in the estuary.
Omnivorous waterfowl	This group comprises ducks which eat a mixture of plant material and invertebrate food such as small crustaceans - Yellow-billed Duck, Cape Teal, Red-billed Teal and Cape Shoveller. Although varying in tolerance, these species are fairly tolerant of more saline conditions.
Benthivorous waders	This group includes all the waders (e.g. Greenshank, Curlew Sandpiper). They are the smallest species on the estuary, and feed on benthic macroinvertebrates in exposed and shallow intertidal areas. Invertebrate-feeding waders forage mainly on exposed sandbanks, mudflats and in the inter-tidal zone. A few resident species occur such as White-fronted Plover and Black-winged Stilt. Many species of palearctic migrants have been recorded on the estuary, often in fairly high numbers.
Piscivorous gulls & terns	This group comprises the rest of the Charadriiformes, and includes all the gull and tern species using the estuary. These species are primarily piscivorous, but also take invertebrates. Most are euryhaline, but certain tern species on the estuary tend to be associated with low salinity environments. Gulls and terns can be very abundant and use the estuary primarily for roosting
Piscivorous kingfishers	Three species of kingfishers occur on the estuary in low numbers. They breed and perch on the river banks and prefer areas of open water with overhanging vegetation.
Piscivorous birds of prey	At Uilkraals the African Fish Eagle is the only species in this group. They are not confined to a diet of fish, also taking other vertebrates and invertebrates.
Other birds of prey	The Marsh Harrier has been recorded on the estuary in the past, and feeds on small vertebrates such as mice and frogs.

3.10.3 Baseline description

The Uilkraals Estuary has been ranked 14th in terms of waterbird abundance in a conservation priority analysis study (Turpie 1995). Regionally, it was ranked 11th out of 65 coastal wetland systems in the south-western Cape in terms of total bird numbers supported (Ryan *et al.* 1988). The estuary has supported large numbers of terns and migratory waders in the past (Summers *et al.* 1976, Heydorn & Bickerton 1982, Ryan *et al.* 1988) and has been recognised as one of the largest mainland tern roosts in the south-western Cape (Ryan *et al.* 1988). A total of 51 water-associated bird species have been recorded at the Uilkraals Estuary, with about 30 species recorded per count. In recent counts (2010-11) between 429 and 657 birds have been recorded on the estuary.

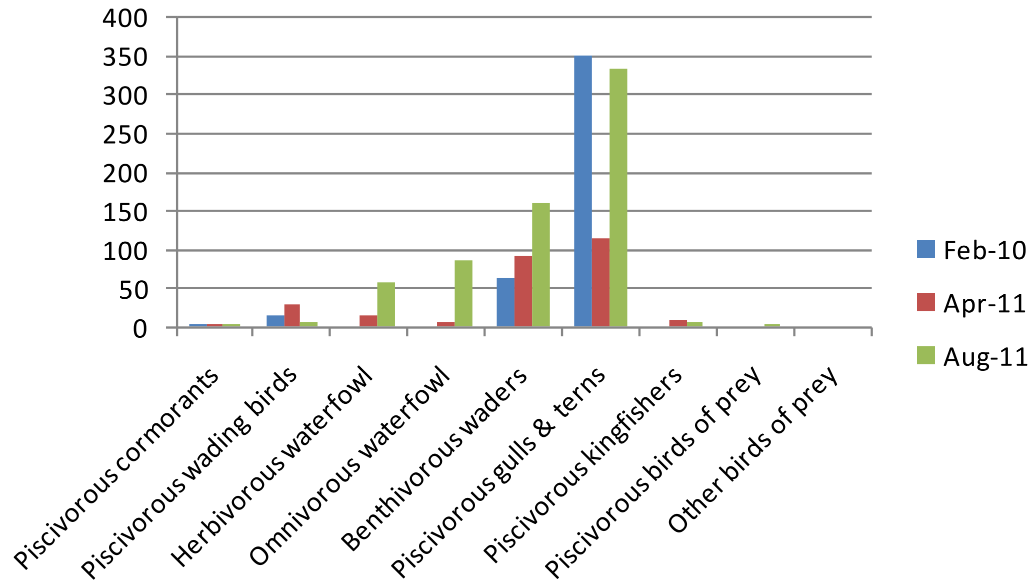


Figure 3.37. Bird community composition on the estuary during different months in 2010-11.

3.10.4 Factors driving waterbird community structure and abundance

Some of the main influencing factors to be considered in estimating the bird community under reference conditions and the alternative scenarios are listed in Table 3.43.

Table 3.43. Effect of abiotic characteristics and processes, as well as other biotic components on bird groupings

Factor	Cormorants & wading piscivores	Kingfishers & fish-eagle	Waterfowl	Waders, gulls and terns
Mouth condition	Indirectly, through influence on water level and fish		Indirectly, through influence on macrophytes	Mouth closures has negative effect on preferred sandbanks in lower estuary
Salinities			Certain species of waterfowl prefer lower salinities	
Turbidity	Negatively affects visibility for foraging	Negatively affects visibility for foraging		
Intertidal area				Waders rely mostly on intertidal areas for feeding.

Factor	Cormorants & wading piscivores	Kingfishers & fish-eagle	Waterfowl	Waders, gulls and terns
Sediment characteristics (including sedimentation)				Most waders prefer med to fine sand; a few prefer coarse sand
Primary productivity	Indirectly though influence on food supply			
Submerged macrophytes abundance			Has positive influence on herbivorous waterfowl numbers	
Abundance of reeds and sedges			Has positive influence on some herbivorous waterfowl species	
Abundance of zooplankton			Assumed positive for some omnivorous species	
Benthic invertebrate abundance				Primary food source for invertebrate-feeding waders
Fish biomass	Piscivores will increase with increasing numbers of small to medium-sized fish			

3.10.5 The reference condition

Many things have changed in the last 20-30 years, including the construction of the bridge over the estuary, the reduction in catchment flows due to invasive alien species, the construction of a dam, and the increase in numbers of people using the estuary for recreational purposes. The most dramatic change has been the closure of the mouth during the past few years. During two of the three most recent counts, the estuary mouth was closed and water levels in the estuary were low.

Under closed mouth conditions, the large intertidal feeding habitat which covered the entire sandflat region below and above the road bridge was lost. Most intertidal invertebrates had probably desiccated and died or migrated elsewhere. While many sand prawn burrows were still present, these animals would have been very deep and not accessible as a food source.

Previous counts conducted between 1976 and 1981 showed bird abundances ranging from 4 864 to 6 746 non-passerine waterbirds. The count conducted in 1996 showed a decrease of over 4 500 individuals compared to the 1981 count. This was due to much lower numbers of terns being recorded, also on subsequent visits to the estuary in the following few days. This decrease was probably caused by changes in habitat availability. Increased erosion and changes in sedimentation and river flow have occurred as a long-term result of the causeway supporting the bridge built in 1973, and the erection of a rubble embankment (Barnes 1996), and more recently the decreased flows due to the upstream dam. Nevertheless, the number of invertebrate-feeding waders present at the estuary was still high in 1996 (Table 3.41), with some 17 species present at that time. By 2010-11, total bird numbers had dropped dramatically, the avifauna was dominated by gulls, and the number of waders had been reduced to about a tenth of their former abundance (Table 3.41). The large flocks of migratory waders that had been recorded in the past have been all but absent in the last few counts, and the number of wader species present had been reduced to 9 or 10 per count.

The low numbers of terns recorded are of particular concern as this site was once a major roost for several tern species including the Caspian Tern, Sandwich Tern and Swift Tern, of which it hosted 6.8%, 2.8% and 6.6% respectively of the south-western Cape's population (Barnes 1996). Whimbrel has previously been recorded in high numbers at the estuary (76 and 65 individuals) making it the second largest population in the south-western Cape after Langebaan Lagoon (Barnes 1996). A maximum of 17 individuals were recorded in 2010-11. Although migratory waders such as Whimbrel are reasonably sensitive to disturbance the main reason for their disappearance from the system is likely to be the loss of intertidal feeding habitat.

In its reference condition the estuary is likely to have been similar to the conditions found in the early 1980s, where the avifauna were typical of a fairly large open estuary with extensive productive mudflats and sandy islands in the mouth area.

Table 3.44. Summary of how the bird groups in the Present condition have changed relative to the Reference condition.

Parameters	Present
⇩Decrease in area of saltmarsh and reedmarsh ⇧Salinity ⇧Waterfowl populations	Waterfowl numbers probably similar to reference
⇩Decrease in fish abundance	⇩ 25-50% decrease in piscivorous cormorants and wading birds
⇩Decrease in fish abundance + increase in perches (alien veg)	⇧ 50% increase in kingfishers
⇩Major decrease in availability of regularly-inundated intertidal area	⇩ benthivorous waders = 23% of reference
⇩Decrease in tidal flows	⇩ suitable tern roosting habitat, gull and tern numbers are about 8% of reference condition
TOTAL CHANGE	⇩ waders ⇩ terns ⇩ most piscivores

3.10.6 Health of the avifaunal component

In its reference condition the estuary is likely to have been similar to the conditions found in the early 1980s, where the avifauna were typical of a fairly large open estuary with extensive productive mudflats and sandy islands in the mouth area. The main changes have been the loss of large numbers of terns and migratory waders from the estuary. Changes in waterfowl numbers have probably been relatively minor. Changes and scores are summarised in Table 3.44 and Table 3.45.

Table 3.45. Similarity scores of birds in the Present condition relative to the Reference condition.

Variable	Change from natural	Score	Confidence
1. Species richness	Several species that have been recorded in the past have not been recorded in recent counts, and several that were once abundant are now relatively rare; this would have a significant impact on the average instantaneous species richness	70	M
2. Abundance	Only about 12% of original bird numbers remain; loss of numbers mainly due to loss of waders and terns.	12	M
3. Community composition	In summer, loss of wader and tern components, though no noticeable replacements by other groups; winter community will have changed less. Disproportionate reduction of invertebrate feeders	22	M
Bird score		**24**	**M**
% impact due to non-flow related impacts - Global losses in numbers of migratory waders; increases in the western cape of certain species of wading birds and waterfowl; increased estuary productivity due to pollution.		15	
Adjusted score		35	

3.11 PRESENT ECOLOGICAL STATUS

3.11.1 Overall EHI score

The Estuarine Health Index (EHI) scores allocated to the various abiotic and biotic health parameters for the Uilkraals Estuary and the overall Present Ecological Status (PES) for the system under the present state are calculated from the overall EHI score (Table 3.46).

The EHI score for the Uilkraals Estuary in its present state was estimated to be 49 (i.e. 49% similar to natural condition, which translates into a Present Ecological Status (PES) of D (summarised in Table 3.47). The Uilkraals Estuary is presently in a D state arising from major changes in the mouth condition of the estuary, coupled with sewage-related pollution of the system.

Table 3.46. PES scores and descriptions

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

Table 3.47. Estuarine Health Score (EHI) for the Uilkraals Estuary, the estimated Estuarine Health Score with non-flow related impacts removed, and confidence levels (scores are derived to produce overall confidence).

Variable	Health score/100	Health score net of non-flow related impacts	Confidence score	Confidence
Hydrology	25	25	30	Very low
Hydrodynamics and mouth condition	65	65	30	Very low
Water quality	59	83	50	Low
Physical habitat alteration	51	66	50	Low
Habitat health score	**50**	**59**	**40**	**Very low**
Microalgae	59	67	43	Low
Macrophytes	60	68	63	Medium
Invertebrates	47	47	50	Low
Fish	52	66	57	Low
Birds	24	66	70	Medium
Biotic health score	**48**	**63**	**57**	**Low**
ESTUARY HEALTH SCORE	**49**	**61**		
PRESENT ECOLOGICAL STATUS	**D**	**C**		
OVERALL CONFIDENCE			**48**	**Low**

3.11.2 Relative contribution of flow and non-flow related impacts on health

Estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an adjusted health score of 61, which would raise the PES to a C category. This suggests that non-flow impacts have played a major role in the degradation of the estuary to a D, but that flow-related impacts are the main cause of its degradation. Thus the highest priority is to address the quantity and quality of influent water. Of the non-flow-related impacts, water quality problem as a result of sewage pollution in the estuary was found to be the most important factor that influenced the health of the system.

3.11.3 Overall confidence

Confidence levels were very low for three of the components. The fact that these included hydrology and hydrodynamics meant that they affected the confidence of all subsequent components. Only two components had enough data to yield medium-confidence assessments. The overall confidence of the study was LOW (Table 3.47).

The implications of this are that

(c) one has to be extremely cautious and apply the precautionary principle in setting the Preliminary Reserve; and
(d) efforts should be made to collect baseline and monitoring data that will help to fill some key gaps in understanding.

Key gaps in our understanding pertain to the abiotic aspects of the estuary. The primary gap is the lack of good data on outflows from the main dam in the catchment. Hydrological understanding would also be improved with better flow data and so that estimates of daily flows can be derived. Data pertaining to hydrodynamics data are also required, including more accurate data on water levels, berm heights and breaching.

4 THE RECOMMENDED ECOLOGICAL CATEGORY

4.1 Conservation Importance of the Uilkraals Estuary

The Estuary Importance Score (EIS) for the estuary takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (Table 4.2). Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. These importance scores ideally refer to the system in its natural condition. The scores have been determined for all South African estuaries, apart from functional importance, which is scored by the specialists in the workshop. In this case, functional importance was deemed to be relatively high (70), because the area has supported large tern roosts in the past. The EIS for the Uilkraals Estuary, based on its present state, was therefore estimated to be 74, i.e., the estuary is rated as "Important" (Table 4.3).

Table 4.1. Estimation of the functional importance score of the Uilkraals estuary

Functional importance score	
a. Estuary: Input of detritus and nutrients generated in estuary	20
b. Nursery function for marine-living fish and crustaceans	60
c. Movement corridor for river invertebrates and fish breeding in sea	60
d. Roosting area for marine or coastal birds	70
e. Catchment detritus, nutrients and sediments to sea	20
Functional importance score - Max (a to e)	**70**

Table 4.2. Importance scores (EIS) for the Uilkraals Estuary

Criterion	Weight	Score
Estuary Size	15	80
Zonal Rarity Type	10	90
Habitat Diversity	25	10
Biodiversity Importance	25	82
Functional Importance	25	70
Weighted Estuary Importance Score		**74**

Table 4.3. Estuarine importance scores (EIS) and significance

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

4.2 Recommended Ecological Category

The Recommended Ecological Category (REC) represents the level of protection assigned to an estuary. The first step is to determine the 'minimum' EC, based on its PES. The relationship between EHI Score, PES and minimum REC is set out in Table 4.4.

Table 4.4. Relationship between the EHI, PES and minimum ERC

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

The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of **importance** and level of **protection or desired** protection of a particular estuary (Table 4.2).

Table 4.2. Estuary protection status and importance, and the basis for assigning a recommended ecological reserve category

Protection status and importance	Recommended Ecological Category	Policy basis
Protected area Desired Protected Area (based on complementarity)	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
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

The PES for the Uilkraals is a D. The estuary is rated as “Important”, and it is a designated as a desired protected area in the Biodiversity Plan for the National Biodiversity Assessment (Turpie *et al*. 2012). Thus the **Recommended Ecological Category** for the estuary is its **Best Attainable State**.

5 OPERATIONAL AND ECOLOGICAL RESERVE SCENARIOS

5.1 Description of the Scenarios

Three scenarios were evaluated as part of this study (Table 5.1). The first two scenarios were decided in consultation with the Department of Water Affairs and the Breede-Overberg Conservation Management Agency.

- **Scenario 1** describes the situation where the full allocation to water users is used. This scenario could be considered the "Business as Usual' scenario, in which water demand increases over time, and the water available for the estuary decreases.
- **Scenario 2** describes situation as at present but with invasive alien plants (IAPs) having been removed from the entire catchment. This scenario represents an improvement over the present, as a result of restoring much of the original base flow flows in the catchment.
- **Scenario 3** was devised during the workshop in order to find the Best Attainable State, and represents an ecological improvement over Scenario 2. This scenario was the same as Scenario 2, except that the mouth was also kept open (the means of keeping the mouth open is deliberately not specified as various options for this still need to be investigated), and the sewage-related pollution problems are significantly ameliorated. The following sections describe the flows and abiotic states under these scenarios.

Table 5.1. Summary of the scenarios evaluated in this study

Scenario name	Description	MAR (x 10^6 m^3)	Percentage remaining
Natural	Natural Flow	39.3	100.0
Present	Present (Includes Irrigation From Run Of River, Afforestation and Alien Invasive Plants)	29.2	74.3
Scenario 1 (Full allocation)	Full allocation	26.3	66.9
Scenario 2 (No IAPs)	Present day flows with invasive alien plants removed	35.2	89.6
Scenario 3 (No IAPs, Open, WQ)	Present day flows with invasive alien plants removed, mouth kept open, reduced pollution	35.2	89.6

5.1.1 Flows and abiotic states under Scenario 2 (Full allocation)

A summary of the monthly flows is presented in Table 5.2, Table 5.3 and Figure 5.2. In general, this scenario involves further reductions in freshwater inflow to the estuary, however, because of the operating rules of the dam, which require that outflows equal inflows during the low flow period, there is little impact on low flows relative to present-day.

Table 5.2. Simulated monthly inflows to the Uilkraals Estuary for Scenario 1 (in $m^3.s^{-1}$)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.004	0.004	0.019	0.004	0.054	0.004	0.004	0.004	7.319	2.733	0.810	1.674
1921	0.190	0.004	0.011	0.896	0.215	0.392	0.123	0.056	0.822	0.325	0.504	0.104
1922	0.015	3.746	0.575	0.004	0.004	0.004	2.828	4.615	2.724	1.747	0.971	0.590
1923	0.209	0.903	0.019	0.004	0.004	0.007	0.012	0.004	1.019	0.482	3.872	1.821
1924	0.183	3.005	0.377	0.004	0.004	0.004	0.004	0.004	2.280	1.400	1.116	0.204
1925	0.478	0.066	0.004	0.004	0.004	0.004	0.004	0.175	0.397	3.539	2.143	0.382
1926	8.494	2.384	0.004	0.004	0.004	0.004	0.004	0.523	0.231	0.060	0.616	0.212
1927	0.007	0.073	0.004	0.004	0.004	0.004	0.004	0.004	0.409	0.153	0.306	0.640
1928	0.112	0.208	0.004	0.004	0.004	0.030	0.085	0.131	0.127	1.792	0.717	0.066
1929	0.007	0.054	0.004	0.004	0.066	0.317	0.228	0.511	0.255	0.190	0.821	1.991
1930	0.426	0.150	0.004	0.004	0.004	0.004	1.605	0.736	0.073	1.217	1.788	0.752
1931	2.236	0.282	0.004	0.004	0.157	0.004	0.004	0.665	0.779	0.549	0.414	6.883
1932	1.979	0.008	0.004	0.004	0.004	0.004	0.004	0.161	1.605	0.997	1.512	0.444
1933	0.075	0.008	0.004	0.004	0.004	0.004	0.085	0.325	0.185	0.549	1.807	1.779
1934	0.325	0.008	0.004	0.004	0.004	0.004	0.552	0.941	0.652	14.475	24.765	7.045
1935	0.112	0.208	0.004	0.105	0.004	0.004	0.104	0.452	0.228	0.239	0.261	0.359
1936	0.097	0.887	0.407	0.004	0.004	0.015	0.019	0.011	2.188	5.298	1.527	1.651
1937	0.534	0.012	0.004	0.004	0.004	0.067	0.077	0.556	0.394	0.609	1.247	4.151
1938	1.150	0.054	0.004	0.004	0.004	0.067	0.147	0.127	0.054	0.877	3.174	1.289
1939	0.366	0.042	0.004	0.004	0.901	0.261	2.014	0.956	2.311	1.038	0.187	0.081
1940	0.116	0.972	0.175	0.246	0.004	0.004	2.677	4.757	4.603	1.934	1.314	3.225
1941	0.926	0.100	0.004	0.004	0.004	0.004	0.004	1.198	0.895	0.250	0.295	0.498
1942	0.060	0.004	0.138	3.222	0.971	0.213	0.455	0.848	0.355	0.627	1.049	0.347
1943	0.273	5.139	1.169	0.004	0.004	0.004	0.004	2.065	7.141	2.065	3.573	7.172
1944	1.699	0.008	0.004	0.004	0.004	0.004	0.177	9.211	8.395	4.790	5.589	1.586
1945	5.037	1.489	0.004	0.004	0.004	0.343	0.143	0.067	0.158	0.190	0.179	0.598
1946	0.317	0.008	0.004	0.004	0.004	0.093	0.208	0.485	0.544	4.256	1.878	0.583
1947	0.205	0.058	0.004	0.004	0.004	0.351	0.301	0.097	0.328	0.635	0.239	0.374
1948	7.407	2.357	0.004	0.004	0.004	0.004	0.841	1.266	0.621	0.478	1.038	0.490
1949	0.007	0.953	0.112	0.004	0.004	0.004	0.397	0.175	0.054	2.315	1.187	1.119
1950	0.269	2.431	0.377	1.983	0.401	0.004	0.644	0.571	8.326	6.411	4.540	6.011
1951	1.352	0.008	0.004	0.004	0.004	0.004	0.015	0.388	0.509	0.945	4.947	2.319
1952	0.709	3.584	0.586	0.004	0.012	0.004	0.810	0.426	0.336	2.229	0.941	0.081
1953	0.082	0.147	0.004	0.004	0.004	0.004	0.112	6.784	3.646	5.126	8.292	2.257
1954	0.063	0.008	0.004	0.004	1.612	0.526	0.046	0.037	2.546	2.897	5.477	1.813
1955	1.001	0.050	0.004	0.004	0.004	0.004	0.035	1.538	2.303	1.090	1.493	0.517
1956	0.153	0.008	0.004	0.004	0.004	0.019	0.042	3.920	8.252	3.760	5.574	2.508
1957	4.428	0.891	0.004	0.004	0.004	0.112	0.559	4.413	2.280	0.261	4.092	1.350
1958	0.194	0.008	0.004	0.004	0.004	0.004	0.629	1.654	0.880	0.534	3.950	1.794
1959	0.773	0.035	0.004	0.004	0.004	0.004	0.015	0.041	0.421	0.556	0.235	0.100
1960	0.063	0.004	0.004	0.004	0.004	0.004	0.039	0.093	0.081	0.538	1.927	1.524
1961	0.254	0.004	0.004	0.004	0.004	0.142	0.421	0.205	2.585	1.378	6.459	2.272
1962	2.479	1.011	0.004	0.004	0.004	0.004	0.004	0.015	0.197	1.154	3.726	1.123
1963	0.007	0.004	0.004	0.004	0.004	0.004	0.027	0.041	1.910	1.725	2.412	0.988
1964	0.030	0.008	0.004	0.004	0.004	0.004	0.027	0.254	0.131	0.351	0.198	0.019
1965	0.134	0.004	0.004	0.004	0.004	0.004	0.023	0.026	0.012	0.131	0.653	0.644
1966	0.149	0.004	0.004	0.004	0.004	0.004	4.059	2.050	1.890	0.967	0.948	0.505
1967	0.183	0.008	0.004	0.004	0.004	0.004	0.004	0.246	1.057	0.538	0.586	0.247
1968	0.142	0.004	0.004	0.004	0.004	0.004	0.552	0.220	0.914	0.362	0.112	0.054
1969	0.019	0.004	0.004	0.004	0.004	0.004	0.004	0.071	1.003	1.060	2.505	1.208
1970	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.101	0.285	1.561	4.585	1.836
1971	0.310	0.023	0.004	0.004	0.004	0.004	1.046	0.728	0.775	0.698	4.618	1.809
1972	0.063	0.004	0.004	0.004	0.004	0.004	0.004	0.146	0.077	0.784	0.388	0.204
1973	0.071	0.004	0.004	0.004	0.004	0.004	0.008	1.008	0.436	0.149	7.519	4.132
1974	0.889	0.081	0.004	0.004	0.004	0.004	0.004	0.926	0.463	1.359	3.771	1.169
1975	0.157	0.008	0.004	0.004	0.004	0.004	0.397	0.213	5.073	3.420	1.251	0.787
1976	0.108	1.069	0.217	0.004	0.161	0.041	0.012	1.695	2.531	5.559	2.419	0.721
1977	0.220	0.008	0.258	0.004	0.004	0.004	0.189	0.123	0.104	0.388	1.169	0.606

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1978	0.246	0.073	0.004	0.004	1.777	0.627	0.015	1.404	0.768	1.113	1.695	0.725
1979	0.276	0.008	0.004	0.004	0.004	0.004	0.008	0.131	0.922	0.317	0.123	0.058
1980	0.007	0.301	0.004	1.620	0.612	0.209	1.385	0.482	0.162	2.483	3.846	1.705
1981	0.224	0.096	0.004	0.004	0.004	0.004	1.354	0.470	0.567	0.426	0.146	0.073
1982	0.007	0.004	0.004	0.004	0.517	0.134	0.174	2.453	3.380	4.006	1.538	1.605
1983	0.437	0.008	0.004	0.004	0.004	0.004	0.004	1.919	1.165	0.478	0.459	0.498
1984	0.974	27.554	8.270	0.004	0.041	0.131	0.563	0.187	0.042	6.881	2.964	0.282
1985	0.620	0.054	0.004	0.004	0.004	0.078	0.066	0.011	0.367	0.694	8.763	3.407
1986	0.123	0.008	0.004	0.004	0.004	0.007	1.134	0.784	2.735	1.113	1.542	1.995
1987	0.441	0.004	0.004	0.004	0.004	0.004	0.197	0.112	1.366	0.680	2.225	1.146
1988	0.478	0.027	0.004	0.004	0.004	3.144	3.978	1.012	0.949	3.995	3.110	2.473
1989	1.706	0.123	0.004	0.004	0.004	0.004	2.589	2.330	6.308	1.997	0.399	0.120
1990	0.052	0.004	0.004	0.004	0.004	0.004	0.019	0.276	0.679	5.343	2.065	0.139
1991	1.161	0.177	0.004	0.004	0.004	0.004	0.127	0.530	0.845	0.743	1.101	1.551
1992	1.266	0.089	0.004	0.004	0.025	0.049	10.274	3.905	3.075	4.958	1.706	0.228
1993	0.007	0.004	0.004	0.004	0.004	0.004	0.872	0.388	6.181	2.509	0.403	0.197
1994	0.056	0.004	0.004	0.004	0.004	0.004	0.027	0.952	0.679	0.489	1.299	0.324
1995	0.078	0.077	0.351	0.004	0.004	0.004	0.015	0.011	0.258	2.158	1.113	0.536
1996	3.062	3.113	0.448	0.004	0.004	0.004	0.278	1.669	2.234	0.553	0.317	0.154
1997	0.007	0.004	0.004	0.004	0.004	0.004	0.135	2.479	1.555	0.265	0.228	0.085
1998	0.007	0.166	2.165	0.351	0.004	0.004	0.274	0.146	0.035	0.026	0.015	1.543
1999	0.463	0.004	0.004	0.004	0.004	0.004	0.023	0.011	0.015	0.821	0.351	0.444
2000	0.075	0.004	0.004	0.004	0.004	0.004	0.004	0.056	0.015	0.960	0.665	0.189
2001	0.119	0.008	0.004	0.325	0.029	0.004	0.004	0.146	0.216	0.862	0.429	0.201
2002	0.101	0.004	0.004	0.004	0.004	3.263	2.022	0.500	0.212	0.022	5.780	2.079
2003	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.007	0.039	0.101	0.060	0.015
2004	1.841	0.475	0.004	0.090	0.004	0.004	3.017	1.815	2.867	0.956	0.202	0.050
2005	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.149	0.116	2.221	2.860	0.687
2006	0.041	0.012	0.004	0.004	0.004	0.004	0.004	0.269	0.459	1.128	0.668	0.193
2007	0.179	1.370	0.127	0.004	0.004	0.004	0.004	0.007	0.054	0.459	0.250	0.590
2008	0.187	1.427	0.284	0.004	0.004	0.004	0.004	0.011	1.119	1.169	0.586	0.096
2009	1.844	0.278	0.004	0.004	0.004	0.004	0.004	0.037	0.316	0.325	0.082	0.012
2010	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.086	0.185	0.101	0.269	0.073

State 1	<0.03	State 2	0.03-3.0	State 3	>3.0

Table 5.3. Summary of the monthly flow (in $m^3.s^{-1}$)distribution under Scenario 1

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	7.516	7.380	2.776	2.106	1.629	3.156	4.680	7.027	8.333	7.640	10.363	7.057
90%ile	1.841	1.489	0.351	0.004	0.157	0.213	1.605	2.330	3.646	4.256	4.947	2.473
80%ile	0.926	0.887	0.019	0.004	0.004	0.067	0.629	1.404	2.311	2.483	3.726	1.813
70%ile	0.441	0.150	0.004	0.004	0.004	0.004	0.301	0.848	1.555	1.747	2.225	1.551
60%ile	0.269	0.073	0.004	0.004	0.004	0.004	0.147	0.511	0.914	1.128	1.542	1.119
50%ile	0.187	0.027	0.004	0.004	0.004	0.004	0.077	0.325	0.679	0.956	1.187	0.606
40%ile	0.123	0.008	0.004	0.004	0.004	0.004	0.023	0.175	0.421	0.680	0.941	0.498
30%ile	0.078	0.008	0.004	0.004	0.004	0.004	0.012	0.127	0.285	0.538	0.586	0.282
20%ile	0.052	0.004	0.004	0.004	0.004	0.004	0.004	0.056	0.185	0.362	0.317	0.189
10%ile	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.011	0.073	0.190	0.202	0.081
1%ile	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.015	0.026	0.055	0.015

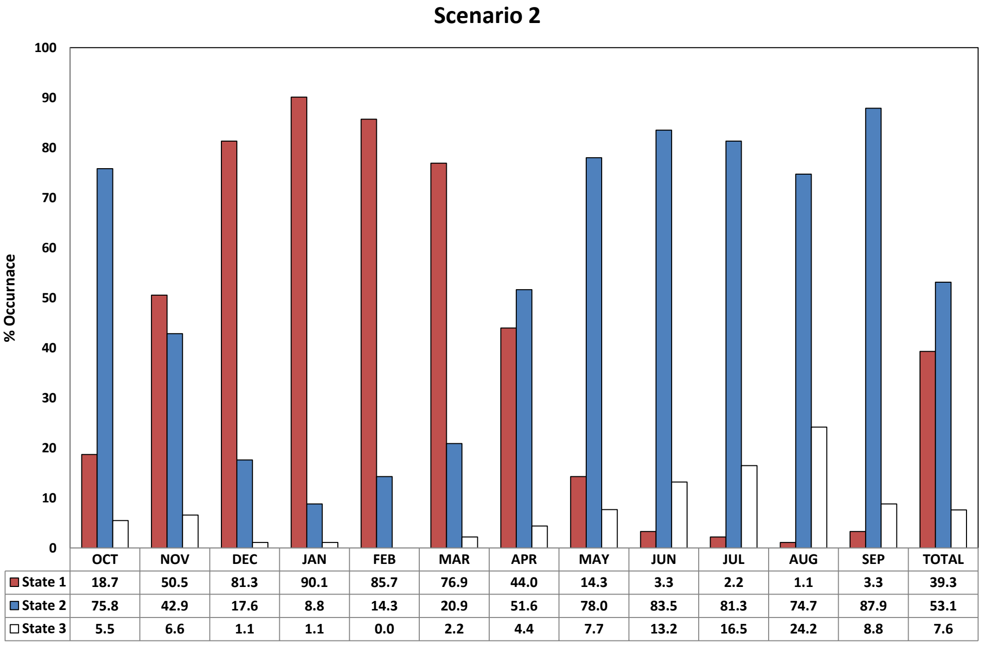


Figure 5.1. **Graphic illustrations of the percentages monthly and annual occurrences of the various abiotic states in the Uilkraals Estuary (Scenario 1)**

5.1.2 Flows and abiotic states under Scenario 2 (No IAPs) and Scenario 3 (No IAPs, Open, WQ amelioration)

A summary of the monthly flows is presented in Table 5.5, Table 5.4 and Figure 5.2. Clearing of alien vegetation leads to increased low flows in the catchment (applicable for Scenarios 2 and 3), and because of the operating rules of the dam, these flows are allowed through to the head of the estuary. The open mouth condition (Scenario 3 only) does not have any bearing on freshwater inflows, thus the hydrological aspects are identical for the two scenarios.

Table 5.4. **Simulated monthly inflows to the Uilkraals Estuary for Scenario 1 and 3 (in $m^3.s^{-1}$)**

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.041	0.031	0.052	0.019	0.083	0.019	0.023	0.030	9.780	3.304	0.963	1.883
1921	0.321	0.035	0.045	1.385	0.314	0.702	0.208	0.105	1.138	0.448	0.635	0.204
1922	0.071	4.194	0.892	0.022	0.021	0.019	3.565	5.010	3.364	2.397	1.254	0.772
1923	0.388	1.119	0.060	0.022	0.025	0.034	0.042	0.034	1.300	0.930	5.238	2.265
1924	0.340	3.291	0.631	0.026	0.025	0.022	0.027	0.030	3.237	1.579	1.340	0.401
1925	0.676	0.120	0.026	0.019	0.021	0.022	0.027	0.224	0.486	5.544	2.655	0.548
1926	9.995	3.094	0.034	0.026	0.029	0.026	0.031	0.609	0.309	0.123	1.064	0.417
1927	0.056	0.123	0.037	0.022	0.025	0.022	0.027	0.026	0.478	0.217	0.392	1.057
1928	0.187	0.328	0.026	0.019	0.021	0.056	0.120	0.179	0.189	3.174	1.437	0.150
1929	0.060	0.104	0.030	0.022	0.099	0.373	0.282	0.851	0.498	0.392	1.591	2.411
1930	0.698	0.255	0.026	0.022	0.021	0.022	2.353	1.135	0.162	1.389	2.192	0.976
1931	2.453	0.463	0.026	0.022	0.198	0.030	0.027	0.747	1.493	1.012	0.556	8.465
1932	2.655	0.046	0.030	0.022	0.025	0.022	0.027	0.209	2.288	1.788	2.016	0.718

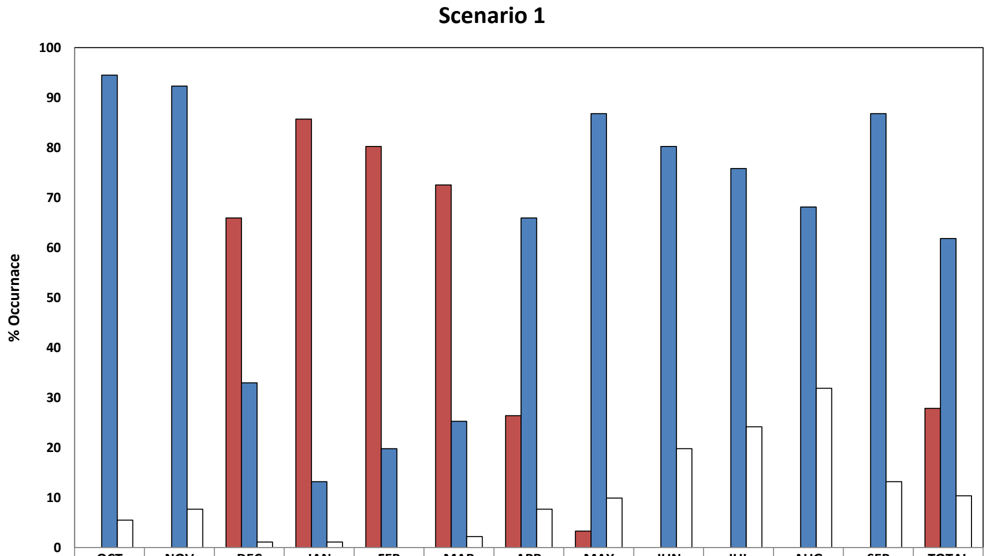
YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1933	0.149	0.046	0.026	0.022	0.025	0.022	0.127	0.396	0.258	0.668	3.808	2.160
1934	0.515	0.050	0.026	0.022	0.021	0.019	0.621	1.396	1.273	18.709	31.485	8.951
1935	0.202	0.332	0.034	0.149	0.033	0.026	0.147	0.534	0.432	0.493	0.538	0.714
1936	0.175	1.582	0.694	0.026	0.025	0.037	0.042	0.037	2.955	6.452	1.986	1.852
1937	0.702	0.066	0.030	0.022	0.025	0.097	0.112	0.646	0.629	1.202	1.979	5.212
1938	1.643	0.112	0.030	0.022	0.025	0.105	0.197	0.179	0.104	1.310	4.716	1.671
1939	0.579	0.096	0.030	0.022	1.157	0.433	2.809	1.086	2.523	1.225	0.317	0.181
1940	0.190	1.424	0.284	0.429	0.025	0.019	3.140	5.085	5.745	2.610	1.755	3.978
1941	1.340	0.177	0.034	0.026	0.029	0.022	0.027	1.531	1.740	0.455	0.422	0.633
1942	0.127	0.035	0.187	4.159	1.281	0.332	0.617	0.967	0.467	0.762	1.221	0.540
1943	0.381	5.617	1.478	0.022	0.021	0.019	0.023	2.759	8.461	2.572	4.592	9.024
1944	2.341	0.050	0.034	0.030	0.029	0.026	0.220	11.768	10.475	6.384	7.157	2.114
1945	5.705	1.860	0.041	0.034	0.033	0.399	0.189	0.112	0.224	0.273	0.362	1.161
1946	0.706	0.050	0.026	0.022	0.025	0.131	0.255	0.568	0.872	6.414	2.401	0.741
1947	0.377	0.108	0.030	0.022	0.025	0.407	0.359	0.146	0.475	1.243	0.482	0.741
1948	8.983	2.917	0.030	0.026	0.025	0.022	1.015	1.960	0.752	0.612	1.213	0.633
1949	0.067	1.381	0.161	0.022	0.021	0.019	0.451	0.220	0.100	3.383	1.359	1.285
1950	0.489	2.697	0.638	2.393	0.666	0.022	0.899	0.676	9.988	8.233	5.914	7.608
1951	1.938	0.054	0.034	0.030	0.029	0.026	0.042	0.459	0.610	1.800	6.754	2.982
1952	0.963	3.981	0.885	0.026	0.041	0.022	1.123	0.777	0.444	2.524	1.124	0.189
1953	0.168	0.228	0.026	0.022	0.025	0.022	0.154	8.860	4.360	6.776	10.659	3.017
1954	0.134	0.050	0.034	0.030	2.426	0.825	0.081	0.075	2.766	3.487	7.127	2.411
1955	1.157	0.116	0.030	0.026	0.029	0.026	0.066	2.233	3.002	1.441	1.997	0.795
1956	0.280	0.046	0.030	0.022	0.025	0.049	0.073	5.234	10.320	5.059	7.202	3.137
1957	5.063	1.308	0.034	0.030	0.029	0.153	0.648	5.701	2.620	0.396	4.958	1.759
1958	0.347	0.046	0.030	0.026	0.025	0.022	0.714	2.711	1.030	0.672	4.992	2.261
1959	1.030	0.093	0.030	0.022	0.025	0.022	0.039	0.075	0.509	0.754	0.508	0.212
1960	0.146	0.031	0.022	0.034	0.021	0.019	0.066	0.142	0.135	0.638	3.808	2.245
1961	0.470	0.042	0.022	0.022	0.025	0.183	0.486	0.265	3.758	1.583	8.389	3.002
1962	2.804	1.146	0.030	0.026	0.025	0.022	0.027	0.045	0.258	1.684	5.171	1.601
1963	0.060	0.042	0.030	0.022	0.025	0.026	0.054	0.078	2.813	2.606	3.226	1.327
1964	0.101	0.046	0.026	0.022	0.025	0.022	0.050	0.310	0.185	0.437	0.284	0.085
1965	0.198	0.039	0.026	0.019	0.021	0.019	0.050	0.056	0.046	0.187	0.773	0.860
1966	0.269	0.035	0.022	0.019	0.021	0.019	5.741	2.259	2.153	1.161	1.258	0.733
1967	0.347	0.046	0.026	0.019	0.021	0.019	0.023	0.299	1.300	1.068	1.161	0.502
1968	0.254	0.042	0.022	0.019	0.021	0.022	0.629	0.276	1.528	0.736	0.254	0.123
1969	0.075	0.035	0.022	0.019	0.021	0.019	0.019	0.101	1.127	1.986	3.984	1.605
1970	0.082	0.039	0.026	0.022	0.021	0.022	0.027	0.142	0.363	2.375	6.851	2.419
1971	0.568	0.077	0.034	0.026	0.029	0.026	1.304	1.393	1.265	0.859	5.955	2.357
1972	0.138	0.042	0.026	0.022	0.025	0.022	0.023	0.187	0.127	0.904	0.624	0.405
1973	0.138	0.035	0.022	0.019	0.021	0.019	0.027	1.120	0.841	0.317	10.529	5.058
1974	1.146	0.139	0.026	0.022	0.025	0.022	0.023	1.116	0.907	1.930	4.846	1.620
1975	0.273	0.046	0.026	0.022	0.025	0.022	0.463	0.273	6.925	4.309	1.680	0.972
1976	0.202	1.505	0.355	0.026	0.203	0.078	0.046	2.431	2.824	7.239	3.185	0.922
1977	0.332	0.050	0.321	0.026	0.025	0.026	0.235	0.172	0.162	0.504	2.337	1.022
1978	0.448	0.143	0.026	0.022	2.373	0.762	0.039	1.587	0.891	1.273	2.102	0.949
1979	0.493	0.054	0.022	0.022	0.021	0.019	0.023	0.172	1.100	0.616	0.261	0.131
1980	0.049	0.394	0.026	2.811	1.112	0.347	1.597	0.579	0.255	2.718	4.898	2.168
1981	0.403	0.158	0.030	0.022	0.025	0.022	1.833	0.922	0.953	0.549	0.276	0.158
1982	0.049	0.031	0.022	0.019	0.591	0.168	0.212	3.517	3.997	5.283	2.027	1.921
1983	0.631	0.046	0.030	0.022	0.025	0.022	0.031	2.823	1.551	0.620	0.597	0.640
1984	1.240	33.275	10.282	0.037	0.087	0.179	0.841	0.370	0.096	8.479	3.622	0.444
1985	0.896	0.116	0.030	0.026	0.029	0.119	0.100	0.045	0.448	1.019	12.186	4.371
1986	0.231	0.050	0.030	0.026	0.025	0.030	1.454	1.475	3.291	1.333	2.009	2.392
1987	0.627	0.042	0.026	0.022	0.025	0.022	0.239	0.157	2.014	1.340	2.920	1.508
1988	0.754	0.081	0.026	0.022	0.025	4.253	4.294	1.157	1.111	5.126	4.148	3.044

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1989	1.941	0.197	0.030	0.026	0.029	0.026	3.657	2.539	7.843	2.572	0.538	0.235
1990	0.127	0.042	0.030	0.026	0.025	0.022	0.039	0.332	0.787	7.762	2.636	0.282
1991	1.501	0.289	0.026	0.022	0.025	0.022	0.166	0.616	1.520	1.366	1.478	1.914
1992	1.546	0.154	0.030	0.022	0.062	0.071	12.323	4.435	3.985	6.661	2.292	0.370
1993	0.067	0.042	0.034	0.030	0.029	0.026	0.980	0.642	8.472	3.118	0.564	0.332
1994	0.142	0.042	0.030	0.026	0.025	0.026	0.058	1.150	1.323	1.016	1.897	0.640
1995	0.153	0.131	0.553	0.034	0.025	0.026	0.039	0.037	0.324	3.607	1.396	0.729
1996	3.704	3.434	0.650	0.026	0.025	0.022	0.332	2.408	2.778	0.810	0.459	0.270
1997	0.056	0.042	0.026	0.022	0.021	0.022	0.177	3.816	1.790	0.414	0.370	0.204
1998	0.056	0.231	2.886	0.568	0.025	0.019	0.324	0.198	0.089	0.075	0.060	2.299
1999	0.661	0.039	0.022	0.022	0.021	0.030	0.054	0.037	0.058	0.956	0.732	0.883
2000	0.153	0.039	0.022	0.019	0.021	0.019	0.023	0.090	0.058	1.101	1.456	0.475
2001	0.213	0.046	0.022	0.385	0.062	0.022	0.027	0.194	0.297	1.680	0.963	0.424
2002	0.239	0.042	0.026	0.022	0.021	5.093	2.191	0.612	0.324	0.093	7.471	2.751
2003	0.086	0.042	0.030	0.022	0.025	0.022	0.027	0.037	0.081	0.172	0.134	0.085
2004	2.569	0.856	0.026	0.134	0.025	0.022	4.726	2.012	3.939	1.381	0.332	0.135
2005	0.060	0.042	0.026	0.022	0.021	0.019	0.023	0.198	0.181	4.163	4.141	1.092
2006	0.119	0.058	0.030	0.022	0.025	0.022	0.031	0.340	0.575	2.404	1.665	0.467
2007	0.381	1.755	0.187	0.026	0.029	0.026	0.027	0.034	0.096	0.568	0.366	1.069
2008	0.381	2.612	0.467	0.022	0.025	0.022	0.023	0.037	1.501	2.468	0.904	0.208
2009	2.345	0.475	0.026	0.022	0.025	0.022	0.023	0.071	0.401	0.441	0.183	0.081
2010	0.060	0.039	0.022	0.019	0.021	0.019	0.023	0.131	0.262	0.187	0.388	0.162

State 1	<0.03	State 2	0.03-3.0	State3	>3.0

Table 5.5. Summary of the monthly flow (in $m^3.s^{-1}$) distribution under Scenario 2 and 3

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	9.084	8.383	3.626	2.946	2.378	4.337	6.399	9.151	10.336	9.502	14.116	8.958
90%ile	2.345	2.612	0.553	0.037	0.198	0.347	2.191	2.823	4.360	6.384	6.851	3.044
80%ile	1.157	1.119	0.052	0.026	0.029	0.097	0.841	1.960	2.955	3.383	4.846	2.357
70%ile	0.676	0.231	0.034	0.026	0.029	0.030	0.359	1.120	2.014	2.524	3.226	1.914
60%ile	0.470	0.123	0.030	0.026	0.025	0.026	0.208	0.646	1.300	1.684	2.102	1.327
50%ile	0.347	0.081	0.030	0.022	0.025	0.022	0.112	0.396	0.953	1.333	1.680	0.949
40%ile	0.231	0.050	0.026	0.022	0.025	0.022	0.050	0.224	0.575	1.019	1.258	0.729
30%ile	0.153	0.046	0.026	0.022	0.025	0.022	0.039	0.172	0.432	0.754	0.904	0.502
20%ile	0.127	0.042	0.026	0.022	0.021	0.022	0.027	0.101	0.258	0.549	0.538	0.332
10%ile	0.060	0.039	0.022	0.019	0.021	0.019	0.023	0.037	0.127	0.392	0.362	0.181
1%ile	0.048	0.031	0.022	0.019	0.021	0.019	0.023	0.029	0.057	0.091	0.127	0.084



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0.0	0.0	65.9	85.7	80.2	72.5	26.4	3.3	0.0	0.0	0.0	0.0	27.8
State 2	94.5	92.3	33.0	13.2	19.8	25.3	65.9	86.8	80.2	75.8	68.1	86.8	61.8
State 3	5.5	7.7	1.1	1.1	0.0	2.2	7.7	9.9	19.8	24.2	31.9	13.2	10.3

Figure 5.2. Percentage occurrence of the various abiotic states under Scenario 2 and Scenario 3.

5.2 Abiotic Components

This section summarises the estimated changes in each of the abiotic components under the different scenarios, and provides expected health scores for each.

5.2.1 Hydrology

The modelled changes in hydrology are summarised in Table 5.6 and scored in Table 5.7.

Table 5.6. Summary of changes under the different scenarios.

Parameter	Scenarios 1 -3
Low flows	Low flows remain unchanged in Scenario 1. In the lowest 35% of monthly flows, the average flows are improved to 45% of natural under Scenarios 2 and 3.
Changes in the occurrences and magnitudes of floods	The dams in the catchment are relatively small and the Kraaibosch Dam is never drawn down completely. It is therefore estimated that the floods are very similar to present.

Table 5.7. Similarity scores for hydrology relative to the Reference condition.

Variable	Present	Scenario 1	Scenario 2	Scenario 3	Conf
a. Low flows in 35% lowest months	7	7	45	45	VL
b. Mean annual frequency of floods	95	95	95	95	L
Hydrology score	**25**	**25**	**55**	**55**	

5.2.2 Hydrodynamics and mouth condition

This section describes changes in the occurrence of the different abiotic states under the different run-off scenarios as a proxy for the change in hydrodynamics. Months in which mouth closure could occur increased to 28 and 39 under Scenario 1 and 2 respectively. In Scenario 3 the mouth is kept open, though the means of achieving this are not defined here. Changes and scores are summarised in Table 5.8 and Table 5.9.

Table 5.8. Summary of changes in the percentage frequency of different abiotic states under the different scenarios.

STATE	SCENARIOS				
	Natural	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)
1	4.9	39.3	39.3	27.8	0.0
2	83.2	52.0	53.1	61.8	88.0
3	11.8	8.7	7.6	10.3	12.0

Table 5.9. Similarity scores for hydrodynamics in the Present condition relative to the Reference condition. Only the first parameter is scored due to lack of data.

Variable	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)	Conf
a. Mouth condition & abiotic states	65	65	76	96	VL
b. Stratification	-	-	-	-	
c. Water retention time	-	-	-	-	
d. Water level	-	-	-	-	
Hydrodynamics and mouth conditions score	**65**	**65**	**76**	**96**	**VL**

5.2.3 Water quality

Scoring of Future scenarios in respect of Salinity/DIN/DIP, SS/Turbidity/ Transparency, DO and Toxic substances, followed a similar approach as described earlier for the Present State. Based on the above the estimated changes in water quality (salinity, DIN, DIP, suspended solids and dissolved oxygen) in different zones under the different scenarios are presented in Table 5.10. Details on the change in the axial salinity gradient, DIN/DIP, suspended solids, dissolved oxygen, and toxic substances are provided in **Error! Reference source not found.**

Table 5.10. Estimated changes in water quality in different zones of the Uilkraals Estuary under Reference, present, future scenarios

Zones in Estuary	Volume weighting for Zone	Estimated <u>SALINITY</u> concentration (PSU) based on distribution of abiotic states				
		Reference	Present	Scenario 1	Scenario 2	Scenario 3
Zone A	0.2	23	30	29	33	32
Zone B	0.5	17	24	19	26	23
Zone C	0.3	1	10	8	12	14

Zones in Estuary	Volume weighting for Zone	Estimated <u>DIN</u> concentration (µg/l) based on distribution of abiotic states				
		Reference	Present	Scenario 1	Scenario 2	Scenario 3
Zone A	0.2	50	148	120	148	50
Zone B	0.5	50	179	156	179	100
Zone C	0.3	50	179	156	179	100

Zones in Estuary	Volume weighting for Zone	Estimated <u>DIP</u> concentration (µg/l) based on distribution of abiotic states				
		Reference	Present	Scenario 1	Scenario 2	Scenario 3
Zone A	0.2	10	45	35	45	10
Zone B	0.5	10	70	64	70	50
Zone C	0.3	10	70	64	70	50

Zones in Estuary	Volume weighting for Zone	Estimated <u>TRANSPARENCY</u> (m) based on distribution of abiotic states				
		Reference	Present	Scenario 1	Scenario 2	Scenario 3
Zone A	0.2	1	1	1	1	1
Zone B	0.5	1	1	1	1	1
Zone C	0.3	1	1	1	1	1

Zones in Estuary	Volume weighting for Zone	Estimated DISSOLVED OXYGEN concentration (mg/l) based on distribution of abiotic states				
		Reference	Present	Scenario 1	Scenario 2	Scenario 3
Zone A	0.2	6	5	5	5	6
Zone B	0.5	6	5	5	5	6
Zone C	0.3	6	4	5	4	6

Table 5.11 Expected changes in axial salinity gradient, DIN/DIP, turbidity, dissolved oxygen, and toxic substances in the Uilkraals Estuary under the present and future flow scenarios

Parameter	Summary of changes
1. Changes in longitudinal salinity gradient and vertical stratification	Under all scenarios, ⇧ due to decrease in flow
2a. DIN/DIP in estuary	Elevated as at present under Sc 1 and Sc 2, but for Sc 3, reduced elevation as no occurrence of State 1 (closed) when nutrient enrichment from diffuse sources accumulates in estuary. Also input from diffuse sources along banks (e.g. runoff from wastewater facility) are reduced.
2b. Suspended solids/Turbidity/ Transparency in estuary	Same as present under all scenarios
2c. DO in estuary	Decreased as at present under Sc 1 and Sc 2, but reduced under Sc 3 as no closed state and inputs from diffuse sources along banks (e.g. runoff from wastewater facility) are reduced
2d. Toxic substances in estuary	⇧ accumulation under all scenarios

Table 5.12 Summary of changes and calculation of the water quality health score.

	Variable	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)	Conf
1	**Salinity**					
	Similarity in salinity	66	62	74	65	M
2	**General water quality in the estuary**					
a	N and P concentrations	36	36	41	60	L
b	Water clarity (measured as suspended solids/turbidity/transparency)	99	99	100	100	L
c	Dissolved oxygen (mg/l) concentrations	91	91	94	100	L
d	Toxic substances	90	90	90	90	L
	Water quality score	**59**	**51**	**64**	**66**	

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

5.2.4 Physical habitat alteration

Scoring motivation: All assessments and scoring for the habitat variables for the scenarios were done similarly to those for the present day situation. Changes and scores are summarised in Table 5.13 and Table 5.14.

Table 5.13. Summary of changes in physical habitats under the different scenarios.

Parameter	Scenarios 1 -3
a. Supratidal area and sediments	This is the same as present in all three future scenarios.
b. Intertidal areas and sediments	Reduced availability of intertidal habitat for Sc 1 (mainly due to drying or inundation during closed state), increased availability of intertidal habitat for Sc 2 and SC 3; ⇧ muddy in upper reaches
c. Subtidal area and sediments	⇧ muddy throughout, especially in upper reaches. This is the same as present in all three future scenarios.
d. Estuary bathymetry/water volume	While the estuary fills and empties under the closed state, these two alternating water levels/volumes average out and thus the score is the same as present in all three future scenarios.

Table 5.14. Similarity scores for physical habitats under different scenarios.

Variable	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)	Conf
a. Supratidal area and sediments	60	60	60	60	L
b. Intertidal areas and sediments	40	40	60	80	L
c. Subtidal area and sediments	70	70	70	70	L
d. Estuary bathymetry/water volume	80	80	80	80	L
Physical habitat score	**51**	**51**	**64**	**66**	

5.3 Biotic components

This section predicts the change in biotic characteristics of the Scenarios compared with the Reference Condition, providing an explanation of the causes of these changes and confidence in the predictions.

5.3.1 Microalgae

There were no available data on the different phytoplankton groups in the Uilkraals Estuary and therefore for the purposes of this study changes are described for phytoplankton and microphytobenthos. However, if data were available, changes could be described for the different groups i.e. cyanophytes, dinoflagellates, chlorophytes, diatoms and flagellates. Changes and scores are summarised in Table 5.15 and Table 5.16.

Table 5.15. Summary of how the microalgae change relative to the Reference and/or Present condition under the different scenarios.

Scenario	Summary of changes
Scenario 1 (Full allocation)	*Species richness*: Slight change from present conditions due to change in intermediate flows and an increase in salinity compared to present day conditions. There has been an increase in nutrient concentrations and closed mouth conditions which would decrease species richness. The loss of intertidal habitat would decrease species richness in the intertidal zone *Abundance*: Same as present day conditions. An Increase in mouth closure and nutrient rich conditions would promote microphytobenthos growth particularly in shallow sheltered areas of the estuary. There was an increase in nutrients in all zones. Loss of intertidal habitat would represent a loss of habitat for benthic microalgae. The abundance score was calculated using the DIN concentration, change in phytoplankton biomass (chlorophyll-a concentration) and similarity index. *Community composition:* Same as present day conditions. Blue-green algae would outcompete other algal groups under nutrient rich, freshwater conditions. Intertidal benthic microalgal communities would be lost at the expense of subtidal communities.
Scenario 2 (No IAPs)	*Species richness*: Salinity has increased from the reference condition due to decrease in baseflows. There has been an increase in nutrient concentrations and closed mouth conditions which would decrease species richness. The loss of intertidal habitat would decrease species richness in the intertidal zone. *Abundance*: An increase in mouth closure and nutrient rich conditions would promote microphytobenthos growth particularly in shallow sheltered areas of the estuary. There was an increase in nutrients in all zones. Loss of intertidal habitat would represent a loss of habitat for benthic microalgae. The abundance score was calculated using the DIN concentration, change in phytoplankton biomass (chlorophyll-a concentration) and similarity index. *Community composition:* Blue-green algae would outcompete other algal groups under nutrient rich, freshwater conditions. Intertidal benthic microalgal communities would be lost at the expense of subtidal communities.
Scenario 3 (No IAPs, Open,	*Species richness:* Salinity has increased from the reference condition due to decrease in baseflows. There has been an increase in nutrient concentrations and closed mouth conditions which would decrease species richness. The loss of intertidal habitat would decrease

WQ)	microphytobenthos species richness in the intertidal zone. *Abundance:* Nutrient input from the catchment would promote high microalgal biomass. Small loss of intertidal habitat (80% from reference) would represent a loss of habitat for benthic microalgae. The abundance score was calculated using the DIN concentration, change in phytoplankton biomass (chlorophyll-a concentration) and similarity index. *Community composition*: Blue-green algae would outcompete other algal groups under nutrient rich, freshwater conditions. Mouth closure would result in a loss of intertidal benthic microalgal communities but a gain in subtidal habitat.

Table 5.16. Similarity scores of microalgae under the different scenarios.

Variable	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)	Conf
1. Species richness	70	73	75	80	L
2 Abundance	55	59	59	68	L
3. Community composition	65	70	70	75	L
Microalgae score	**59**	**63**	**64**	**71**	

5.3.2 Macrophytes

This section describes the changes in macrophytes for the different run-off scenarios. Changes and scores are summarised in Table 5.17 and Table 5.18.

Table 5.17. Summary of how the macrophytes change relative to the Reference condition under the different scenarios.

Scenario	Summary of changes
Scenario 1 (Full allocation)	Although there is a further reduction in low flows and a further decrease in MAR, 66.9% for Scenario 2 compared with 74% for Scenario 1 this does not translate into major changes in the physico-chemical characteristics of the estuary which remain similar to the present state, therefore the macrophytes would be similar to that described for the present state. There is a small increase in salinity as a result of the loss of intermediate flows which would influence species richness. *Species richness:* Increase in flooding and water level because of mouth closure and an increase in salinity would result in a loss of sensitive species characteristic of the supratidal salt marsh hummocks and reed & sedge habitats. This would also pose a threat to the richness of the supratidal habitat. Change in nutrient status of the sandy nutrient poor substrate conditions of the salt marsh could also result in loss of specialist species adapted to these conditions. This is a rare type of salt marsh in South Africa. *Abundance* Closed mouth conditions results in loss of intertidal salt marsh. There has also been a small loss due to development and building of the road bridge. Increase in nutrient conditions from the reference condition result in an increase in macroalgae particularly during closed mouth conditions. *Community composition*: Loss of intertidal salt marsh as a result of mouth closure and high water levels. Macroalgae would increase due to nutrient enrichment and could displace the submerged macrophyte. Mats of macroalgae cover the salt marsh when the water level drops

	causing die-back and bare patches
Scenario 2 (No IAPs)	Scenario 2 represents an improvement in low flow conditions due to the removal of alien vegetation in the catchment area. The mouth would close less frequently although there would still be a loss of 50% of the intertidal habitat which result in die-back of sensitive species and loss of diversity. Less macroalgae would occur compared to present conditions due to an improvement in nutrient conditions. *Species richness:* Increase in flooding and water level because of mouth closure and an increase in salinity would result in a loss of sensitive species characteristic of the supratidal salt marsh hummocks and reed & sedge habitats. This would also pose a threat to the richness of the supratidal habitat. Change in nutrient status of the sandy nutrient poor substrate conditions of the salt marsh could also result in loss of specialist species adapted to these conditions. This is a rare type of salt marsh in South Africa. *Abundance*: Closed mouth conditions results in loss of intertidal salt marsh. There has also been a small loss due to development and building of the road bridge. Increase in nutrient conditions from the reference condition result in an increase in macroalgae particularly during closed mouth conditions. However this would occur less frequently than under present conditions. *Community composition*: Loss of intertidal salt marsh as a result of mouth closure and high water levels. Macroalgae would increase due to nutrient enrichment and could displace the submerged macrophytes. Mats of macroalgae cover the salt marsh when the water level drops causing die-back and bare patches
Scenario 3 (No IAPs, Open, WQ)	*Species richness:* Loss of sensitive species characteristic of the supratidal salt marsh hummocks and reed & sedge habitats due to low flow and an increase in salinity. Change in nutrient status of the sandy nutrient poor substrate conditions of the salt marsh could also result in loss of specialist species adapted to these conditions. This is a rare type of salt marsh in South Africa. *Abundance*: There has also been a small loss of habitat due to development and building of the road bridge. Increase in nutrient inputs from the river could increase microalgal biomass. *Community composition*: Macroalgae would increase due to nutrient enrichment and could displace the submerged macrophyte

Table 5.18. Similarity scores of macrophytes under the different scenarios.

Variable	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)	Conf
1. Species richness	60	60	65	80	L
2 Abundance	86	86	92	93	M
3. Community composition	54	54	58	62	M
Microalgae score	**60**	**60**	**65**	**70**	

5.3.3 Invertebrates

This section describes the changes in invertebrates for the different run-off scenarios. Changes and scores are summarised in Table 5.19 and Table 5.20.

Table 5.19. Summary of how the invertebrates change under the different scenarios.

Scenario	Summary of changes
Scenario 1 (Full allocation)	With the dam operating at full allocation, a reduction in flow and prolonged mouth closure would be observed, resulting in a scenario which is 51% similar to that of the reference condition. This happens to be exactly the same as the present scenario indicating that increasing the dam to full allocation would have little to no effect on the present state of the invertebrate macrofauna.
Scenario 2 (No IAPs)	With alien vegetation removed from the catchment, an improvement in flow would be observed in comparison to the present condition. The mouth would close less frequently but limited restoration of intertidal habitat is expected (still only 50% of reference). The result is a scenario which is 76% similar to the reference condition with lower abundance of marine dominated taxa (i.e. prawns, marine polychaetes etc.) than under reference conditions. Slightly higher species richness and abundance are observed in comparison to the present condition.
Scenario 3 (No IAPs, Open, WQ)	With aliens removed from the catchment and an open mouth condition maintained, the system would begin to return to its former tidal state, attracting marine dominated species back which were previously resident in the reference scenario (e.g. *Upogebia africana*). Species richness and abundance would improve such that the system would be 87% similar to that of the reference condition. Species sensitive to disturbance (e.g. *Arenicola loveni*) are unlikely to return due to the presence of the bridge which impedes flow and tidal exchange of the estuary.

Table 5.20. Similarity scores of invertebrates under the different scenarios.

Variable	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)	Conf
1. Species richness	45	36	76	82	L
2 Abundance	53	51	61	77	L
3. Community composition	51	43	76	76	L
Invertebrate score	**47**	**40**	**66**	**77**	

5.3.4 Fish

This section describes the changes in fish for the different run-off scenarios. Changes and scores are summarised in Table 5.21 and Table 5.21Table 5.22.

Table 5.21. Summary of how the fish change under the different scenarios.

Scenario	Summary of changes
Scenario 1 (Full allocation)	Under this scenario, even though winter baseflows are reduced relative to present this does not affect frequency of mouth closure, there is a small change in the longitudinal salinity gradient and other WQ characteristics, but little change in the other biotic components (microalgae, macroalgae, invertebrates); thus very little change in fish populations.
Scenario 2 (No IAPs)	Removal of AIPs results in a restoration of much of the summer and winter baseflows, reduction in the frequency of mouth closure, an increase in tidal exchange and restoration of some of the historic intertidal area. This results in increased recruitment opportunities and consequently an increase in the diversity and abundance of estuary associated and vagrant marine species in the estuary and a reduction in abundance of resident species, thus improving resemblance towards reference conditions
Scenario 3 (No IAPs, Open, WQ)	Maintenance of an open mouth state and improved water quality results in further restoration of natural water quality characteristics, increase in intertidal area and invertebrate biomass, improved water quality characteristics and consequently further increases in diversity and abundance of estuary associated and vagrant marine species bringing things closer to the reference condition.

Table 5.22. Similarity scores for fish under the different scenarios.

Variable	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)	Present
1. Species richness	64	60	72	84	M
2 Abundance	46	41	59	66	L
3. Community composition	62	58	74	80	L
Fish score	**52**	**47**	**64**	**71**	

5.3.5 Birds

This section describes the changes in birds for the different run-off scenarios. The main parameters used to estimate these changes are summarised in Table 5.23. Changes and scores are summarised in Table 5.24 and Table 5.25.

Table 5.23. Summary of the main parameters used to estimate changes in the bird community, expressed as percentage of present day. Estimates are from the other specialists.

Parameters	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)
Intertidal sand and mudflats	100%	150%	150%
Salt marsh	100%	108%	111%
Reeds and sedges	100%	98%	95%
Fish abundance	94%	105%	97%
Open mouth	100%	118%	164%

Table 5.24. Summary of how the birds change under the different scenarios.

Scenario	Summary of changes
Scenario 1 (Full allocation)	Numbers of piscivores decrease slightly as a result of a decline in abundance of small fish and loss of alien vegetation along the banks. Other groups may remain unchanged or continue to decline.
Scenario 2 (No IAPs)	The changes to the piscivorous groups will be quite small – with minor increase under Scenario 1. The main change will be to terns and waders, which are expected to return in greater numbers as the health of the intertidal areas is restored to some extent.
Scenario 3 (No IAPs, Open, WQ)	Numbers of piscivores decrease slightly as a result of a decline in abundance of small fish and loss of alien vegetation along the banks. Numbers of terns and waders will recover to a greater extent than under Scenario 2.

Table 5.25. Similarity scores for birds under the different scenarios.

Variable	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)	Conf
1. Species richness	71	66	83	86	M
2 Abundance	12	12	18	47	M
3. Community composition	22	21	30	63	M
Bird score	**24**	**23**	**32**	**55**	**M**

5.4 Ecological Categories associated with runoff scenarios

The individual EHI scores, as well as the corresponding ecological category under different scenarios are provided in Table 5.1. The estuary is currently in a D-category. It will deteriorate slightly under Scenario 1 (Full allocation), but is expected to remain in a D-category. The estuary will improve under Scenario 2 (No IAPs) to a C category, and overall health improves markedly under Scenario 3 (No IAPs, Open, WQ), though remaining in a C-category. A rough estimate of the contribution of non-flow related impacts suggests that if these are removed, the estuary could be raised to a C-class, and if this is done in conjunction with Scenario 3, the estuary may reach a B health category.

Table 5.1. EHI score and corresponding Ecological Category under the different runoff scenarios

	Wt	Present	1 (Full alloc)	2 (No IAPs)	3 (No IAPs, Open, WQ)	Conf
Hydrology	25	25	25	55	55	30
Hydrodynamics and mouth condition	25	65	65	76	96	30
Water quality	25	59	58	64	68	50
Physical habitat alteration	25	51	51	64	66	50
Habitat health score		**50**	**50**	**65**	**72**	**40**
Microalgae	20	59	63	64	71	43
Macrophytes	20	60	60	65	70	63
Invertebrates	20	47	40	66	77	50
Fish	20	52	47	64	71	57
Birds	20	24	23	31	56	70
Biotic health score		**48**	**46**	**58**	**69**	**57**
ESTUARY HEALTH SCORE		**49**	**48**	**61**	**70**	**48**
PRESENT ECOLOGICAL STATUS		**D**	**D**	**C**	**C**	**Low**
EHI after non-flow impacts removed		61	60	72	78	
PES after non-flow impacts removed		C	D	C	B	

The Recommended Ecological Category is Best Attainable State, which is a B category.

6 RECOMMENDATIONS

6.1 Recommended ecological flow requirement for the Uilkraals estuary

For a high confidence study, the **'recommended Ecological Flow Requirement' scenario,** is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the recommended Ecological Category. Where any component of the health score is less than 40, then modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. For lower confidence studies, such as this one, a more conservative flow scenario (or a slight modification thereof to address low-scoring components) should be chosen, using the following guidelines.

Table 6.1. Guidelines for identification of the recommended Ecological Flow Requirement' scenario

Overall confidence	Choice of recommended ecological flow requirement' scenario
Very Low (rough estimate) <40% certain	The scenario with the lowest change in river inflow that will maintain the estuary in the recommended Ecological Category or obtain a health score that is one class higher (large safety buffer).
Low <40 - 60% certain	The scenario with the highest change in river inflow that will maintain the estuary in the recommended Ecological Category or obtain a health score that is one class higher (large safety buffer)
Medium 60-80% certain	The scenario with the highest change in river inflow that will maintain the estuary in the recommended Ecological Category or obtain a health score that is half a class higher (small safety buffer)
High >80% certain	The scenario with the highest change in river inflow that will still maintain the estuary in the recommended Ecological Category (no safety buffer)

Based on this assessment, we have ascertained that the Best Attainable State for the estuary could be a **B-category**. It should be noted, however, that some of these impacts would be difficult to remove, such as the global impacts on migratory birds, and the status of marine fish stocks. **The flow requirements for the estuary are the same as those described for Scenarios 2 and 3**. A summary of the monthly flows for these two scenarios is presented in Table 6.3.

Table 6.2. Summary of the monthly flow (in $m^3.s^{-1}$) distribution under Scenario 2 and 3

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	9.084	8.383	3.626	2.946	2.378	4.337	6.399	9.151	10.336	9.502	14.116	8.958
90%ile	2.345	2.612	0.553	0.037	0.198	0.347	2.191	2.823	4.360	6.384	6.851	3.044
80%ile	1.157	1.119	0.052	0.026	0.029	0.097	0.841	1.960	2.955	3.383	4.846	2.357
70%ile	0.676	0.231	0.034	0.026	0.029	0.030	0.359	1.120	2.014	2.524	3.226	1.914
60%ile	0.470	0.123	0.030	0.026	0.025	0.026	0.208	0.646	1.300	1.684	2.102	1.327
50%ile	0.347	0.081	0.030	0.022	0.025	0.022	0.112	0.396	0.953	1.333	1.680	0.949
40%ile	0.231	0.050	0.026	0.022	0.025	0.022	0.050	0.224	0.575	1.019	1.258	0.729
30%ile	0.153	0.046	0.026	0.022	0.025	0.022	0.039	0.172	0.432	0.754	0.904	0.502
20%ile	0.127	0.042	0.026	0.022	0.021	0.022	0.027	0.101	0.258	0.549	0.538	0.332
10%ile	0.060	0.039	0.022	0.019	0.021	0.019	0.023	0.037	0.127	0.392	0.362	0.181
1%ile	0.048	0.031	0.022	0.019	0.021	0.019	0.023	0.029	0.057	0.091	0.127	0.084

6.2 Resource quality objectives

Note that since the estuary has to be restored from a D to a B-category, the thresholds of potential concern (TPCs) should be seen as targets to be met within 5 years. Thereafter the estuary should be maintained such that these thresholds are not breached. The TPCs for the Uilkraals Estuary area listed in Table 6.3 and Table 6.4.

Table 6.3. Ecological specifications and thresholds of potential concern for abiotic components

Abiotic Component	Ecological Specification	Threshold of Potential Concern
Water quality	Salinity intrusion should not cause exceedance of TPCs for fish, invertebrates, macrophytes and microalgae (see above)	Salinity greater than 20 PSU for longer than 3 months in Zone C at Site 8 (4 km) upstream from the mouth (this would have an impact on the brackish saltmarsh, reeds and sedges) Salinity greater than 35 ppt DO < 4 mg/l in more than 75% of estuary DIN and DIP concentrations >100 µg/land > 50 µg/l, respectively , unless from natural origin (e.g. occasional upwelling which will be indicate by low seawater temperatures)
Hydrodynamics	Maintain a flow regime to create the required habitat for birds, fish, macrophytes, microalgae and water quality	River inflow distribution patterns differ by more than 5 % from that of Scenario 1/ 3 (i.e. recommended flow scenario for the Uilkraals). River inflow below 0.03 m^3/s persist for longer than 2 months Mouth closure occurs Water level in the estuary above 1.0 m MSL for 3 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	River inflow distribution patterns of intermediate and high flows (flood components) differ by more than 10% (in terms of magnitude, timing and variability) from that of the Present State (2012) Suspended sediment concentration from river inflow deviates by more than 20 % of the sediment load-discharge relationship to be determined as part of baseline studies (present state 2012). Findings from the bathymetric surveys undertaken as part of the monitoring programme indicate changes in the sedimentation and erosion patterns in the estuary have occurred (± 0.25 m).

Table 6.4. Ecological specifications and thresholds of potential concern for biotic components

Component	Ecological Specification	Threshold of Potential Concern
Microalgae	Phytoplankton biomass, measured as water column chlorophyll-a should not exceed 10 ug l^{-1}. Maintain high subtidal benthic microalgal biomass during the closed mouth phase and high intertidal benthic microalgal biomass during the open phase.	Phytoplankton biomass greater than 10 ug l^{-1}. Deviation in benthic microalgal biomass by 20 % compared with Present State concentrations. No brackish epipelic diatoms are found during the closed phase
Macrophytes	Maintain the distribution of plant community types i.e. Submerged macrophyte, *Ruppia cirrhosa* beds during closed mouth brackish conditions, salt marsh, *Salicornia meyeriana* marsh during open mouth conditions, *Phragmites australis* stands in the middle / upper reaches and salt marsh grasses indicative of brackish conditions.	Greater than 20 % change in the area covered by different macrophyte habitats for baseline open and closed mouth conditions.
Benthic Invertebrates	The estuary should have viable populations of *Callianassa kraussi* in sandy zones and *U. Africana* in muddy zones. Breeding in both species ceases at salinities lower than 17ppt during prolonged mouth phase. In *U. africana* and export of larvae into marine and postlarvae back to estuary ceases.	Abundance of *C. kraussi* and *U. Africana* drops below 50% of recorded total abundances in each season. No recruits in population recorded. (Identify zones where these are abundant based from the study and these would be where the above would be assessed)
Zooplankton	Prolonged close mouth would result in a loss of marine species (e.g. *Pseudodiaptomus sp.) from the* zooplankton community,	Absence of indicator marine species (*Pseudodiaptomus sp.) changes by more than 50% of current levels (still to be determined).*
Fish	Retain the following fish assemblages in the estuary (based on abundance): estuarine species (30-40%), estuarine associated marine species (60-70%) and indigenous freshwater species (<1%). All numerically dominant species are represented by 0+ juveniles.	Level of estuary associated marine species drops below 50% of total abundance. Level of estuarine species increases above 50% of total abundance. Occurrence of alien freshwater species in the estuary. Absence of 0+ juveniles of any of the dominant fish species.
Birds	The estuary should contain a rich avifaunal community that includes representatives of all the original groups, significant numbers of migratory waders and terns, as well as a healthy breeding population of resident waders. The estuary should support thousands of birds in summer and hundreds in winter.	Numbers of White-fronted Plovers fall below 60 during the breeding season Numbers of terns recorded in midsummer are fewer than 2000 Numbers of bird species drop below 20 for 3 consecutive counts.

6.3 Mouth management

It was clear from the results of this reserve determination study that while it was highly desirable to maintain the mouth of the Uilkraals estuary in a permanently open state from an ecological perspective as it was under reference conditions, this may not be easy given existing demands for freshwater in this catchment. Specialists involved in the RDM study therefore put forward recommendations for the key elements of a mouth management plan for the system and identified key research questions that need to be answered prior to implementing such a plan.

This plan needs to be presented to the broader stakeholder group identified through the Estuary Management Planning process for the Uilkraals estuary commissioned by the C.A.P.E. Estuaries Management Programme and Cape Nature, before being finalised.

6.3.1 Purpose statement

The following purpose statement was put forward by the experts at the RDM workshop as being the reasons why artificial manipulation of the mouth in addition to clearance of alien vegetation in the catchment is necessary:

1. Uilkraals estuary was historically a permanently open system with no known records of closure prior to 2008.
2. The estuary is currently experiencing anomalous periods of prolonged mouth closure attributable to:
   - Significant alien infestation in the catchment (which deplete baseflow in summer and winter) as well as abstractions for irrigation and domestic and industrial use (which deplete medium and low flows in winter), and
   - Long-term variations in rainfall and runoff (drought cycles), and has recently entered a drought cycle (last 2 years only).
3. Mouth closure is impacting on:
   - Water quality by exacerbated elevated levels of nutrients in the estuary originating from anthropogenic sources (WWTW and agriculture) and allowing hypersaline conditions to develop in the estuary when the mouth is closed and freshwater flow is very low;
   - Movements of estuary associated fish and invertebrates and diadramous fish between the estuary and the sea and hence the nursery function of the system which is of high regional importance due to most other systems is region being closed for much of the time;
   - Salt marsh vegetation of the estuary, which has a high conservation importance due to the presence of genetically distinct species assemblages by drowning (prolonged inundation with fresh for brackish water), and
   - Loss of intertidal habitat and associated invertebrate fauna, fish and birds through reduced tidal influence, desiccation (reduced frequency or absence of tidal inundation, and or drowning.

4. Closed mouth status likely to be progressive or “self reinforcing” due to progressive sediment build up in the estuary particularly in the mouth region thereby increasing the likelihood of future closure
5. Removal of all alien vegetation from the catchment is a high priority (see section 6.5) and will go a long way towards restoring summer and winter baseflows at the head of the estuary, but in itself may not be sufficient to keep the mouth of the estuary open.

6.3.2 Objectives of the mouth management plan

The objectives of the mouth management intervention(s) as agreed by the workshop participants are as follows:

1. Enhance and maintain estuary health and ecosystem functions including:
   - Maintaining connectivity with the sea and hence protecting the nursery function of the estuary and its role as a passage for diadramous fish species;
   - Preventing further loss of and/or restoring conservation-worthy salt marsh vegetation in the estuary;
   - Preventing macroalgae and/or benthic micro-algae from reaching unnatural densities in the estuary
   - Preventing further loss of and/or restoring intertidal habitat, invertebrate and bird communities in the estuary; and
   - Preventing further degradation in the water quality of the estuary and as far as possible restoring this to what it was like under reference conditions.
2. Reducing the risks of the closed mouth status becoming “self-reinforcing” (i.e. of sediment build up at the mouth) and thereby increasing likelihood of future closure.

6.3.3 Monitoring/research requirements (to be implemented prior to any future breaching)

The following issues were identified as requiring further investigation prior to any further artificial manipulation of the mouth with a view to informing the most appropriate mouth management interventions:

1. Commissioning of a topographic survey of the estuary and an assessment of sedimentary process in the estuary including the impacts of encroachment by alien vegetation.
2. Continuous monitoring of water levels in the estuary. (Note that DWA have installed a water level recorder in the estuary but this instrument needs to be relocated to a more suitable position as it is unable to record low water levels in its current position (see Figure 6.1).

Additional issue that should also be investigated were identified as follows:

1. Continuous monitoring of freshwater inflows at the head of the estuary
3. Daily monitoring of the mouth state of the estuary (preferably using a web cam).
4. Monitoring of the following water quality parameters in the system at intervals as specified below:

- Nutrients NO_x and PO_4 on an ad hoc basis when problems develop e.g. macro- or microalgal blooms);
- Dissolved oxygen (ad hoc as above); and
- Continuous monitoring of temperature and salinity at a position below the road bridge and/or Site 7 (Figure 2.2).

Figure 6.1. DWA water level recorder on the Uilkraals estuary (Photo: Sue Mathews)

6.4 Invasive alien plants

Invasive alien plants (IAPs) make a significant impact on flows in the Uilkraals catchment, reducing options for water use. The IAPs need to be cleared from the catchment in order to restore the Uilkraals estuary to its best attainable state. Thereafter the catchment needs to be kept free of IAPs.

6.5 Water quality management

There appear to be two main sources of organic pollution into the estuary –spillover from the waste water treatment works to the west, and seepage from sewage systems in the resort development at the mouth. Pollution from these sources needs to be eliminated. This will probably involve a combination of compliance issues and seeking new engineering solutions. A specialist study needs to be commissioned on how best to achieve this.

6.6 Monitoring requirements

Recommended minimum monitoring requirements to ascertain impacts of changes in freshwater flow to the estuary and any improvement or reductions therein are listed in Table 6.5.

Table 6.5. Recommended minimum requirements for long term monitoring

Ecological Component	**Monitoring action**	**Temporal scale (frequency and when)**	**Spatial scale (no. Stations)**
Hydrodynamics	Record water levels	Continuous	At bridge
	Measure freshwater inflow into the estuary	Continuous	At Kraaibosch dam and Boesmans above the estuary
	Aerial photographs of estuary (spring low tide)	Every 3 years	Entire estuary
Sediment dynamics	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detailed in the mouth (every 100m). The vertical accuracy should be about 5 cm.	Every 3 years	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	Every 3 years (with invert sampling)	Entire estuary
Water quality	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow	Monthly continuous	At river inflow
	Assess and better quantify wastewater input (e.g. nutrients and organics) from diffuse sources (e.g. caravan park, WWTW).	Once-off detailed Possibly long-term (e.g. peak seasons) if input remains significant (preferably these should be mitigated)	In stream (source/s)
	Record longitudinal salinity and temperature profiles (and any other in situ measurements possible e.g. pH, DO, turbidity)	Seasonally, every year	Entire estuary (10 stns)

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. Stations)
	Take water quality measurements along the length of the estuary (surface and bottom samples) for system variable (pH, dissolved oxygen, suspended solids/turbidity) and inorganic nutrients in addition to the longitudinal salinity and temperature profiles	Seasonal surveys, every 3 years or when significant change in water inflows or quality expected	Entire estuary (10 stns)
Microalgae	Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. HPLC, fluoroprobe Intertidal and subtidal benthic chlorophyll-a measurements,	Summer and winter survey every 3 years	Entire estuary (5 stns)
Macrophytes	Ground-truthed maps; Record 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; Record percentage plant cover, salinity, water level, sediment moisture content and turbidity on a series of permanent transects along an elevation gradient; Take measurements of depth to water table and ground water salinity in supratidal marsh areas	Summer survey every 3 years	Entire estuary (5 stns)
Benthic Invertebrates	Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary. Record benthic invertebrate species and abundance, based on van Veen type grab samples in subtidal and core samples in intertidal at a series of stations up the estuary, and counts of hole densities. Measures of sediment characteristics at each station	Summer and winter survey every 3 years	Entire estuary (5 stns)
Zooplankton	Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary.	Summer and winter every 3 years	Entire estuary 5stn
Fish	Record species and abundance of fish, based on seine net and gill net sampling.	Summer and winter survey every 3 years	Entire estuary (5 stns)

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. Stations)
Birds	Undertake counts of all water associated birds, identified to species level.	A series of monthly counts, followed by winter and summer survey every year	Entire estuary (3 sections)

7 REFERENCES

Adams, J.B., Snow, G.C. and Veldkornet, D.A. 2010. Updated estuary habitat and plant species data. National Spatial Biodiversity Assessment 2010: Estuaries Component. Report submitted to CSIR.14 pp.

Barnes, K.N. 1996. Specialist bird report on the proposed resort development on Farm Sand Down (estate number 200, Bredasdorp), and the impacts on the Uilkraals River Estuary. Avian Demography Unit Research Report No. 15.

Department of Water Affairs (DWA) 2010. Feasibility Study into the Potential Development of Further Surface Water Supply Schemes for the Western Cape: Rapid determination of the Environmental Water Requirements for the Palmiet River Estuary. Report submitted by CSIR to DWA (CSIR Report No. CSIR/NRE/CO/ER/2010/0077/A) . Pretoria.

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

Department of Water Affairs and Forestry (DWAF) 2008. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries. Version 2. Pretoria.

Harrison, T. D. 1999. A preliminary survey of Estuaries on the South-West Coast of South Africa, Cape Hangklip - Cape Agulhas, with particular references to the fish fauna. Transactions of the Royal Society of South Africa 54(2): 257-283.

Heydorn, A.E.F. and Bickerton, I.B..1982. Report No. 9: Uilkraals (CSW 17). In: Estuaries of the Cape. Part 2. Synopses of available information on individual systems. Heydorn, A.E.F. & Grindley, J.R. (eds)., Report, Green Series,

Mucina, L., Janssen, J. A. and O'Callaghan, M. 2003. Syntaxonomy and zonation patterns in the coastal salt marshes of the Uilkraals Estuary, Western Cape (South Africa). Phytocoenologia, 33: 309-334.

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

Summers, R.W., Pringle, J.S. & Cooper, J. 1976. The status of Coastal Waders in the south-western Cape, South Africa. Report on the summer 1975/76 ornithological survey of coastal wetlands and shorelines of the south-western Cape by the Western Cape Wader Study Group. Percy FitzPatrick Institute, University of Cape Town. 162pp.

Teske, P.R., Von der Heyden, S., McQuaid, C.D. and Barker, N.P. 2011. A review of marine phylogeography in southern Africa. South African Journal of Science,107 (5/6): 43-53.

Turpie, J.K. & Clark, B.M. 2007. The health status, conservation importance, and economic value of temperate South African estuaries and development of a regional conservation plan. Report to CapeNature.

Turpie, J.K. 1995. Prioritising South African estuaries for conservation: a practical example using waterbirds. Biological Conservation 74: 175-185.

Turpie, J.K., Adams, J.B., Joubert, A., Harrison, T.D., Colloty, B.M., Maree, R.C., Whitfield, A.K., Wooldridge, T.H., Lamberth, S.J., Taljaard, S. & van Niekerk, L. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation. Water SA 28, 191-206.

8 APPENDIX A. Data available for the study

Component	Baseline information requirements for high confidence	Data available for this study
General	Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the Reference condition (if available).	Aerial photos for 1938, 1961, 1973, 1990. 2005
	Available orthophotographs	
Hydrology	Catchment size delineation	Simulated monthly flows, 1920 to 2010
	Measured river inflow data (gauging stations) at the head of the estuary over a 5-15 year period	
	Measured rainfall data in the catchment (or in a representative adjacent catchment)	
	Hydrological parameters (evaporation rates, radiation rates)	
	Flow losses (e.g. abstraction, impoundment) and gains (e.g. discharges, transfer schemes)	
	Flood hydrographs	Flood hydrographs for reference condition
Bathymetry	Bathymetric/topographical surveys including berm height, cross sections at 10 – 50 m in the mouth region, cross section profiles at 500 m to 1000 m intervals upstream of the mouth, and floodplain topography.	Bathymetric data available
Hydrodynamics	Continuous water level recordings near mouth of the estuary	No data
	Water level recordings at 2-6 stations along the length of the estuary over a spring and a neap tidal cycle (i.e. at least a 14 day period)	No data
	Long term data on daily mouth state (open/closed/overtopping) for temporarily open/ closed estuaries, particularly in systems that have a semi-closed mouth state.	Limited information, for last few years, great uncertainty regarding dates of closure
	Data on wave conditions.	Not used
Sediments	Sediment grabs samples collected using a Van Veen or a Zabalocki-type Eckman grab (to characterize recent sediment movement) for particle size analyses, along entire estuary at 500 to 1 000 m intervals.	Samples collected at 5 stations in 2011
	Sediment core samples collected using a corer (for historical sediment characterization) at intervals similar to cross-section profiles (see bathymetry) or where considered appropriate by sediment specialist; collected at 3 - 6 year intervals, as well as after flood events.	No data
	Sediment load at head of estuary (including detritus component – particulate carbon/loss on ignition).	No data
Water quality	Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary and in near-shore seawater	No data available
	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)	Limited data Heydorn and Bickerton 1982 (1979); Anchor Environmental, unpublished data (2011)

Component	Baseline information requirements for high confidence	Data available for this study
	peak of high flow season (i.e. period of maximum flushing by river water)	
	Water quality measurements, i.e. system variables (pH, DO, turbidity, suspended solids, TDS and temperature) and nutrients (inorganic nitrogen [nitrite, nitrate and ammonia], reactive phosphate and silicate) 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	Limited data Heydorn and Bickerton 1982 (1979); Anchor Environmental, unpublished data (2011)
	Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary	No data available
	Effluent discharges at end of pipe just before entering the estuary - measurements of flow rate and other parameters, depending on the composition of the effluent	No data available
Microalgae	Data on relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae, during typical high and low flow conditions	No data available
	Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions,.	Anchor Environmental field data – this study only for chlorophyll a for 22 April and 17 August 2011
	Intertidal and subtidal benthic chlorophyll-a measurements,	No data
	Along with measures of water salinity, inorganic nutrients, sediment particle size and total organic matter.	Anchor Environmental field data – this study, on salinity and sediments
Macroalgae	Ground-truthed aerial photographs or maps	No
	Data on 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	Mucina *et al*. 2003 provides some data
	Permanent transects along an elevation gradient with measurements of percentage plant cover, salinity, water level, sediment moisture content and turbidity	No data
	Measurements of depth to water table and ground water salinity in supratidal marsh areas	No data
Invertebrates	Species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary.	No data
	Benthic invertebrate species and abundance, based on subtidal grab samples and intertidal core samples at a series of stations up the estuary, and pump sampling or counts of hole densities.	This study – April and August 2011.
	Organic matter and particle size analysis of sediment at each station	This study
Fish	Species and abundance data of fish, based on seine net and gill net sampling at about 2km intervals along the estuary, including all habitat types, e.g. *Zostera* beds, prawn beds, sand flats, and with at least one sample sets in the 0 to 1 ppt reach of the system. These data should be available for four seasons of the year, or for low and high flow periods in a series of years.	This study – Apr and Aug 2011

Component	Baseline information requirements for high confidence	Data available for this study
Birds	One year of monthly counts of all water associated birds, by species, for the whole estuary, preferably separated into counting areas and/or a series of at least 10 years of summer and winter counts, in addition to historical data on the same.	Recent estuary counts from Feb 2010, Apr 2011 and Aug 2011, the latter two by area One-off historical summer counts from 1981 and 1996 A few partial counts. No regular counts are undertaken at the estuary (e.g. CWAC)