Orange-Senqu River Basin

Orange-Senqu River Commission Secretariat
Governments of Botswana, Lesotho, Namibia and South Africa

UNDP-GEF
Orange-Senqu Strategic Action Programme
(Atlas Project ID 71598)

Estuary and Marine EFR assessment, Volume 1: Determination of Orange Estuary EFR

Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth

Technical Report 32
Rev 1, 30 October 2013

UNDP-GEF
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Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth

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This document has been issued and amended as follows:

Revision	Description	Date	Signed
0	Initial draft for review	Jul 2013	LvN, DL
1	Second draft including recommendations	30 Oct 2013	LvN, DL

Project executed by:
UNOPS

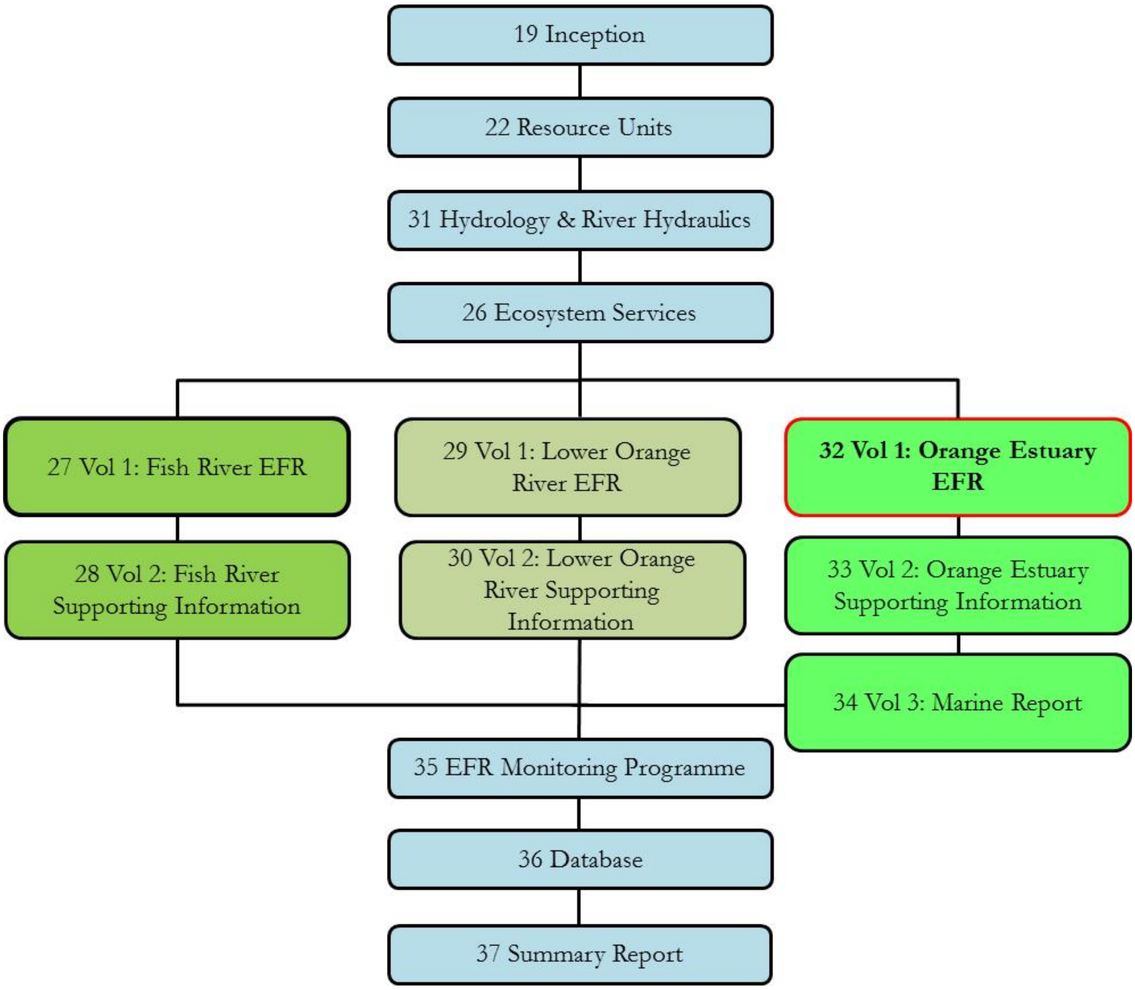
Report list

A list of the Technical Reports that form of this study is provided below. A diagram illustrating the linkages between the reports is also provided.

Technical Report No	Report
19	Inception Report, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
22	Delineation of the Study Area – Resource Unit Report, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
26	Consequences of Scenarios on Ecosystem Services, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
27	River EFR assessment, Volume 1: Determination of Fish River EFR Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
28	River EFR assessment, Volume 2: Fish River EFR, supporting information Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
29	River EFR assessment, Volume 1: Determination of the lower Orange River EFR Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
30	River EFR assessment, Volume 2: Lower Orange River EFR, supporting information Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
31	River and Estuary EFR assessment, Hydrology and River Hydraulics Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
32	**Estuary and Marine EFR assessment, Volume 1: Determination of Orange Estuary EFR** **Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth**
33	Estuary and Marine EFR assessment, Volume 2: Orange Estuary EFR: Supporting Information Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
34	Estuary and Marine EFR assessment, Volume 3: Assessment of the Role of Freshwater Inflows in the Coastal Marine Ecosystem Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
35	EFR monitoring programme, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth

Technical Report No	Report
36	Database, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth
37	Summary Report, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth

Bold indicates current report.



Acknowledgements

The following persons and institutions are gratefully acknowledged for assisting with information presented in this report:

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Hydrology
All hydrological observed/real time data obtained from Ministry of Agriculture, Water and Forestry, Department of Water Affairs and Forestry, Namibia.

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Executive summary

Introduction

The Orange-Senqu Strategic Action Programme supports ORASECOM in developing a basin-wide plan for the management and development of water resources, based on integrated water resources management (IWRM) principles (ORASECOM, 2011). Rivers for Africa was appointed to address the 'Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth'. The study area for this project is the Orange River downstream of the Fish River confluence (including the estuary and immediate marine environment) and the Fish River (Technical Report 22).

This report focuses on the Orange Estuary. The objectives of this component of the study included:

- the development and implementation of a baseline monitoring programme covering flow-related biophysical parameters;
- research and assessment of non-flow-related impacts on the estuary;
- description of the present ecological state (PES) of the estuary;
- determining the environmental flows that would be required to maintain a range of ecological conditions in the estuary;
- recommend attainable and satisfactory environmental flows for the estuary;
- design of a long-term monitoring programme to assess the efficacy of environmental flows and other management interventions for the estuary.

Study site

The Orange Estuary is situated between the towns of Alexander Bay in South Africa and Oranjemund in Namibia. The study area extended from the mouth to the head of tidal influence at the Sir Ernest Oppenheimer Bridge, approximately 11 km upstream, and included the banks up to the 5 m contour. The total area is approximately 2,700 ha.

Method

Methods to determine EFRs have been slightly modified in the development and refinement of methods for rivers, estuaries, wetlands and groundwater, but in South Africa the same process is essentially followed in each. This study therefore involved the following steps:

- initiate the study, defining the study area, the study team, and the level of study (rapid, intermediate or comprehensive environmental flow requirement (EFR) determination);
- define the resource units, delineating the geographic boundaries of each water resource unit;

- estimate the reference condition (the natural, pristine state) and assess the present ecological status by means of an estuary health index. The output from this index provides the estuary health score, which is allocated an ecological category (EC) rating of A (natural) to F (critically modified) depending on the resource condition;
- evaluate the estuary importance, in terms of both conservation importance (size, habitat diversity, zonal type rarity and biodiversity importance) and functional importance;
- assign a recommended ecological category (REC) between A and D, taking into account the level of protection and management required;
- quantify the EFR for the recommended category and alternative categories, by describing various flow scenarios;
- evaluate the ecological consequences of flow scenarios in terms of the predicted future biotic and abiotic condition of each;
- recommend the EFR, representing the flow scenario allowing the highest change in river inflow while still maintaining the estuary in the REC.
- recommend EFR specifications, which entails setting the resource quality objectives (quantitative specifications), and the water quantity and quality parameters of the flow requirement.

Taking the recommended EFR, and the ecological and socio-economic importance of the water resource into consideration, the various regulating authorities will make a decision on the EC of the water resource. Where possible, the ecologically processes of the water resource will be maintained to ensure sustainable development (i.e. not depleting the "natural capital" such as fish nurseries and biodiversity).

Results

Present ecological status

The health scores allocated to the various abiotic and biotic parameters for the Orange Estuary are used to calculate the overall health score. The Orange Estuary has an overall health score of 51 relative to the natural condition. This is mostly attributed to the following factors:

- significant freshwater flow modification – both loss of floods and increased baseflows;
- lack of estuary mouth closure and resulting backflooding of saltmarshes with fresher water;
- road infrastructure in the form of the old causeway across the saltmarshes and old bridge crossings;
- nutrient input from catchment downstream of Vioolsdrift;
- gill netting of indigenous fish species and considerable fishing effort at the mouth on both sides of the estuary;
- riparian infrastructure – levees preventing backflooding;
- mining activities;

- wastewater disposal (sewage and mining return flow);
- grazing and hunting.

The estuary health score for the Orange Estuary under present conditions and the study confidence levels are provided below.

Variable	*Weight*	*Health score*	*Confidence*
Hydrology	25	44	Low/Medium
Hydrodynamics and mouth condition	25	70	Low
Water quality	25	53.2	Medium
Physical habitat alteration	25	78	Medium
Habitat health score		***61***	***Medium***
Microalgae	20	40	Low
Macrophytes	20	50	Medium
Invertebrates	20	45	High
Fish	20	50	Medium
Birds	20	23	Medium
Biotic health score		*42*	***Medium***
Estuary health score		51	
Present ecological status		D	
Overall confidence			***Medium***

The overall health score translates to a PES of D, representing a largely modified system (summarised in the second table below).

Estuary health 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

Estuary importance

Following South Africa's accession to the Ramsar Convention, the Orange Estuary was designated a Ramsar Site, i.e. a wetland of international importance, on 28/06/1991 (Cowan, 1995). Namibia ratified the Ramsar Convention in 1995, after which the designated area was enlarged and the Namibian part of the wetland was designated too. In September 1995 the South African Ramsar Site was placed on the Montreux Record (a list of Ramsar Sites around the world that is in a degraded state) as a result of a belated recognition of the severely degraded state of the saltmarsh on the south bank (CSIR, 2001). The implication is that the Orange Estuary may lose its status as a Ramsar Site unless the condition of the saltmarsh can be restored.

The Namibian section of the Orange Estuary was recently included in the proclamation of the Sperrgebiet National Park in Namibia. However, the section in South Africa is still in the process of being formally protected through legislation. Turpie et al. (2002) ranked the Orange as the seventh most important estuary in South Africa in terms of conservation importance. The Orange Estuary is also one of only two estuaries on the Namibian coast, the other being the Kunene River mouth.

Estuary importance is an expression of the value of a specific estuary to maintaining ecological diversity and functioning of estuarine systems on local and wider scales. The estuary importance score takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity importance and functional importance of the estuary into account. The biodiversity importance score is in turn based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. The rationale for selecting these variables, as well as further details on the estuary importance index, are discussed in Turpie et al. (2002) and updated in *Resource Directed Measures for protection of water resources; Volume 5: Estuarine component* (DWA, 2008).

The importance scores ideally refer to the system in its natural condition. The scores have already been determined for all South African estuaries, apart from the functional importance score, which is derived by specialists in a workshop (DWA, 2008). For this project, the functional importance score was derived at a specialist workshop held in Stellenbosch in March 2013.

The functional importance score determined for the Orange Estuary is provided below.

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

In this case, the functional importance of the estuary was deemed to be very high (100), since the sediment supply from the Orange River catchment feeds the beaches to the north of the mouth. The sediment input from the river is also very important for flatfish in the nearshore environment in the vicinity of the mouth as it provides the habitat on which they depend.

The estuary importance scores for the Orange Estuary are provided below.

Criterion		*Weight*	*Score*
Estuary size		15	100
Zonal rarity type		10	90
Habitat diversity		25	100
Biodiversity importance		25	99
Functional importance		25	100
Estuary importance score	**99**		

The estuary importance for the Orange, based on its present state, was therefore estimated to be 99 out of 100, i.e. the estuary is rated as 'highly important'.

Recommended ecological category

The REC represents the level of protection assigned to an estuary. The first step is to determine the 'minimum' EC, based on its present condition (or PES). The relationship between the estuary health score (derived from the estuary health index), PES and minimum REC is set out below.

Estuary health 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, as shown below.

Protection status and importance	*REC*	*Policy basis*
Protected area Desired protected area	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.
Low to average importance	PES, min D	Estuaries to remain in a D category.

* BAS = Best attainable state

The PES for the Orange Estuary is a D. The estuary is rated as 'highly important', it is a designated Ramsar Site, a Protected Area on the Namibian side; and a desired protected area in the South African Biodiversity Plan for the 2011 National Biodiversity Assessment (Turpie et al., 2012). The REC for the estuary is therefore an A or its best attainable state which is estimated as a category C.

The following key actions are required to improve the health of the system:

- decreasing the winter baseflows;
- enhance nursery function for estuarine dependant fish species;
- improve the water exchange into the lower marsh areas high flow and flood events;
- decreasing nutrient input from the catchment;
- reduce/control destruction of habitat (e.g. wind-blown dust from mining activities, grazing, reducing number of access roads).

Scenario evaluation

The following scenarios (Sc) were evaluated as part of this study.

Scenario	***MAR (Mm^3/a*)***	***% Remaining***	***Orange River drivers***	***Fish River drivers***
Sc OF 2	4 411.05	39	Metolong Dam, Tandjieskoppe, acid mine drainage (AMD) treated.	Neckartal Dam. Increase in Naute Dam irrigation.
Sc OF 3	4 418.26	39.1	Metolong Dam, Tandjieskoppe, AMD treated.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Sc OF 4	4 469.77	39.5	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Sc OF 5	3 837.16	33.9	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released, Polihali Dam, Vioolsdrift Balancing Dam (small). Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Sc OF 6	2 326.26	20.6	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam. Increase in Naute Dam irrigation.
Sc OF 7	2 329.31	20.6	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.

* Mean annual runoff (MAR) is provided as Million cubic metres per year (Mm^3/a).

Note that for simplicity sake, scenarios refer to the NUMBER and exclude OF. OF refers to the Orange Fish and indicates that each scenario includes drivers from both systems.

The individual health scores, as well as the corresponding EC under different scenarios, are provided in the following table. The estuary is currently in a D category. It would deteriorate slightly under Sc 2, 3 and 5, but would likely remain in a D category. The estuary would improve under Sc 4 (decrease baseflows) to a C/D category. Under Sc 6 and 7 the estuary would significantly decline in health to an F category.

Scenario 4 minus anthropogenic impacts (indicated as Sc 4 – Anth) provides an evaluation of the contribution of non-flow-related impacts – removal of the causeway, reduction in baseflows to allow for mouth closure, a 50% decrease in nutrients, decreasing fishing effort. It suggests that if some of these are achieved in conjunction with the flow regime of Sc 4, the estuary condition could be raised to a C category.

The final scenario represents a combination of Sc 5 with a significant decrease in baseflows (similar to Sc 4 and indicated as Sc 5 – rehab & baseflows) in conjunction with some remedial/rehabilitation actions. Under this scenario the estuary would remain in a C/D category.

The health score and corresponding EC under the runoff scenarios are provided below.

			Scenarios							
Component	***Weight***	***Present***	***2***	***3***	***4***	***5***	***6***	***7***	***4 – Anth***	***5 – rehab & baseflows***
Hydrology	25	44	48	48	57	47	20	21	57	52
Hydrodynamics and mouth condition	25	70	50	60	90	60	0	0	90	90
Water quality	25	53	54	55	60	52	40	42	68	68
Physical habitat alteration	25	78	78	78	78	63	13	13	82	67
Habitat health score		**61**	**57**	**60**	**71**	**56**	**18**	**19**	**74**	**69**
Microalgae	20	40	40	39	40	37	28	29	40	40
Macrophytes	20	50	50	50	55	48	6	6	70	65
Invertebrates	20	45	35	35	70	55	10	10	80	50
Fish	20	50	40	45	50	40	30	30	60	50
Birds	20	23	23	24	26	18	7	7	43	38
Biotic health score		**42**	**38**	**39**	**48**	**40**	**16**	**16**	**59**	**49**
Estuary health score		**51**	**48**	**49**	**60**	**48**	**17**	**18**	**66**	**59**
Ecological category		**D**	**D**	**D**	**C/D**	**D**	**F**	**F**	**C**	**C/D**

Conclusions and recommendations

Ecological classification and estuary environmental flow requirement

For a high-confidence study, the 'recommended environmental 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 REC. Where any component of the health score is less than 40, modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. Based on this assessment, the best attainable state for the estuary is a C category.

None of the flow scenarios presented as part of this study meet the REC of C based solely on river inflow.

Therefore the recommended EFR is Sc 4 in conjunction with the recommended remedial measures outlined below.

- Decreasing the winter baseflows sufficiently to allow for mouth closure and related backflooding of the saltmarshes with brackish water to reduce soil salinities.
- Controlling the fishing effort on both the South African and Namibian side through increased compliance and law enforcement. This also requires the alignment of fishing regulations (e.g. size and bag limits) and management boundaries on either side of the transboundary estuary.
- Removal of the remnant causeway that still transects the saltmarshes to improve circulation during high flow and floods events. This will also assist with increasing the water circulation into the lower marsh areas.
- Decreasing nutrient input from the catchment downstream of Vioolsdrift, through improved agricultural practices.
- Controlling windblown dust and wastewater from mining activities.
- Reduce/remove grazing and hunting pressures.

The flow requirements recommended for the Orange Estuary are the same as those described for Sc 4. A flow duration table of the mean monthly flows (in m^3/s) for the scenario is presented below.

Duration	***Oct***	***Nov***	***Dec***	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***
10%	54.8	258.4	151.1	518.2	1544.7	646.5	571.0	158.5	63.2	30.3	31.3	30.2
20%	34.0	74.5	108.6	162.3	847.2	459.9	278.5	128.9	48.7	29.0	29.1	29.8
30%	32.9	71.0	82.2	105.7	216.5	295.1	139.5	76.1	46.5	28.3	28.5	28.9
40%	31.5	69.4	79.0	94.7	138.3	177.7	116.7	66.7	42.9	27.2	26.5	28.2
50%	28.8	66.7	62.6	84.6	99.4	133.6	104.7	60.4	38.9	26.2	24.1	25.0
60%	25.3	63.4	52.8	62.1	77.6	102.6	90.8	55.4	35.2	25.2	20.2	19.4
70 %	17.7	41.3	42.2	35.6	51.5	63.6	57.0	44.5	21.3	19.1	15.3	10.5
80%	9.9	22.1	23.7	25.5	39.0	45.3	40.1	13.2	11.3	11.2	8.5	3.8
90%	4.1	8.8	18.8	18.1	34.1	38.6	16.0	7.7	5.9	6.7	4.7	0.0
99%	0.0	0.0	11.0	9.6	29.2	28.4	8.2	5.9	4.3	3.8	2.6	0.0

Estuary management plan recommendations

It should be noted, however, that some of these proposed mitigation measures, such as the reduction in fishing pressure, would be difficult to achieve in the short-term. It is therefore strongly recommended that the estuary management plan currently being developed for the Orange Estuary prioritise these actions for future implementations. It is also recommended that the management plan proactively addresses potential issues stemming from estuary mouth closure:

- determining the water level (relative to mean sea level) at which critical infrastructure and developments will be inundated if mouth closure occurs (e.g. by means of a Lidar survey of both South African and Namibian estuary floodplains);
- investigating the protection of the aforementioned infrastructure (e.g. golf course on the Namibian side);
- development of an mouth breaching protocol based on 'Guidelines for the mouth management of the Orange Estuary' (Van Niekerk and Huizinga, 2005);
- monitoring of water quality during the closed period.

Contents

List of tables

List of figures

Abbreviations

AMD	*Acid mine drainage*
anth	*anthropological*
BAS	*Best attainable state*
CSIR	*Centre of Scientific and Industrial Research*
DWA	*Department of Water Affairs*
DWAF	*Department of Water Affairs and Forestry*
DIN	*Dissolved inorganic nitrogen*
DIP	*Dissolved inorganic phosphate*
DO	*Dissolved oxygen*
DRS	*Dissolved reactive silicate*
EC	*Ecological category*
EFR	*Environmental flow requirements*
IWRM	*Integrated water resources management*
MAR	*Mean annual runoff*
MSL	*Mean sea level*
MPB	*Microphytobenthos*
NWA	*National Water Act*
ORASECOM	*Orange-Senqu River Commission*
POM	*Particulate organic matter*
PSU	*Practical salinity units (also called parts per thousand (ppt))*
PES	*Present ecological state*
REC	*Recommended ecological category*
RDM	*Resource Directed Measures*
REI	*River-estuary interface*
Sc	*Scenario*
WMA	*Water Management Area*

1 Introduction

1.1 Scope of study

The Orange-Senqu Strategic Action Programme supports the Orange-Senqu River Commission (ORASECOM) in developing a basin-wide plan for the management and development of water resources, based on integrated water resources management (IWRM) principles. The project is currently in the proses of finalising a Transboundary Diagnostic Analysis that will serve as the scientific basis for developing a set of interventions under the framework of a basin-wide Strategic Action Programme and associated National Action Plans in the riparian States. In 2009 the ORASECOM commissioned a study into environmental flow requirements (EFR) in the lower Orange-Senqu River basin. This study has defined both the present ecological state (PES) and the environmental flows that would be required to maintain a range of ecological states at eight representative sites upstream of the confluence of the Fish and Orange Rivers. EFR of the ephemeral but nevertheless significant Fish River and the Orange River from its confluence with the Fish down to the mouth were not covered by the study. This outstanding work is to be the subject of this research project. One of the focus areas of the larger project is the Orange-Senqu River mouth (the Estuary) and the adjacent marine environment.

The Orange Estuary study will focus on sediment and hydrodynamics, water quality, microalgae, vegetation, invertebrates, fish and birds. For the Orange Estuary component the following is to be undertaken:

- develop and implement a baseline monitoring programme covering flow-related biophysical parameters;
- research and assess non-flow-related impacts on the estuary;
- describe the present ecological state of the estuary;
- determine the environmental flows that would be required to maintain a range of ecological conditions in the estuary;
- recommend attainable and satisfactory environmental flows for the estuary; and
- design a long-term monitoring programme to assess the efficacy of environmental flows and other management interventions for the estuary.

Furthermore, this project proposes an assessment on the role of freshwater inflows and associated fluxes in the coastal marine ecosystems linked to the estuary and the potential effects of changes in the freshwater-related fluxes into these ecosystems. This will be done in order to recommend allowable changes in freshwater inflow into the marine environment within the constraints of maintaining or improving the present health status of the marine ecosystem and optimisation of the existing ecosystem services provided by the coastal ecosystem. This study will focus on sediment and hydrodynamics, microalgae, invertebrates and fish using available catch data, remote sensing and numerical modelling.

1.2 Estuary flow requirement method

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

Methods to determine the EFR of estuaries 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 determine the desired health state (also called recommended ecological category (REC) in South Africa) and the associated flow allocation (called ecological reserve in South Africa). The methods have been slightly modified for rivers, estuaries, wetlands and groundwater, but essentially the same process is followed in each. This study follows Version 2 of the prescribed method for estuaries, but will incorporate refinements developed as part of Version 3 where it will add resolution and allow for compatibility with future studies (DWA, 2008; DWA, 2012). The steps of the estuary flow requirement method are outlined below (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.

Step 3: Determine recommended ecological category (EC)

This step entails estimating the reference and present condition and ecological importance in order to determine the REC. The reference condition refers to the natural, un-impacted characteristics of a water resource, and must represent a stable baseline. This usually requires expert judgment in conjunction with local knowledge and historical data. The 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 includes mouth condition;
- character, composition and distribution of aquatic biota.

The PES of the resource (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.

The REC is set as one of the first four ECs (A to D) utilised in identifying the present status assessment (Table 1). These categories are targeted for protection and management of the resource. It could be the same as the PES, or could be higher if an improvement in resource conditions is desired. It has always been intended that when the full implementation phase begins, the process of assigning the EC 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 EFR

The EFR 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 a range of conditions for a particular resource.

Step 5: Ecological consequences of flow scenarios

Flow scenarios are evaluated in terms of the predicted future condition of each scenario.

Step 6: Decide on management category

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

Step 7: Flow requirement specification

This entails the setting of the resource quality objectives (quantitative specifications), and the water quantity and quality parameters of the flow requirement. In a flow requirement study, these are presented as recommendations.

Table 1. The description of ecological categories. Categories A to D are within the desired range, whereas E and F are not (Kleynhans and Louw, 2007)

EC	***Description***
A	**Unmodified, or approximate 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 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 completely 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 well-being 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 function 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

1.3 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. For this study, effort lies somewhere between rapid and intermediate, because although some field data collection was carried out, overall it would be classed as a 'rapid' study. The paucity of historical data on the system determined an expectation of low to medium confidence of the study. This is a situation that can only be remedied with some comprehensive and long-term data collection. Criteria for the confidence limits attached to statements in this study are shown in Table 2.

Table 2. Confidence levels for an Estuarine EFR study

Confidence level	***Situation***	***Expressed as %***
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

1.4 Assumptions and limitations for this study

The following assumptions and limitations should be taken into account:

- The accuracy and confidence of an estuarine ecological flow requirements study is strongly dependant on the quality of the hydrological data. The overall confidence in the hydrological data supplied to the estuarine study team is of a medium level (60 – 80), with a particular concern regarding the accuracy of the simulated baseflows during the low flow periods into the estuary (Confidence: Very low).
- Accurate inflow data were not available at the head of the estuary to allow for a good correlation between river inflow, mouth state, and water quality characteristics. River inflow at Vioolsdrift was adjusted, taking into account evaporative losses and legal water uses, to approximate the baseflows to the estuary over the last 20 years providing context to historical observations and measurements.

2 Estuary delineation

The Orange Estuary, situated between the towns of Alexander Bay in the Northern Cape Province, South Africa and Oranjemund in Namibia has an area of about 2,700 ha.

The estuary of the Orange River comprise an (almost) permanently open river mouth, a 2 to 3 m deep tidal basin, a braided channel system (located between sand banks covered with pioneer vegetation) and a severely degraded saltmarsh on the south bank of the river mouth (Cowan, 1995). A satellite image of the estuary is shown in Figure 1.

Figure 1. Satellite image of the Orange Estuary showing the contour for 5 m above mean sea level contour in red (source: Google Earth)

Previous freshwater requirement studies indicated that the Orange Estuary extends from the Sir Ernest Oppenheimer Bridge to the mouth, approximately 11 km upstream (CSIR; 2004).

Tidal variations of a few centimetres are observed during springtide at this bridge. The estuary has been disturbed by human activities such as the agricultural developments at Alexander Bay, the levees protecting these developments, the oxidation pond system near the village of Alexander Bay, the road across the salt marsh to the river mouth on the south bank and the golf course, protected by a dyke on the north bank. Although the flows have been drastically reduced and regulated, the estuary is still dominated by river flow and the marine water interchange is limited to the lower section of the estuary under normal flow conditions.

At times the mouth is located at the northern bank and sometimes at the southern bank. In the past the location has been strongly influenced by the managed breachings of the mouth. These mouth breachings were alternatively undertaken on the north and south sides of the river, by Namdeb and Alexcor respectively. The objective was to protect low-lying infrastructure from being flooded.

For the purposes of the Orange Estuary flow requirement study, the geographical boundaries of the systems are estimated as follows:

- downstream boundary: The estuary mouth (28°37'58.91"S, 16°27'16.02"E);
- upstream boundary: Head of tidal influence at the Sir Ernest Oppenheimer Bridge, approximately 11 km for mouth (28°33'43.63"S, 16°31'23.02"E);
- lateral boundaries: Five meter above mean sea level (MSL) contour along the banks.

3 Baseline description and health assessment

3.1 Study area

The Orange Estuary forms part of the river basin (or catchment), the largest river basin south of the Zambezi, covering an area of approximately 0,9 million km^2 (Van Niekerk et al., 2003). The basin stretches over four countries, Botswana, Lesotho, Namibia and South Africa with the Orange River itself forming part of the border between South Africa and Namibia. The two main tributaries are the Senqu and the Vaal rivers. At the confluence of the Senqu and Vaal rivers, the Orange River flows in a westerly direction to the west coast entering the Atlantic Ocean through the Orange Estuary (Figure 2). A smaller tributary, the Fish River, joins the Orange River in the lower Orange catchment.

The study area is the Orange River downstream of the Fish River confluence (including the estuary and immediate marine environment) and the Fish River (Technical Report 22). The focus of this task within the above study and report is the lower Orange River only.

Rainfall within the lower Orange River is very low (50 mm in the west) and strongly variable. The potential evaporation rates are highest in the western parts.

Land-use is primarily irrigation and mining, with the area highly dependent on water from the upper Orange River via releases from the Vanderkloof Dam. Large mining operations occur in various parts, with mining activities (present and defunct) found along the whole stretch to the mouth. The water quality in the Lower Orange Water Management Area (WMA) is affected by upstream activities in the Vaal and Orange River catchments. Water requirements on the lower Orange (downstream of the confluence with the Fish River) are limited. There is significant water use in the lower reaches of the Orange River with water supply to irrigation (10 million m^3/annum (Mm^3/a)), domestic use at Alexander Bay and Oranjemund (7,4 Mm^3/a) and for mining at Rosh Pinah (24,4 Mm^3/a).

The various large impoundments notably the Gariep and Vanderkloof dams in South Africa and the Naute and Hardap dams on the Fish River in Namibia, have reduced summer flood peaks in the lower Orange River and Orange River estuary by as much as 50%. Except for the releases through the Orange–Fish tunnel (Eastern Cape) and those into the Vanderkloof canals, all the releases from Gariep and Vanderkloof Dams are made directly into the Orange River to supply downstream users. These river releases are also used to simultaneously generate hydropower.

The study area is provided in Figure 2.

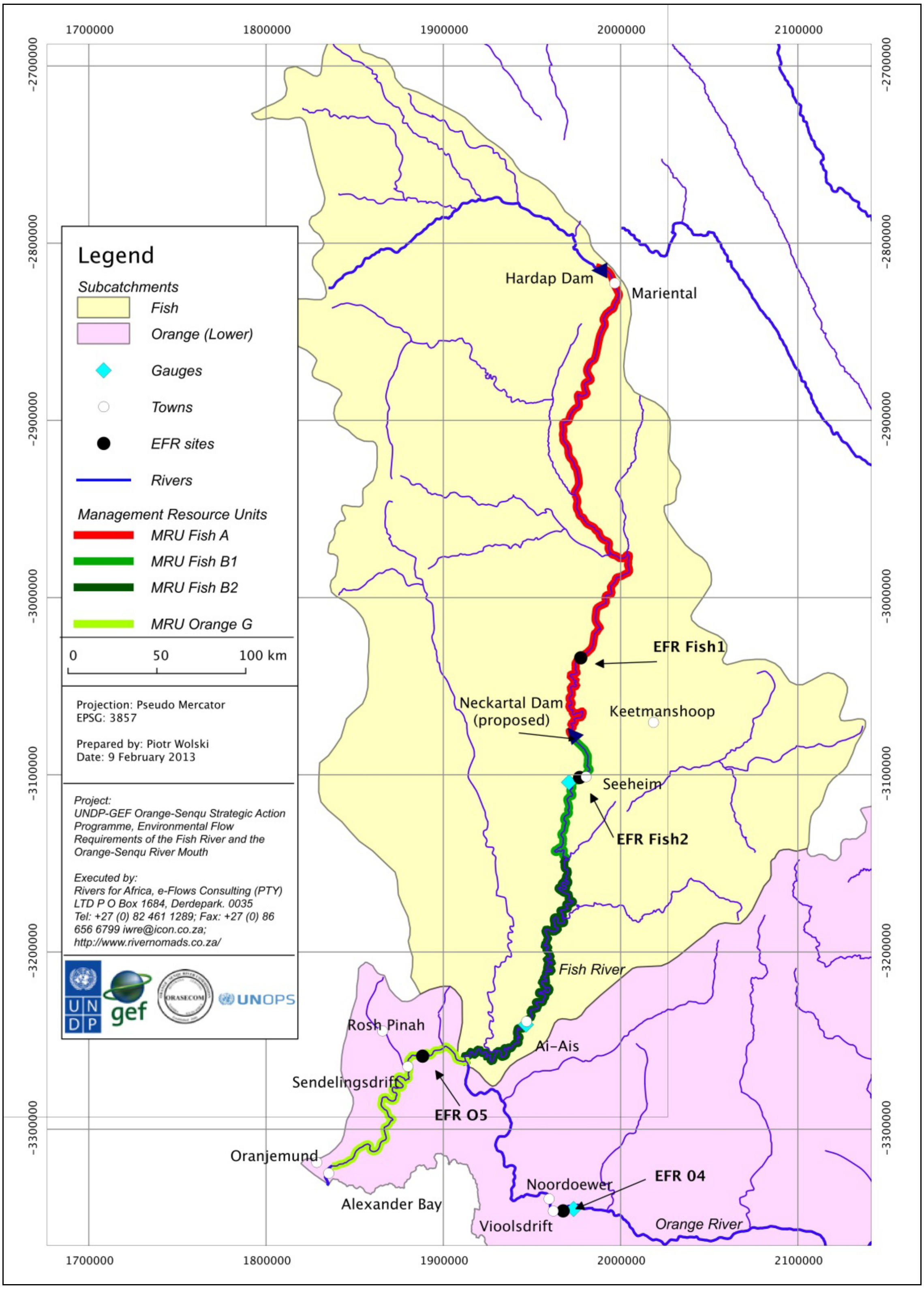


Figure 2. Study area

3.2 Human influences affecting the estuary

3.2.1 Flow-related influences

Flow modification (damming and regulation of flows in catchment): Water resource development in the Orange-Senqu River basin has reduced runoff to the Orange Estuary by more than 50%. Major dams and their capacity in in million cubic metres (Mm^3) in the basin are listed in Table 3.

Table 3. Major dams in the Orange-Senqu River basin

Name	*Year*	*River*	*Full capacity (Mm^3)*
Van Wyksvlei	1884	Van Wyksvlei	145
Smart Syndicate	1912	Ongers	100
Vaalharts	1936	Vaal	63
Vaal	1938	Vaal	2,536
Kalkfontein	1938	Riet	324
Erfenis	1960	Grootvet	211
Allemanskraal	1960	Sand	176
Krugersdrif	1970	Modder	77
Bloemhof	1970	Vaal	1,269
Gariep (Hendrik Verwoerd)	1972	Orange	5,670
Welbedagt	1973	Caledon	40
Vanderkloof (PK le Roux)	1977	Orange	3,236
Sterkfontein	1977	Wilge	2,617
Groot Draai	1978	Vaal	359

Hydropower generation has also modified flow patterns to the estuary: Surplus releases for the generation of hydropower purposes are currently in the process of being significantly reduced from about 320 Mm^3/a, as was the case up to two or three years ago, to 60 Mm^3/a at present. The Mohale Dam has also started to impound water and is significantly reducing the flow available in Gariep and Vanderkloof Dams. It is expected that this surplus will be reduced even more in the future due to the escalation in demands, such as planned increased irrigation.

3.2.2 Non-flow-related influences

Structures (e.g. weirs, bridges, mouth stabilisation): The estuary has been disturbed by human development such as the agricultural developments at Alexander Bay, the levees protecting these developments, the oxidation pond system near the village of Alexander Bay, the road across the salt marsh to the river mouth on the south bank and the golf course, protected by a dyke on the north bank.

Wastewater discharges affecting water quality (e.g. dump sites, storm water, sewage discharges): Agricultural activities in the catchment are the most likely sources of inorganic nutrients (nitrogen and phosphate) to the river. Although some enrichment can occur in the estuary, it is expected that river vegetation largely acts as a filter of inorganic nutrients. Anthropogenic activities in the catchment are also likely to result in pH levels occasionally increasing to about 9.

It has been reported on occasion, that algal blooms occur. These algal blooms can make their way downstream, resulting in river water entering the estuary being almost anoxic.

Wastewater discharges from the mining activities at Alexander Bay also tend to modify interstitial/groundwater salinity levels in the adjacent saltmarsh area.

Input of toxic substances from catchment: There is no information on the toxic inputs from mining operations and adjacent towns and developments or agriculture practices (e.g. pesticide use). This will have to be confirmed through measurements.

Fishing effort in the Orange Estuary: Legal gill netting and seining in South Africa ceased with the Marine Living Resources Act (No. 18 of 1998, South Africa) and South African government policy to phase out all netting in estuaries countrywide. Unfortunately there is still significant fishing effort in the form of illegal gill netting and an orders of magnitude increase in recreational angling in the mouth region and adjacent surf-zone. The latter arose from a redistribution of effort that occurred after Namibian authorities implemented more stringent catch control measures including bag limits specifically aimed at anglers leaving the country's borders. Comparable catches and limited fisheries control saw an increase in angling effort on the Alexander Bay side. Local compliance enforcement on the Namibian side is also hampered by the demarcation of the formal protected area only up to the high water mark (i.e. the park do not include the estuary open water area).

There has also been a slight increase in interest in flyfishing from Brand Kaross to the mouth for freshwater species as well as for flathead mullet *M. cephalus,* elf *P.saltatrix* and leervis *L.amia*. This aspect of recreational angling has potential for a low-key tourist activity.

Total catch from the Orange Estuary, comprising both legal and illegal take is estimated 5 – 10 tonnes per annum.

Grazing: Domestic livestock, cattle and goats, regularly graze in the South African side of the Ramsar site and frequently cross over the river into the Namibian section of the site. Grazing further degrades the saltmashes, compete with indigenous herbivores and detract from the tourism value of the site.

Hunting: Since the cessation of mining activities and access control on the South African side, hunting with dogs has become a regular occurrence on the islands of the estuary. Apart from the quarry, this hunting is also causing death by stampede and drowning of Oryx and cattle grazing in the floodplain of the system (pers. comm., Dr SJ Lamberth, 2013).

3.3 Hydrology

3.3.1 Present seasonal variability in river inflow

Monthly-simulated runoff data for present state and reference condition, over a 66-year period (1920 to 1985) indicate that the MAR under the present state is 4,515.16 Mm^3 (40% of the natural MAR), with the reference condition MAR estimated at 11,306.29 Mm^3. Figure 3 provides a graphic illustration of the reduction in median (50 percentile) and drought (10 percentile) river inflow from the reference condition to present state.

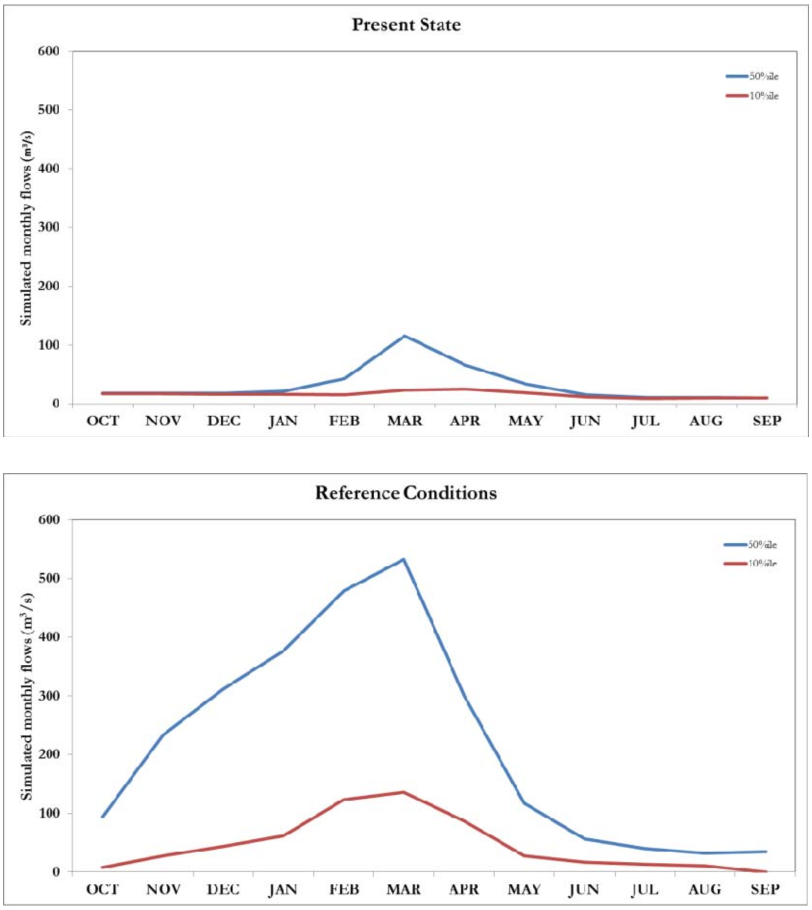


Figure 3. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) under the present state and reference conditions to the Orange Estuary.

3.3.2 Present flood regime

No detailed analyses have been done on the reduction in magnitude and frequency of floods to the Orange Estuary for the purpose of sediment modelling.

On a flow volume basis, preliminary analyses indicate that floods have been reduced by as much as 85% for 1 in 2 year and 74% for 1 in 5 year events respectively (i.e. 15% (1:2) and 26% (1:5) remaining) (Technical Report 31). Similarly, it is estimated that 1 in 20 year floods are reduced by about 20%, while 1 in 100 year floods are reduced by about 10% from reference condition to present state (CSIR, 2004). Larger floods (indicated by months with average runoff volume greater than 5,000 Mm^3) play an important role in resetting the habitat of the estuary. An evaluation of the present state simulated runoff scenario indicates that there has been a marked reduction in the occurrence of monthly runoff volumes greater than 5,000 Mm^3 (represented by a flow rate of 1,867 m^3/s in the simulated mean monthly flow tables).

On an occurrence basis, 'reference' floods in the order of 1 in 2 to 5 years occurred about 2 to 3 *times* more frequently than during the present state (i.e. they now occur on average 1 in 8 to 11 years), while 'reference' 1 in 10 year floods occurred in the order of 7 *times* more than currently (i.e. they now occur on average 1 in 66 years).

3.3.3 Present hydrological health

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:

(a) general inflow patterns, highlighting the changes in low flows;

(b) the frequency and magnitude of flood events (Table 4).

The relative weighting of these two parameters (60:40) is set according to their estimated importance as drivers of the estuarine system. The present hydrological health score is calculated as:

Score = (0.6*a) + (0.4*b)

Table 4. Calculation of the hydrological health score

<table>
<tr><th>Variable</th><th>Motivation</th><th>Score</th></tr>
<tr><td>a: % similarity in the occurrence of low flows from reference condition to present state for the 66-year simulation period.</td><td>Flows below 50 m^3/s are seen as low flows to the Orange Estuary. To provide an overview of change in this flow range a frequency analysis were conducted on the 66-year period of simulated data.
<table>
<tr><th>Flow (m^3/s)</th><th>Reference</th><th>Present</th></tr>
<tr><td><10</td><td>5.7</td><td>3.2</td></tr>
<tr><td>10 – 20</td><td>6.2</td><td>48.9</td></tr>
<tr><td>20 – 30</td><td>6.1</td><td>11.0</td></tr>
<tr><td>30 – 40</td><td>4.3</td><td>5.2</td></tr>
<tr><td>40 – 50</td><td>5.1</td><td>2.3</td></tr>
<tr><td>>50</td><td>72.7</td><td>29.5</td></tr>
</table>
This analyse indicate that low flows (as statistically defined</td><td>52</td></tr>
</table>

Variable	*Motivation*	*Score*
	<50 m^3/s) have significantly increased from reference conditions to the present state, with a drastic increase in the 10 – 20 m^3/s inflow range. Note: Confidence is low due to gauging weir inaccuracies in flows <50 m^3/s. Confidence: Very low	
b: % similarity in the occurrence of major floods from the reference conditions to the present state for the 66-year simulation period.	For the Orange Estuary months with flood volumes greater than 5,000 Mm^3 (represented by a flow rate of 1,867 m^3/s in the simulated mean monthly flow tables) were judged to be resetting events. These have been significantly reduced from 25 under the reference conditions to 8 under the present state for the 66-year simulation period. Confidence: Medium	32
Hydrology score **Confidence: Low – Medium**		**44**

3.4 Physical habitats

3.4.1 Broad description

Estuarine sediment processes operate at different scales from hydrodynamic, biogeochemical and biological processes. Sediment transport and other morphologal responses can occur at hourly to decadal and even longer time scales. Accretion and erosion of subtidal areas (which can result in changes in volume) often occur at shorter time scales, whereas intertidal areas often vary over mid-range time scales. Supratidal geo-morphologic process cycles tend to occur at the longer end of the time scale range, as it requires relatively major resetting events to 'reset' or reconfigure these areas, which occur much less frequently.

The Orange Estuary usually consists of a braided channel system with many islands in the upper estuary, which feeds into open tidal basin area. The mouth is maintained by river inflow, and sediment passes through the estuary and is deposited in the sea, where it is dispersed. Based on the field investigations and the sediment sampling, as well as the available literature, some generalised conclusions about the sediment characteristics can be made. Sediments found in the estuary and its banks are virtually all of fluvial origin and are deposited in the estuary by river flows. The majority of these sediment deposits are fine grained material consisting of sands, silts and clays/muds. Less prevalent deposits of medium to coarse grained sands, gravels, pebbles and cobbles are occasionally found in channel and bank deposits. Some of the muddy and sandy sediment deposits located at the high water level or above have become vegetated and consolidated. However, some of the supratidal sediment deposits are not covered by vegetation and are prone to wind action (a contributing factor in some areas could be trampling and grazing by livestock).

Overall, large floods are crucial in maintaining the long-term dynamic equilibrium with respect to the sediment regime in the Orange Estuary. During large floods in the river, large volumes of sediment are flushed out of the entire estuary, removing many of the islands between the braided channels, scouring out the tidal-basin area and flushing a large part of the sand bar into the ocean.

Bremner et al. (1990) state that nearly all sediment transported during the 1988 floods was derived from bank erosion and river-bed scouring downstream of the major dams. Thus, although the dams trap much of the catchment sediments, large volumes of sediment still reach the estuary (an estimated total of 81 million tons during the 1988 floods). During the falling stage of the flood hydrograph, fluvial sediments are again deposited throughout the estuary with large depositions in the upper estuary area. It is probable that initial post-flood mud deposition is succeeded by a rapid downstream migration of fine sand as bed-load, which soon fills in the estuarine channel and reduces the tidal prism. After the flood has passed, the sand bar across the mouth is rapidly rebuilt by coastal processes. Smaller river floods tend to move some of the sediment from the upper estuary towards the tidal basin area through scouring of the braided channels or erosion of the islands.

During periods of low river flow, tidal flows through the mouth (especially during spring flood tides) transport littoral sediment into the tidal basin area. The marine sediment is non-cohesive and much coarser than the fluvial sediment. In the offshore zone, sediments on the inner continental-shelf mudbelt are associated with the Orange River prodelta, and are dominated by laminated clay-rich sediments.

3.4.2 Physical habitat health

In broad terms the river inflow predominantly determines the sediment characteristics, as well as the geomorphology of the Orange Estuary. At present the MAR has been reduced by 60% from reference condition. Overall, floods and especially large floods, are crucial in maintaining the long-term dynamic equilibrium with respect to the sediment regime in the Orange Estuary. The large changes in the flood regime (see section 3.3.2), are considered to be very significant for the estuarine habitat.

As mentioned, the supratidal estuarine geomorphology requires relatively major resetting events to 'reset' or reconfigure these areas. Because these floods now occur much less frequently (in the order of 1 in 10 years or longer), the fluvial sediment deposits in these areas, which generally contain significant proportions of cohesive material, consolidate much more and enable more 'permanent' vegetation establishment. Consequently, these areas become more resistant to erosion during floods. The overall effect is that the supratidal habitat is considered to be much more stable (with probably more compacted soil) and more resistant to new channel formation or changes in braiding/meandering of existing channels.

To provide context to present ecological health of an estuary, and future trajectories of change, the physical habitat of the estuary is disaggregated into three principal physical habitat types as discussed in Table 5. The physical habitat score is calculated as:

$$\text{Score} = \frac{\text{mean}\,(1a + 1b) + 2}{2}$$

Table 5. Calculation of the physical habitat score and adjusted score (net of non-flow impacts)

Variable	***Change from natural***	***Score***
1a: % similarity in present to reference intertidal area.	Currently the braided/meandering channels in the upper estuary are more stable than under the reference conditions. The estuary bank adjacent to the golf course has been artificially stabilised. Similarly, the salt marsh area has also been cut off from the main estuary through the fixing of the south-eastern estuary bank (road, oxidation pond protected). This has also resulted in a reduction of the estuary mouth-location envelope. Confidence: Medium	65
1b: % similarity in in present to reference sand fraction relative to total sand and mud.	Although the river flow volumes and sediment carrying capacity were reduced from reference to present state, and the major dams are now trapping a significant percentage of the sediment, the sand/mud ratio is still very similar in the river load. In short, the riverine sediment is still dominant over marine sediment intrusion. Confidence: Medium	85
2: Resemblance of subtidal estuary to reference condition: Depth, bed and channel morphology.	The depth and bed morphology are very similar to reference condition over most of the estuary, but the channels in the upper estuary are more stable, probably slightly narrower and/or shallower. The average extent of the marine sediment (non-cohesive and coarser than riverine) intrusion is only slightly further upstream. Confidence: Medium	80
Physical habitat score **Confidence: Medium**		**78**
Percentage of overall change in intertidal habitat caused by anthropogenic activity as opposed to modifications to water flow into estuary.	Impacts of roads and bank protection for golf course and oxidation ponds are much larger than impacts of more stable braided channels and reduction in mouth closure. Confidence: Medium	65
Percentage of overall change in subtidal habitat caused by anthropogenic modifications (e.g. bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary.	Most change is due to reduced river flows and reduced smaller floods (1 in 2 to 1 in 10 years). Confidence: Medium	10

3.5 Hydrodynamics and abiotic states

3.5.1 River flow and abiotic states

Based on historical data and projected future flow modifications five typical abiotic conditions were identified for the Orange Estuary (Table 6). Following a precautionary approach and to reduce the uncertainty in the correlation between measured and simulated river inflow data and abiotic states, broad flow ranges were identified and linked to river inflow. Also note that 'State 1: Closed and hyper saline' is only a predicted condition as extended periods (>6 month) of zero inflow have not been observed under the present inflow regime.

Table 6. Typical abiotic conditions linked to river inflow

State	Description	Flow range (m^3/s)
1	Closed for extended period and hyper saline	0
2	Closed, with strong marine influence	0 – 5
3	Marine dominated (open mouth)	5 – 20
4	Brackish (open mouth)	20 – 50
5	Freshwater dominated (open mouth)	>50

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 percentile are listed separately to provide a quick comprehensive overview;
- Colour coding (indicated above) was used to visually highlight the occurrence of the various abiotic states under different scenarios.

3.5.2 Present distribution of abiotic states

A statistical analysis of the simulated mean monthly runoff data in m^3/s for present state is provided below in Table 7 based on the abiotic states described (and colour coded) in Table 6 and Figure 4.

Table 7. Summary of the mean monthly flow (in m^3/s) distribution under the present state

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
10%	114.8	235.1	194.3	523.6	1762.0	649.3	734.9	204.0	101.7	51.3	62.9	25.6
20%	19.2	24.0	94.2	209.7	882.9	504.9	364.9	150.1	51.3	28.8	24.3	11.2
30%	18.0	20.6	36.3	101.3	224.0	370.0	171.2	108.3	30.8	14.4	11.5	10.2
40%	17.8	19.0	21.1	34.2	113.4	199.1	113.4	56.8	16.9	11.5	10.6	10.1
50%	17.6	18.1	18.0	21.4	43.1	116.0	65.9	34.2	15.4	11.0	10.4	10.1
60%	17.5	17.9	16.9	16.6	22.4	50.1	42.6	22.9	14.3	10.7	10.2	10.0
70%	17.4	17.6	16.4	16.5	16.6	30.8	34.4	21.3	13.4	10.3	10.2	10.0
80%	17.2	17.4	16.4	16.4	15.0	26.9	28.8	20.1	13.1	10.2	10.1	10.0
90%	17.1	17.1	16.4	15.8	14.8	22.9	25.1	18.8	11.6	9.1	10.0	10.0
99%	10.3	13.0	11.9	9.0	7.6	18.1	18.0	17.9	11.1	8.8	9.7	9.2

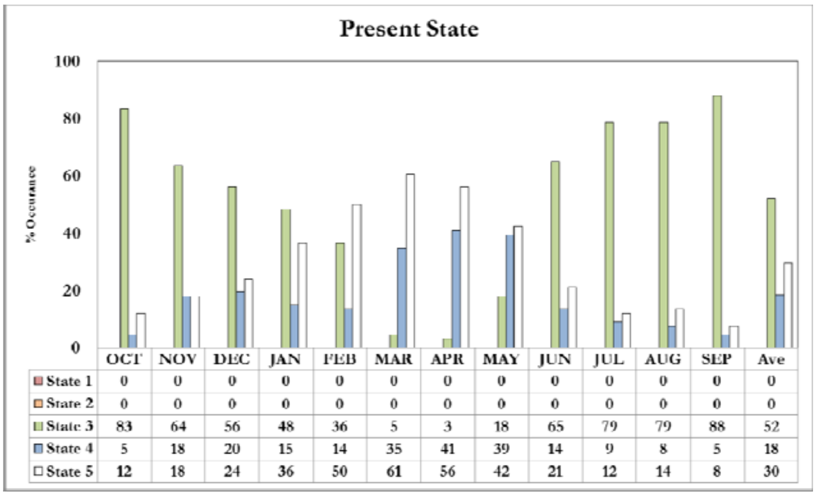


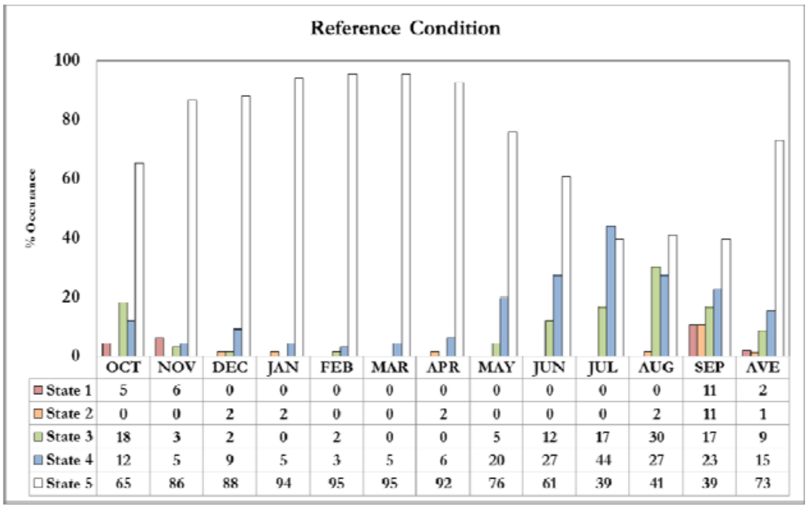
Figure 4. Graphic illustrations of the percentages monthly and annual occurrences of the various abiotic states under the present state

3.5.3 Abiotic states under the reference condition

A statistical analysis of the simulated mean monthly runoff data in m³/s for present state is provided below in Table 8 and Figure 4 and 5.

Table 8. Summary of the mean monthly flow (in m³/s) distribution under reference conditions

	Oct	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
90%	678.7	783.3	932.6	1355.1	2285.7	1818.1	954.2	358.0	183.9	145.8	153.7	203.5
80%	299.3	585.2	612.6	895.2	1590.7	983.3	694.4	265.1	139.4	95.8	97.7	105.1
70%	214.6	468.2	502.7	728.0	1159.0	739.4	462.0	218.2	91.4	71.8	80.0	68.6
60%	148.4	326.3	386.5	503.8	704.3	646.1	348.8	154.4	69.0	49.3	52.1	46.2
50%	93.8	233.9	311.7	377.2	479.0	532.7	299.7	117.0	56.6	39.8	32.2	34.8
40%	61.6	188.0	281.0	254.2	360.0	348.2	246.0	106.0	53.6	32.9	23.4	22.4
30%	41.8	154.2	206.8	192.1	280.8	266.1	188.1	72.8	43.6	27.2	19.2	11.6
20%	19.7	111.1	84.1	127.5	209.1	201.3	144.8	47.5	29.3	20.5	16.1	3.8
10%	7.9	28.0	43.8	61.4	123.2	135.8	86.7	27.5	16.6	13.6	10.7	0.1
1%	0.0	0.0	11.7	16.9	20.2	37.8	17.9	5.6	7.0	8.4	5.9	0.0



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
State 1	5	6	0	0	0	0	0	0	0	0	0	11	2
State 2	0	0	2	2	0	0	2	0	0	0	2	11	1
State 3	18	3	2	0	2	0	0	5	12	17	30	17	9
State 4	12	5	9	5	3	5	6	20	27	44	27	23	15
State 5	65	86	88	94	95	95	92	76	61	39	41	39	73

Figure 5. Graphic illustrations of the percentages monthly and annual occurrences of the various abiotic states under the reference conditions

3.5.4 Hydrodynamic health

Table 9. Calculation of the hydrodynamics score based on the mouth condition

Variable	*Motivation*	*Score*
Mouth condition	Years within which flows decrease sufficiently for mouth closure to potentially occur, decreased from 32% under reference to 0% under present state. Under natural conditions closure would have been for periods varying between days to weeks at a time. Confidence: Low	70
Hydrodynamics (mouth conditions) score **Confidence: Low**		**70**

3.6 Water quality

A detailed assessment of the water quality in the Orange Estuary is presented in Technical Report 33. For the purposes of this study, it was important to characterise the water quality within different areas of the estuary under various abiotic (or river inflow) states. Based on its bathymetry and flushing regime the Orange Estuary was therefore divided into two main areas (Figure 6):

- the lower estuary (approximately 6 km in length), with a deep basin of 2 – 4 m. This region is also characterised by shifting braided channels and islands, which provide localised areas (pockets) of high retention;
- the upper reaches (from about 6 – 11 km), with an average depth of less than 1 m. While braided channels and islands also occur in this region, flushing is more effective and retention less.

Table 10. Simulated mean monthly inflows (in m³/s) into the Orange Estuary under the present state

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Closedd
1920	17.29	17.47	16.84	22.55	26.41	46.38	59.59	21.55	13.60	66.14	61.48	10.09	0
1921	17.43	20.32	16.58	16.47	10.62	23.96	27.27	19.97	13.43	10.19	10.11	10.07	0
1922	9.14	17.49	16.94	17.20	16.47	23.00	25.78	17.90	11.75	9.00	9.70	10.04	0
1923	17.14	19.92	35.58	1216.68	1024.35	581.79	364.92	115.23	63.44	14.69	10.53	10.23	0
1924	18.73	345.93	662.44	20.29	30.66	162.11	139.35	191.87	51.28	10.95	62.38	10.05	0
1925	17.25	17.89	16.46	16.42	14.97	107.08	107.50	159.15	39.90	10.30	10.23	10.63	0
1926	17.75	830.02	190.40	788.19	1401.11	268.36	59.27	20.11	13.43	10.19	10.13	10.02	0
1927	17.14	17.54	20.41	30.84	72.93	29.45	20.35	32.22	16.74	11.10	10.36	10.03	0
1928	17.46	10.15	31.25	68.00	1475.30	414.16	79.62	24.83	14.59	12.62	133.37	51.13	0
1929	19.72	192.82	132.67	19.95	55.51	75.35	230.38	216.07	35.06	11.15	10.15	16.60	0
1930	18.60	21.84	129.74	293.04	490.63	134.27	118.73	50.94	14.66	10.46	10.36	10.04	0
1931	17.53	16.92	16.35	16.42	140.89	161.05	43.32	36.14	18.19	10.51	10.71	10.02	0
1932	26.16	20.22	198.30	189.27	19.09	26.88	920.20	1256.11	308.19	406.93	145.71	39.47	0
1933	394.88	1712.55	1344.68	392.46	2111.18	500.52	31.51	20.26	30.29	11.27	10.54	10.09	0
1934	97.47	36.06	16.35	17.01	15.03	277.42	84.56	20.14	13.39	10.80	10.26	10.04	0
1935	17.90	17.55	20.62	23.99	16.20	27.70	58.75	31.46	15.37	10.24	10.15	10.46	0
1936	17.52	17.48	16.37	15.89	14.82	16.52	32.30	19.31	11.71	9.16	10.13	10.03	0
1937	17.46	17.31	17.63	15.70	16.67	608.60	741.25	43.44	34.57	10.30	10.18	10.02	0
1938	17.35	17.71	17.58	9.15	12.71	25.89	35.89	19.38	12.04	9.35	9.75	10.04	0
1939	17.18	16.96	16.37	16.42	127.84	411.96	403.28	807.29	203.94	67.47	206.76	20.44	0
1940	19.21	17.50	36.46	34.17	25.44	32.16	25.98	21.38	15.30	10.74	10.17	10.02	0
1941	17.48	17.09	18.37	16.42	129.98	114.52	28.12	18.61	11.46	89.53	37.59	10.07	0
1942	17.56	18.70	16.87	16.42	113.39	117.44	35.03	25.10	13.35	10.21	10.61	10.16	0
1943	17.36	18.97	47.22	34.54	10.08	532.89	567.11	45.30	16.77	10.99	10.39	10.06	0
1944	17.19	17.40	16.43	135.69	2024.84	509.13	190.81	57.33	18.29	14.06	10.61	10.16	0
1945	17.82	22.44	21.08	16.98	224.63	1183.07	728.59	140.80	20.33	11.95	10.99	10.02	0
1946	17.53	18.23	890.15	500.40	64.98	180.77	112.25	24.93	16.13	19.40	10.63	1511.09	0
1947	1580.75	410.63	104.10	869.26	193.46	26.86	66.03	190.61	83.30	11.30	10.11	10.02	0
1948	17.12	17.63	23.01	24.97	20.71	24.45	26.94	221.43	110.52	93.33	16.92	10.02	0
1949	17.33	17.95	16.66	16.54	30.30	199.10	118.75	63.53	14.10	10.69	15.59	10.03	0
1950	17.36	17.84	94.17	87.70	14.98	346.39	670.47	235.81	236.49	90.73	33.10	10.07	0
1951	17.14	22.88	11.52	19.18	948.63	335.38	21.87	132.60	16.90	10.85	11.03	10.40	0
1952	17.17	20.58	18.08	486.32	418.55	599.62	745.60	137.13	31.29	51.51	24.29	10.19	0
1953	17.81	59.06	112.39	16.50	14.80	129.07	243.38	18.01	11.58	18.87	10.00	11.19	0
1954	132.19	277.42	137.62	130.13	14.55	50.05	41.98	22.62	13.08	10.27	10.20	10.02	0
1955	17.25	17.75	16.10	66.49	510.57	21.36	16.13	20.27	13.29	10.12	10.11	10.02	0
1956	19.97	19.00	16.91	209.73	1620.83	447.98	1268.68	660.67	279.28	45.52	11.38	10.13	0
1957	17.76	15.04	21.53	16.42	14.80	106.00	65.80	56.80	26.98	10.37	10.24	10.02	0

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Closedd
1958	17.47	14.60	12.14	16.45	57.98	42.06	35.84	22.89	14.28	10.28	10.27	10.02	0
1959	17.58	17.10	16.35	16.42	20.01	27.42	24.20	18.11	11.80	8.80	10.41	10.03	0
1960	10.89	18.93	17.42	14.98	26.39	33.81	29.87	21.36	13.57	17.63	12.93	10.09	0
1961	17.66	17.25	16.35	124.36	166.68	324.05	293.53	131.51	14.49	10.25	10.18	10.02	0
1962	17.19	17.39	16.35	16.42	23.38	48.72	48.53	23.41	13.44	10.83	10.21	10.05	0
1963	18.56	18.04	25.74	1237.94	3499.19	2243.30	551.83	175.38	53.31	16.24	138.01	30.85	0
1964	17.94	108.84	337.75	455.50	1953.54	872.27	289.35	63.57	16.90	32.02	10.30	10.06	0
1965	17.24	18.02	676.71	2108.52	2903.04	3205.76	1451.27	540.92	163.66	46.98	17.30	11.51	0
1966	669.80	530.32	54.67	114.99	879.57	833.72	151.62	66.69	16.29	10.45	9.90	9.90	0
1967	17.92	21.75	17.90	452.17	299.64	504.90	867.42	165.90	39.59	13.98	10.41	10.14	0
1968	18.02	17.34	16.38	24.04	77.85	39.62	25.31	19.63	16.45	12.62	42.64	17.28	0
1969	17.49	17.93	16.39	16.42	16.61	92.61	102.59	20.36	13.10	9.94	89.08	72.16	0
1970	27.74	23.92	18.32	38.42	223.37	393.65	30.62	48.84	85.65	10.14	145.89	102.20	0
1971	17.47	18.76	19.16	16.43	14.87	21.06	35.50	20.93	12.21	12.21	10.26	10.02	0
1972	17.77	17.63	13.74	16.59	14.82	21.10	18.97	21.40	11.96	8.79	9.62	10.06	0
1973	17.55	20.58	13.22	16.52	14.95	18.99	22.81	18.97	11.47	9.09	10.16	10.02	0
1974	17.69	17.77	16.35	15.44	22.40	22.90	33.87	18.43	11.46	8.79	10.10	10.02	0
1975	20.92	24.01	53.29	52.04	7.71	28.69	42.57	21.59	35.44	16.01	9.69	10.06	0
1976	17.69	17.89	16.35	16.42	7.47	28.08	28.85	20.06	11.46	9.00	9.70	11.25	0
1977	382.11	132.70	39.46	8.70	3156.35	3368.39	742.90	150.10	92.82	39.23	42.01	273.47	0
1978	190.67	162.74	371.87	546.80	1903.18	518.10	248.68	124.16	140.02	51.08	63.37	10.06	0
1979	17.15	18.00	16.40	16.45	17.70	212.71	452.94	163.69	55.35	45.72	10.14	10.02	0
1980	17.13	16.96	17.18	188.31	882.95	690.03	120.56	42.28	15.44	11.20	11.44	11.57	0
1981	570.82	363.53	41.00	15.20	14.80	19.26	24.83	17.85	11.46	8.81	10.13	10.19	0
1982	17.43	18.12	16.35	16.47	18.18	26.08	35.76	18.52	10.46	9.44	10.15	10.02	0
1983	18.30	19.23	16.40	23.67	105.04	56.68	113.41	65.14	13.42	10.69	10.14	10.02	0
1984	17.16	17.39	16.35	14.65	14.89	28.58	33.70	21.26	14.29	11.49	11.51	10.67	0
1985	18.06	20.17	36.18	667.42	1465.40	416.81	136.63	101.42	14.46	28.78	13.38	7.79	0

State 1 **0.00** **State 2** **0.0 – 5** **State 3** **5 – 20** **State 4** **20 – 50** **State 5** **>50** **Floods > 2000**

Table 11. Simulated mean monthly inflows (in m³/s) into the Orange Estuary under the reference condition

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Closed
1920	49.92	17.98	33.50	468.19	416.70	322.70	961.36	325.39	44.91	252.15	111.04	6.34	0
1921	64.81	310.23	144.52	53.70	478.22	306.96	74.27	23.01	15.79	13.45	4.80	29.69	1
1922	23.01	103.70	96.61	53.77	116.76	147.63	54.58	20.51	14.84	13.38	6.82	0.00	1
1923	0.00	1270.00	1292.29	3455.42	1852.31	1164.93	694.45	261.46	139.44	93.92	141.82	25.97	1
1924	156.42	1068.49	990.91	178.79	237.62	646.08	301.47	238.07	104.46	32.12	139.80	53.58	0
1925	6.57	40.42	79.82	249.57	277.33	589.77	356.01	382.61	140.25	48.60	23.43	1.37	1

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1926	137.91	2196.85	656.46	1400.41	1907.08	552.00	120.71	29.53	24.75	20.46	10.92	0.00	1
1927	15.28	0.00	308.70	511.20	940.89	249.15	287.43	156.60	148.28	79.39	97.73	36.59	1
1928	306.97	184.61	437.87	874.11	2116.92	741.92	179.51	98.24	59.10	105.29	237.05	103.79	0
1929	278.56	622.20	298.39	156.34	360.04	704.14	476.13	327.08	131.07	48.74	23.00	244.39	0
1930	106.74	268.46	462.42	662.35	1226.76	349.08	282.80	79.17	26.66	32.93	23.71	25.41	0
1931	158.52	33.87	31.34	507.22	903.80	897.41	343.95	116.57	49.74	23.70	87.72	46.21	0
1932	217.39	370.33	1118.81	562.18	129.72	246.90	1317.83	1321.44	376.09	523.85	279.17	195.49	0
1933	760.91	2010.47	1629.23	790.79	2316.41	709.67	146.18	57.10	167.43	80.96	33.17	211.46	0
1934	292.87	176.08	17.52	24.66	234.43	983.34	309.70	67.13	48.20	28.16	12.33	0.00	1
1935	0.00	0.00	41.80	673.01	540.38	460.73	242.98	349.79	139.24	34.31	12.55	0.00	3
1936	274.41	225.86	84.10	127.51	300.14	229.74	264.84	104.86	54.88	35.55	19.53	129.58	0
1937	215.02	170.86	538.51	509.34	413.66	2327.13	904.54	107.19	38.15	20.34	10.33	0.69	1
1938	44.65	56.68	21.50	163.86	179.88	256.53	144.77	83.25	44.93	26.25	13.60	0.61	1
1939	41.61	326.33	612.63	299.52	688.96	1866.99	1820.26	861.16	235.29	125.68	329.80	146.55	0
1940	33.25	13.73	502.06	503.80	279.29	201.04	183.62	84.26	53.62	41.65	31.31	25.21	0
1941	602.18	188.03	73.36	174.12	821.54	371.00	118.34	47.73	41.32	265.50	149.20	65.82	0
1942	35.60	199.13	241.09	100.99	1520.39	654.17	385.47	154.44	48.57	24.38	18.72	9.52	0
1943	147.37	185.47	313.52	243.49	437.21	1936.27	947.09	117.48	56.22	27.46	10.26	0.00	1
1944	9.03	133.82	186.27	1519.74	2726.45	736.97	298.43	136.05	69.02	47.34	18.50	0.18	1
1945	42.01	241.92	398.62	272.86	1313.98	2034.77	1233.47	217.41	76.72	40.35	17.34	3.85	1
1946	148.37	377.41	1742.30	887.99	352.12	520.21	246.04	49.18	39.03	147.11	150.68	1926.21	0
1947	1933.13	682.13	373.66	1309.86	460.72	121.14	244.93	320.45	136.48	35.07	15.83	37.70	0
1948	19.32	257.41	503.24	254.21	282.32	156.60	425.52	647.05	185.69	161.45	79.12	14.34	0
1949	153.92	302.29	584.58	322.74	479.81	528.70	295.58	126.31	56.38	38.15	70.38	50.52	0
1950	124.63	290.21	693.57	383.80	160.73	1067.39	926.34	328.32	304.71	164.08	71.87	17.44	0
1951	8.15	487.56	609.23	205.50	1551.23	536.70	140.38	147.39	42.39	20.50	10.41	10.38	0
1952	6.09	497.81	243.60	1891.52	946.20	858.85	928.48	211.01	71.47	175.87	85.72	37.04	0
1953	60.62	712.16	386.46	378.62	168.16	544.13	389.52	59.40	56.88	64.27	52.05	51.81	0
1954	884.78	691.00	295.14	375.79	200.32	79.34	348.79	106.05	74.60	58.17	52.26	96.02	0
1955	86.09	111.06	35.75	1252.89	1091.16	125.33	37.19	24.36	16.27	9.17	6.47	0.00	1
1956	12.82	77.55	315.12	1934.85	2273.69	753.47	1349.07	596.57	381.47	95.85	44.53	26.55	0
1957	19.82	188.84	187.47	37.53	15.07	332.70	300.97	265.14	88.57	49.28	18.92	33.95	0
1958	7.61	22.11	280.99	68.94	219.85	625.25	450.82	186.46	93.40	31.75	21.63	0.15	1
1959	322.45	153.51	309.91	139.94	224.21	40.75	4.74	5.73	6.70	10.92	16.28	54.03	1
1960	265.78	154.92	428.78	432.07	536.09	225.94	481.72	225.72	54.57	39.00	23.42	18.39	0
1961	19.66	169.17	306.63	1013.01	1590.71	1769.19	684.17	219.09	65.38	31.36	20.34	7.65	0
1962	52.18	115.84	45.75	2.34	374.17	282.11	197.34	43.77	23.30	11.58	97.35	71.42	1
1963	79.69	127.42	351.33	3533.90	5157.59	2985.24	874.58	366.11	174.52	63.54	429.10	101.99	0
1964	18.02	801.90	699.30	782.91	2312.85	1285.41	473.22	118.82	63.06	89.53	44.48	99.53	0

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Closed
1965	183.15	585.17	1248.61	3005.76	3806.52	3877.99	1786.64	728.96	281.88	144.46	81.87	128.27	0
1966	1373.23	868.11	225.59	342.17	1707.10	1184.98	335.26	109.49	56.17	39.23	21.65	85.83	0
1967	307.59	190.54	219.55	1261.43	704.27	630.56	1101.26	257.71	90.77	59.68	41.51	158.94	0
1968	214.22	79.13	656.46	222.24	349.04	202.78	41.74	46.20	53.62	86.67	422.94	274.74	0
1969	299.28	209.76	257.55	244.83	530.46	465.14	209.36	25.55	15.99	15.91	92.87	145.01	0
1970	95.62	211.29	297.49	893.35	1063.00	683.29	140.13	112.00	182.12	44.79	258.10	249.50	0
1971	61.60	123.63	339.74	164.55	81.50	115.00	494.54	194.99	65.16	61.90	38.27	22.27	0
1972	176.83	548.71	55.42	26.48	22.89	32.18	43.77	47.53	46.84	59.18	45.32	12.86	0
1973	92.01	460.32	519.70	496.97	109.06	146.23	151.95	113.38	30.18	21.05	29.23	64.94	0
1974	71.64	123.19	80.42	118.01	654.08	348.24	99.08	18.42	22.52	15.28	8.10	0.00	1
1975	121.07	470.96	874.38	428.34	324.56	165.79	130.55	43.46	71.39	27.03	27.13	105.10	0
1976	355.38	992.29	193.99	126.77	179.84	178.90	179.36	41.68	14.67	13.75	80.82	1476.83	0
1977	1401.73	764.68	568.13	332.09	3828.65	3849.40	926.51	226.89	143.04	111.84	119.82	537.36	0
1978	653.82	465.44	725.24	895.19	2170.75	770.16	352.19	208.17	241.32	136.23	156.75	22.38	0
1979	32.17	598.42	378.51	205.62	209.09	656.60	663.10	275.89	92.09	99.67	68.46	46.21	0
1980	7.63	0.00	82.38	1182.43	1407.54	964.46	259.45	41.92	32.41	27.78	24.09	39.76	1
1981	1364.79	545.41	243.70	78.04	37.57	47.53	24.97	5.23	7.13	6.85	16.06	15.38	0
1982	55.53	487.93	97.12	51.76	322.26	201.33	183.87	77.96	16.87	10.11	15.75	0.24	1
1983	703.59	350.89	393.27	874.66	1493.41	323.04	301.80	108.23	29.28	26.24	25.04	7.56	0
1984	0.00	0.00	1.00	80.14	86.82	275.59	192.31	67.62	29.01	14.34	18.33	9.69	3
1985	81.83	365.72	1609.86	1253.59	2297.69	1158.84	222.75	117.42	58.65	92.14	76.74	35.65	0

State 1 **0.00** **State 2** **0.0 – 5** **State 3** **5 – 20** **State 4** **20 – 50** **State 5** **>50** **Flood** **> 2000**

In view of the strong stratification that occurs at about 1.0 m depth under elevated flow ranges, both the lower and upper reaches are subdivided into surface and bottom waters. It was thus possible to sub-divide the Orange Estuary into four distinct zones, namely: surface water in lower estuary (Zone A), surface water in upper estuary (zone B), bottom water in lower estuary (Zone C and bottom water in upper estuary (Zone D) (Table 9, Figure 6 and 7).

From the detailed water quality assessment typical water quality characteristics were derived for each of the four zones under each of the five abiotic states. These characteristics are summarised in Table 12.

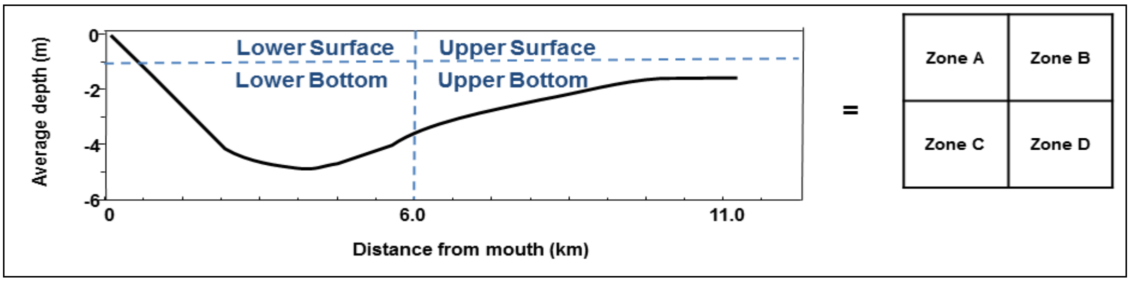


Figure 6. A schematic illustration of the Orange Estuary zonation

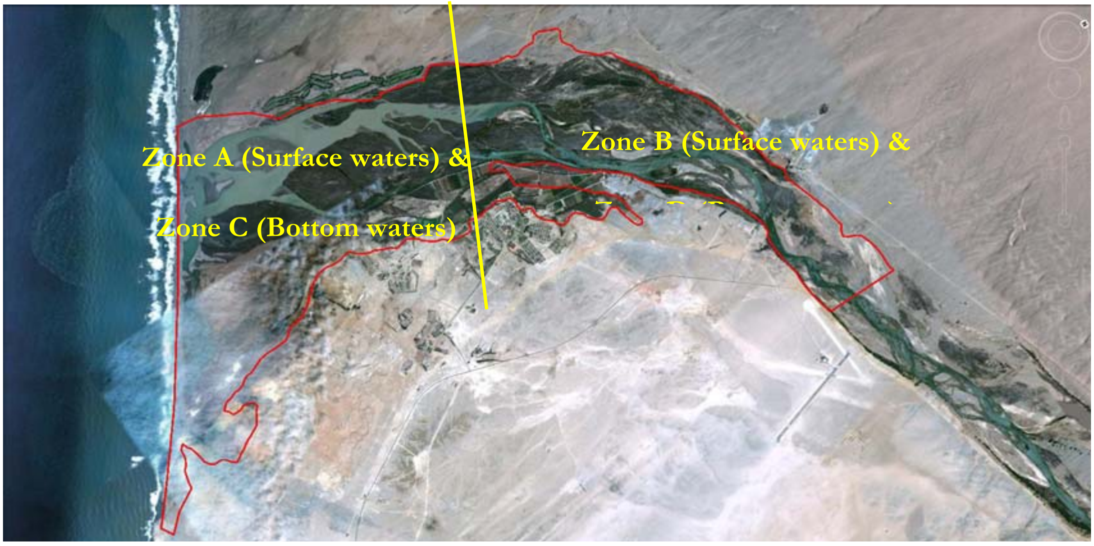


Figure 7. Satellite image showing the lower and upper reaches of the Orange Estuary (source: Google Earth)

Table 12. Summary of hydrodynamic and water quality characteristics of different abiotic states in the Orange Estuary

Parameter	***State 1: Hyper saline***	***State 2: Closed***	***State 3: Marine***	***State 4: Brackish***	***State 5: Fresh***
Flow range (m^3/s)	0	0 – 5	5 – 20		
Mouth condition	Closed	Closed	Open	Open	Open
Water level variation	None	None	1.5 m	1.5 m	1.5 m
Inundation	None, very low water level	Intertidal and some of supratidal	Intertidal area	Intertidal area	Intertidal and floodplain
Circulation	Wind mixing	Wind mixing	Tidal	Freshwater flushing and tidal	Freshwater flushing
Salinity (PSU)[1]	Reference 35 35 35 35 Future 45 35 45 35	25 10 30 15	20 0 30 5	5 0 25 0	0 0 5 0
Temperature (°C)	Summer 25 25 25 25 Winter 15 15 15 15	Summer 25 25 25 25 Winter 15 15 15 15	Summer 10 25 10 25 Winter 10 15 10 15	Summer 25 25 10 25 Winter 15 15 10 15	Summer 25 25 25 25 Winter 15 15 15 15
pH	Reference condition: Fresher waters had lower pH levels (6.5 – 7) compared to saline waters (7.9 – 8.2). Present/Future: Fresher water has higher pH levels (8.5 – 8.9) compared with lower pH levels (7.5 – 8) in saline waters.				

Parameter	***State 1: Hyper saline***		***State 2: Closed***		***State 3: Marine***		***State 4: Brackish***		***State 5: Fresh***	
Dissolved Oxygen (DO) (mg/ℓ)	6	6	>6	>6	>6	>6	>6	>6	>6	>6
	4	4	4	4	>	4	>6	>6	>6	>6
Turbidity (NTU)	10	10	10	20	10	30	30	30	100	100
	10	10	10	20	1	30	10	30	100	100
DIN[2] (µg/ℓ)	50	50	Reference		Reference		Reference		Reference	
	50	50	150	100	200	50	50	50	50	50
			150	100	200	50	200	50	50	5
			Present/Future		Present/Future		Present/Future		Present/Future	
			150	150	20	100	100	100	30	300
			150	150	20	100	200	100	300	300
DIP[3] (µg/ℓ)	0	10	Reference		Reference		Reference		Reference	
	10	10	30	20	40	10	10	10	10	10
			30	20	40	10	40	10	0	10
			Present/Future		Present/Future		Present/Future		Present/Future	
			30	30	40	20	20	20	50	50
			30	30	40	20	0	20	50	50
DRS[4] (µg/ℓ)	100	1000	500	3000	00	6000	4000	6000	6000	6000
	1000	1000	200	2000	200	6000	1000	6000	6000	6000

1 For the purposes of summarising typical salinity distributions, the system was sub-divided into 4 'boxes' representing the lower (0 – 6 km) and upper (6.0 – 11 km) estuary (moving upstream from the mouth left to right) and into surface (water depth < 1.0 m) and bottom (water depth > 1.0 m) waters (see Figure 6). Salinity units measured in practical salinity units (PSU - also called parts per thousand (ppt)).
2 Dissolved inorganic nitrogen
3 Dissolved inorganic phosphate
4 Dissolved reactive silicate.

3.6.1 *Reference versus present water quality*

Overall changes in water quality parameters are estimated in Table 13 and estimated concentrations are summarised for the four estuary zones.

Table 13. Summary of changes in water quality from reference to present state

Parameter	*Description of change from reference*	*Zone*	*Reference*	*Present*
Salinity (µg/ℓ)	Salinities have increased from reference due to decrease in baseflows.	A	3	11
		B	1	0
		C	11	22
		D	1	3
DIN (µg/ℓ)	Average DIN concentrations increased from reference as a result of anthropogenic loading from the catchment, despite a marked reduction in State 5 (fresh). An increase in the occurrence of State 3 (brackish) also contributed to higher DIN in the lower estuary (Zones A and C). The sea is a source of DIN along the west coast as a result of strong upwelling.	A	64	211
		B	51	159
		C	88	229
		D	51	159
DIP (µg/ℓ)	Average DIP concentrations increased from reference as a result of anthropogenic loading from the catchment, despite a marked reduction in State 5 (fresh). An increase in the occurrence of State 3 (brackish) also contributed to higher DIP in the lower estuary (Zones A and C). The sea is a source of DIP along the west coast as a result of strong upwelling.	A	13	39
		B	10	29
		C	18	43
		D	10	29
Turbidity (NTU)	The reduction in average turbidity in the estuary is associated with the marked decrease in the occurrence of State 5 (Fresh) when river inflow introduced highest turbidity to the estuary. This is further enhanced by an increase in State 3 (marine) also resulting in a stronger influence of clearer seawater	A	79	40
		B	80	51
		C	75	37
		D	80	51
DO (mg/ℓ)	No marked change in the DO concentrations occurred from reference to present. The water column is relatively shallow and exposed to strong wind mixing. As in the reference condition the estuary seldom closes during the present state.	A	6	6
		B	6	6
		C	6	6
		D	6	5
Toxic substances	Agricultural development in the catchment may have introduced some pesticides and herbicides into the estuary.	A-D	Assume similarity to reference as 85%	

3.6.2 *Scoring present water quality*

The similarity in each parameter (e.g. DO) 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 = 0.15; B = 0.15; C = 0.4; D =0.3);

- different **abiotic states** (**S**) (i.e. states 1 to 5);
- define the **flow scenarios** (i.e. reference, present, future scenarios);
- determine the% **occurrence** of abiotic states for each scenario;
- allocate water quality concentration ranges (C).

Similarity of salinity in present or any flow scenarios relative to reference was calculated as follows:

- Calculate average concentration for each zone for reference and present/future scenarios, respectively:
  - o Average Conc (ZA) = [({∑% 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 concentration reference and present/future scenario for each zone using the Czekanowski's similarity index: $\frac{\sum(\min(ref,pres)}{(\sum ref + \sum pres)/2}$.

The water quality health score was calculated as:

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

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

Table 14. Summary of changes and calculation of the water quality health score

	Variable	*Summary of change*	*Score[1]*	*% non-flow*
1	Salinity			
	Similarity in salinity	⇧ due to decrease in flow	55	0
2	General water quality in the estuary			
a	N and P concentrations	⇧ due to nutrient enrichment from catchment especially during State 5, as well as stronger marine influence also introducing nutrient (upwelling) to lower estuary	52	80
b	Water turbidity	⇩due to a marked reduction in high flows (decrease in State 5)and stronger influence of clear marine waters in the lower reaches (increase in State 3)	71	0
c	Dissolved oxygen concentrations	No marked changes. The water column is relatively shallow and exposed to strong wind mixing. State 1 (closed) seldom occurs	98	0
d	Toxic substances	⇧ of toxic input associated with agricultural activity in catchment	85	100
Water quality health score			**53.2**	
Confidence			**Medium**	

1 Net of non-flow impacts

3.7 Microalgae

3.7.1 Microalgae groups

Two groupings of microalgae are considered in this study (Table 15); phytoplankton and benthic microalgae (also called microphytobenthos (MPB)).

Table 15. 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 Orange system covering up to 46 ha. The MPB community generally consists of euglenophytes, cyanophytes and bacillariophytes (diatoms). Benthic diatoms, typically those living in mud (epipelics), are the most useful indicators of estuarine health.
Phytoplankton	The phytoplankton can consist of cells from the following groups; flagellates, diatoms, dinoflagellates, cyanophytes, chlorophytes, euglenophytes and coccolithophorids. The flagellates, diatoms, chlorophytes and dinoflagellates were the only groups recorded during the August 2012 sampling session.

The microalgal biomass, based on a once-off survey by Harrison et al. (CSIR, unpub. data), was expected to be low. On that sampling occasion, the entire estuary was fresh indicating strong river flow that prevented the intrusion of seawater. Under normal flows, 20 to 50 m^3/s, there is strong salinity intrusion into the estuary creating a strong vertical salinity gradient up to 6 km from the mouth. In August 2012, the highest concentration of dissolved nutrients was measured in these more saline waters. Average phytoplankton biomass, using chlorophyll a as an index, was low at the mouth of the estuary but increased significantly within the first kilometre from the mouth. Considering the high turbidity of the estuary, it was surprising to find that the highest biomass, typical of blooms, was found in 2 m deep saline water in the middle to lower reaches of the estuary. A closer investigation of the community showed that flagellates were the dominant group at these sites, with a minor contribution from dinoflagellates. In contrast, the bloom densities of diatoms and chlorophytes (>10,000 cells/ml) were introduced into the estuary in the river water. This suggests that under normal flows there was enough residence time in the estuary for a strong river-estuary interface zone (REI) to develop, and that diatoms and chlorophytes would dominate in the estuary during periods of high river flow (>50 m^3/s).

The high biomass and cell density of planktonic microalgae indicate eutrophic conditions in the Orange Estuary. This was supported by the high chlorophyll a content in the subtidal and intertidal sediment. A median content of 48,8 mg/m^2 is classified as being very high compared to other permanently open estuaries in South Africa. The benthic diatom community structure supports this finding where the vast majority of the 70-plus taxa collected in August 2012 are used as indicators of eutrophic or strongly polluted aquatic environments.

3.7.2 Description of factors influencing microalgae

The factors influencing the different microalgal groups are summarised in Table16. Based on these considerations, the expected influence of the different abiotic states on microalgae is described in Table 17.

Table 16. Effect of abiotic characteristics and processes, as well as other biotic components on microalgae groupings

	Phytoplankton					**MPB**
	Cyanophytes	**Dino-flagellates**	**Chlorophytes**	**Diatoms**	**Flagellates**	
Temperature[1]	⇧	⇧	⇧	⇧	⇧	⇧
% Fines (<63 μm)	-	-	-	-	-	⇧ in epipelic diatoms
Salinity[2]	⇧	⇧	⇧	⇧	⇧	-
External P input	⇧	⇧	⇧	⇧	⇧	⇧
Grazing	⇩	⇩	⇩	⇩	⇩	⇩
Oxygen	⇧ as O_2 ⇩	-	-	-	-	-
Stratification	-	⇧ in middle reaches	-	-	-	-
External N input	⇧	⇧	⇧	⇧	⇧	⇧
Turbidity[3]	⇩	⇩	⇩	⇩	⇩	⇩
Organic content[4]	⇧	⇧	⇧	⇧	⇧	⇧

1 Temperature a co-variable with nutrients (released from organic/fines-rich sediment).
2 Salinity is a co-variable with residence time (i.e. microalgae ⇧ with residence time).
3 Highest biomass measured at 2 m during natural flow in response to nutrient-rich seawater intrusion; turbidity a minor factor influencing primary production.
4 Organic matter a co-variable with dissolved oxygen and nutrients.

Table 17. Summary of microalgal biomass using chlorophyll a as an index of different abiotic states

State	**Predicted chlorophyll a response**
1	Stable conditions, productivity limited by availability of nutrients. Mouth closed, loss of nutrient-rich seawater intrusion and intertidal zone. More stable environment favouring the establishment of benthic microalgae.
2	Stable conditions, favours very high microalgal biomass. Nutrients imported in seawater and river water.
3	Marine intrusion of nutrients and strong vertical stratification supports high biomass in REI zone as well as import of high biomass in the river water.
4	Marine intrusion of nutrients and strong vertical stratification supports high biomass in REI zone as well as import of high biomass in the river water. Productivity limited by residence time of water in the estuary. Benthic microalgal biomass highest in more protected areas (in areas where sediment dominated by fines and elevated organic content).
5	Very strong river flow limits microalgal growth due to low residence time and limited intrusion of nutrient-rich seawater. Scouring and deposition of sediment reduces MPB biomass.

3.7.3 Reference condition

Under reference conditions, the river flow was 2.5 times greater than at present, flood events would have been more frequent and intense, and the concentration of dissolved nutrients would have been low (DIN <50 μg/ℓ and DIP <10 μg/ℓ). These conditions would have supported a low biomass of benthic microalgae (<11 mg/m²), and phytoplankton biomass would have been low too (<3,5 μg/ℓ), being dominated by diatoms with few chlorophytes. Saline intrusion of nutrient-rich seawater (from coastal upwelling events) would have supported slightly higher biomass of microalgae in Zone C.

Table 18. Summary of how the microalgae in the present condition have changed relative to the reference condition

Abiotic factor	Changes
River flow	Low residence time limits microalgal growth.
Nutrients	Lower nutrient concentrations would have limited microalgal growth.
Turbidity	Poor light conditions would have limited microalgal productivity.

3.7.4 Health of the microalgae component

Health scores are summarised in Table 19. Ten percent of the impact on microalgae was thought to be non-flow-related.

Table 19. Similarity scores of phytoplankton in the present condition relative to the reference condition

Variable	Change from natural	Score
Phytoplankton		
Species richness	It is likely that the reduction in river flow and increase in nutrients has increased the chlorophytes and flagellates to similar density as the diatoms. Conditions also favour some dinoflagellates becoming established. As a result, there has been an estimated 40% increase in species richness (based on evenness of phytoplankton groups). Confidence: Low	60
Abundance	Based on the scoring technique used for water quality, it was calculated there would have been a 40% increase in biomass from the reference state. The intrusion of nutrient-rich seawater would have supported a medium level of biomass in the deeper waters in the lower reaches of the estuary (Zone C). Confidence: Low	40
Community composition	The phytoplankton at present was dominated by flagellates, diatoms and chlorophytes with a few dinoflagellates at normal flow. Cell density would have been much lower during the reference condition and dominated by diatoms with very few cells from the other groups. It is likely that flagellates, diatoms and chlorophytes were present during the reference condition, but conditions favouring the establishment of an REI zone, with associated dinoflagellates would not have occurred as frequently as at present. Expect a 20% change from reference.	80
Benthic microalgae		
Species richness	The system is still variable, salinity ranging from fresh to saline, and closed mouth events have been lost. A 30% change in MPB richness expected. Loss of closed mouth events. Confidence: Low	70

Variable	***Change from natural***	***Score***
Abundance	Saline intrusion of nutrient-rich upwelled coastal water likely to have sustained an elevated MPB biomass. Reductions in river flow in combination with nutrient-rich river water supports a higher biomass of benthic microalgae (36% increase). Confidence: Low	64
Community composition	A community shift is likely to have occurred related to the increase in the trophic status of the estuary (reduced river flow and increased nutrients). A large proportion of diatoms collected in August 2012 indicate eutrophic or highly polluted conditions. Confidence: Low	60
Microalgal health score (minimum score) **Confidence: Low**		**40**
% non-flow-related impacts		
Microalgal growth has been supported through the reduction in river flow as well as the import of nutrients in seawater and polluted river water. The contribution change through pollution is ~10%. Confidence: Low		10

3.8 Macrophytes

3.8.1 Macrophyte groups

The main habitats and macrophytes groups are described in Table 20.

Table 20. Macrophyte habitats and functional groups recorded in the estuary

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	The Orange Estuary is very dynamic. Some past aerial photographs show no sand islands around the mouth area. In 2010 there was increase in sand close to the mouth. This sand island moved closer to the mouth area when a ground-truthing exercise was undertaken in 2012. An increase in sand in the lower reaches has led to closure of small streams that feed tidal water to intertidal saltmarshes. Approximately 144 ha of intertidal sand and mudflats were present in 2012.
Submerged macrophytes	Rooted submerged macrophytes are not a dominant feature of the estuary probably because of the high flows and turbidity. However in August 2012 the submerged macrophyte *Stuckenia pectinata* (pondweed) was found in the upper reaches in small channels. This plant grows best at salinity less than 10 ppt.
Macroalgae (50% of submerged area)	No resident macroalgae have previously been recorded in the estuary. In 2012 along the west bank high abundances of green algae *Ulva capensis, Ulva intestinalis* and the red alga *Polysiphonia* sp. were found. Filamentous green algae are commonly occur in areas of nutrient enrichment and low salinity.
Intertidal salt marsh	Aerial photographs from 2010 combined with a field survey in 2012 showed that there is an area of intertidal salt marsh on the west bank. A diversity of *Sarcocornia* species were found in 2012. Intertidal marsh with the brackish species *Cotula coronopifolia* as a dominant had developed previously where the causeway was broken through to the desertified salt marsh. Some of this marsh has subsequently died as a result of sand build-up and no tidal exchange. *Cotula coronopifolia* would not tolerate salinity conditions greater than 20 ppt.

Habitat type	***Defining features, typical/dominant species***
Supratidal salt marsh	Supratidal species cover the largest area of salt marsh in the Orange Estuary. The dominant species is the salt and drought tolerant *Sarcocornia pillansii*. Wind-blown dust and saline conditions due to the causeway and no flow exchange have resulted in the loss of this habitat in the desertified marsh area. Recent aerial photographs (2010) and ground-truthing in 2012 showed a small increase in vegetation cover in the desertified salt marsh. On the side of the causeway that is closer to the main channel there was an increase in *S. pillansii* cover. There were also patches of the supratidal species *Suaeda fruticosa*. The invasive alien species, *Acacia cyclops* occurs in the desertified salt marsh.
Reeds and sedges	Dense stands of *Phragmites australis* (common reed) occurred along the length of the water channels where they provide important habitat for invertebrates, fish and birds. This species is known to thrive in brackish conditions when salinity is less than 15 ppt and is thus indicative of the freshwater status of the Orange Estuary. The reeds were not found on banks close to the mouth probably as a result of salinity intrusion. The sedge *Schoenoplectus scripoides* was also dominant along the banks. A patch of *Bolboschoenus maritimus* occurred closer to the water's edge but individuals showed signs of what was probably salt stress.

The present area of the different vegetation types and their distribution of within the 5 m contour around the estuary are given in Tables 21 and 22.

Table 21. Area of each habitat type mapped from 2010 images and ground-truthed in 2012

Habitat type	***Area (ha)***
Open surface water area	609
Intertidal sand and mudflats	144
Submerged macrophytes	<1
Macroalgae	<1
Intertidal salt marsh	144
Supratidal salt marsh	602
Desertified marsh area	511
Reeds and sedges	316
Terrestrial vegetation	383
Total	**2709**

3.8.2 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 22.

Table 22. Effect of abiotic characteristics and processes, as well as other biotic components on macrophyte habitats

Abiotic factor
Macrophytes
Mouth condition (provide temporal implications where applicable)
Closed mouth conditions would promote the growth and proliferation of macroalgae. However the mouth is mostly open with strong river inflow and therefore macroalgae are only found in quiet backwater areas. Kelps and other non-resident marine species may be washed into the estuary when the mouth is open. High flow prevents the establishment of large submerged macrophyte beds. Currents less than 0.1 m/s favour the growth and establishment of submerged macrophytes such as *Stuckenia pectinata* which does occur in the estuary also in quiet backwater areas. Intertidal salt marsh grows better under regular tidal inundation. Since the causeway has been removed in the vicinity of the mouth, the salt marsh showed signs of recovery that is dependent on regular tidal inundation. The location of the mouth could influence the salinity of the water reaching the salt marsh on the south bank near the mouth. When the location of the mouth at the southern position, considerable amounts of seawater enter the area at spring tides, but the salinity of the water entering the salt marsh would be much lower if the mouth were located at the northern bank. The needs of the salt marsh, therefore, should be considered before the mouth is breached (van Niekerk et al., 2003). Prolonged mouth closure could result in the die back of intertidal salt marsh species. Standing water and long-term inundation can result in die back of supratidal salt marsh and remaining vegetation in the desertified marsh area. Under open mouth conditions with a strong river inflow freshwater would provide suitable conditions for the growth of reeds and sedges. It can also be expected that this group would expand further towards the mouth. Under open mouth conditions with strong marine influence reeds and sedges will be limited to areas where salinity is less than 15 ppt, as under present conditions. Under closed mouth conditions it is expected that salinity penetration would be reduced and reeds would expand further towards the mouth.
Retention times of water masses
Greater water retention time would provide better opportunities for nutrient uptake by macrophytes thereby favouring their abundance. Low flow conditions could cause the expansion of reeds and sedges into the water channel further reducing flow. Circulation/water movement is necessary to maintain the salt marsh dynamics. Shaw et al. (2007) suggested that if sections of the causeway or the whole of should be reduced, thereby introducing less saline water and establishing favourable geohydrological conditions for salt marsh growth.
Flow velocities (e.g. tidal velocities or river inflow velocities)
Low flow velocities would encourage the growth of macroalgae, submerged macrophytes and reeds and sedges associated with the water column. Flow velocity and the stability of the sediment influence colonisation by emergent macrophytes such as reeds and sedges. The vegetation on the braided system of islands within the lower reaches of the river is ephemeral due to periodic flooding. Scouring of the island surfaces or deposition of high sediment loads occurs during floods.
Total volume and/or estimated volume of different salinity ranges
Rapid changes in estuarine water depth can leave submerged plants such as *S. pectinata* high and dry.
Floods
Floods are important for resetting the estuary and removing accumulated sediment and macrophyte growth. It has been said that the vegetation on the braided system of islands within the lower reaches of the river are ephemeral due to periodic flooding. Reduced flooding will result in reed encroachment. Morant and

Abiotic factor **_Macrophytes_**
O'Callaghan (1990) report on the effect of a major flood in 1988 on the biota of the Orange Estuary. This flood destroyed 315 ha of wetland vegetation through erosion and deposition of coarse sediment. However the flood was important in reducing salt marsh salinity and stimulating germination, seedling growth and flowering of *S. pillansii*. Floods would also deposit rich organic mud in the mouth area and thus floods have an important nitrifying effect. Floods are essential for the maintenance of the desertified marsh area. Under the reference condition high river inflows/floods (1:1 to 1:10 year floods) combined with high spring tides would have increased water level resulting in inundation of the desertified marsh area. There has been a reduction in floods from the reference to the present condition and thus this mechanism of inundating the salt marsh does not occur. Seasonal flow has been changed from that being high in summer and low in winter to similar but reduced flow in both summer and winter. The high summer flow was probably important in maintaining reduced salinity levels when evaporation was at its highest.
Salinity The vegetation of the lower part of the river is typical of a low salinity coastal wetland. Salinity is mostly less than 15 ppt and the macrophytes present reflect this. Increases in salinity are unlikely to effect the composition or biomass of the macroalgae as they can tolerate a wide range of conditions. Reeds and sedges are sensitive to increases in salinity but can survive if their roots and rhizomes are located in salinity less than 20. However if freshwater seepage is reduced then it may lead to die back. Freshwater inflow dilutes salts, preventing hypersaline conditions in saltmarshes. 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 will result in dry bare patches in the supratidal areas. High groundwater level and freshwater flooding would be important in influencing the marsh. In the desertified salt marsh area in 1994 a layer of crystallised salt occurred on the sediment surface and this was a highly saline environment. The salt marsh plant *S. pillansii* occurred in some of the elevated areas. This plant has a wide salinity tolerance range of 0-70 ppt (Bornman, 2002). The salinity of the water table in the vicinity of the desertified marsh has increased over time and this has also contributed to the demise of the salt marsh. To re-establish *S. pillansii* in the elevated areas the salts would need to be flushed out. CSIR (1991) believed that prior to the cut-off of freshwater input to the marsh the area would have supported a mosaic of communities associated with freshwater and brackish conditions (e.g. reeds and sedges). When the desertified marsh area was cut-off from the main channel an isolated coastal lake developed behind the dunes in the lower part of the salt marsh and the water in this lake became highly saline, mainly because of ongoing evaporation (CSIR, 1990).
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 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

Abiotic factor
Macrophytes
(especially N and P) are known to stimulate the abundance of ephemeral and epiphytic macroalgae. *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, by depleting the oxygen in the water column upon decomposition.
Sediment characteristics (including sedimentation)
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. Increased sedimentation could result in the closure of small channels preventing tidal exchange necessary for the maintenance of intertidal saltmarshes.

Table 23. Responses of different groups of macrophytes to estuary state

Estuary state	***Macrophyte group: Description***
Salt marsh	
State 1[1]	The death of intertidal salt marsh due to lack of tidal action is expected. Impact on supratidal salt marsh through changes in groundwater salinity.
State 2[2]	Prolonged inundation would cause die-back of salt marsh. Supratidal salt marsh is particularly sensitive to waterlogged conditions.
State 3[3]	Intertidal salt marsh grows well.
State 4[4]	This state maintains current macrophyte conditions where reeds and sedges and intertidal salt marsh are found in the lower reaches.
State 5[5]	Promotes the growth of reeds and sedges. Changes to a finer sediment type could result in the local extinction of species.
Reeds and sedges	
State 1	Death of reeds in sedges in the upper reaches due to hypersaline conditions.
State 2	Under closed mouth conditions it is expected that salinity penetration would be reduced and reeds could expand further towards the mouth. However growth would be reduced by prolonged inundation.
State 3	Under open mouth conditions with strong marine influence reeds and sedges will be limited to areas where salinity is less than 15 ppt.
State 4	Reeds and sedges will be limited to the middle and upper reaches of the estuary.
State 5	Increased freshwater flushing to the system and an increase in the deposition of fine sediments could lead to the expansion of reeds and sedges.
Submerged macrophytes	
State 1	Some submerged macrophytes such as *Ruppia* spp. can survive but this would be dependent on salinity and competition from macroalgae. Low water level could results in loss of habitat and desiccation of all macrophyte habitats.
State 2	An increase in water level and stable high water level conditions would promote the growth of the submerged macrophytes as long as turbidity was low. However high nutrient input could result in macroalgae out competing *S. pectinata*.
State 3	Stronger marine influence would prevent the growth of *S pectinata*.
State 4	Submerged macrophytes would occur in quiet backwater areas. Flow >1 m s-1 would result in a decrease or disappearance of submerged macrophytes.
State 5	Should the river inflow bring more suspended matter into the system there is likely to be a decrease in transparency which would reduce cover and biomass.

Estuary state	***Macrophyte group: Description***
Macroalgae	
State 1	Macroalgae tolerant to hypersaline conditions may become abundant. When this is associated with relatively high nutrients and temperature, such as in summer, macroalgae may flourish. Low water level could result in loss of habitat and desiccation
State 2	Closed mouth conditions would also promote the growth and proliferation of green macroalgal species.
State 3	Under open mouth conditions with strong marine inflow it is expected that there would be an increase in the number of species in the estuary, such as kelps and other non-resident species.
State 4	These are ideal conditions to promote macroalgal species diversity
State 5	Under open mouth condition with a strong river inflow freshwater would provide suitable conditions for the growth of green macroalgae in the genus *Ulva* and *Cladophora*.

1 Closed, hypersaline, low water level.
2 Closed, high water levels.
3 Open, tidally dominated.
4 Brackish, open freshwater flushing and tidal.
5 Open, fluvially dominated.

3.8.3 Reference condition

Table 24 indicates the percentage change in the abundance (area cover) of the macrophyte habitats in response to the various abiotic changes. The final abundance score is a measure of the similarity in overall abundance for the present state compared to that in the reference state.

Overall submerged macrophytes have probably not changed in area cover as the stable conditions would have promoted growth, however the increase in baseflow conditions would increase turbidity and decrease growth. Macroalgae have increase in response to nutrient input particularly in quiet backwater areas where there is greater water retention. Reeds and sedges have increased in response to reduced flows and stable sediment conditions as have intertidal saltmarshes.

Large floods (greater than 5,000 Mm^3) are important resetting events. These have been significantly reduced from a frequency of 25 under the reference conditions to 8 under the present state. MAR into the estuary is currently 40% of reference conditions. Stable sediment conditions would encourage macrophyte growth. Smaller floods (1:2 and 1:5) would have occurred more frequently resulting in sediment mobilisation and reworking of the channels and islands. The more dynamic environment would result in diverse macrophyte communities characterised by both primary colonisers and climax species at any one time.

Low flows have significantly increased from reference conditions to the present state in the 10 – 20 m^3/s inflow range. This would introduce silt to the system, increase turbidity and result in a loss of submerged macrophytes. However the decrease in large floods would promote growth of submerged macrophytes thus cancelling out this response. Salinity has increased due to a decrease in flow. Under reference conditions the estuary was mostly in the freshwater dominated state (State 4). The high salinity under present conditions would result in a loss of reeds and sedges which thrive under brackish conditions. According to Bornman and Adams (2010) low flows in the

Orange River during 2004 and 2005 increased seawater penetration into the estuary and caused the die-back of less salt-tolerant species such as *Phragmites australis* and *Schoenoplectus scirpoideus* in the lower reaches.

Higher flows in summer would have reduced evaporation effects and accumulation of salts in the intertidal salt marsh. Brackish communities would have also been lost from the desertified salt marsh area but are still represented in the main river channel.

Under reference conditions the mouth would have closed, backflooding of the now desertified salt marsh area may have been important in reducing salinity and promoting growth. However the greater impact on the salt marsh has been the causeway which restricted flow into the marsh area particularly during floods. Anthropogenic effects therefore account for the change in the desertified marsh area. This area would have functioned like a brackish wetland with some halophytic salt marsh species. Typical intertidal salt marsh would have occurred near the mouth and in the elevated areas there would have been supratidal marsh represented by *Sarcocornia pillansii* and *Suaeda* spp. Water would enter this area from the main channel as there would be no road embankment blocking tidal flow. Old channels would have been active during floods (1:2 and 1:5 year floods) feeding water into this area. This was probably important in maintaining brackish conditions in this area. The occurrence and magnitude of these small floods particularly during the summer months has been reduced (CSIR, 2004). The desertified salt marsh area has been unable to recover over the last 20 years because of the persistently high sediment and groundwater salinity (Bornman and Adams, 2010).

Exotic weeds have been found in the river mouth area. These would have been absent under reference conditions and thus community composition has changed. After the 1988 flood, (Morant and O'Callaghan, 1990) reported that the bare sand on the islands and banks were colonised by exotic species, mainly *Paspalum paspaloides*, *Nicotiana* spp and *Datura stramonium*. The persistence of these species is unknown. As salinity increased the brackish wetland species i.e. *Phragmites australis* and S*porobolus virginicus* could have outcompeted these weeds. There has been a slight increase in the terrestrial habitat (2 ha) in the estuary boundary as a result of expansion of invasives such as *Acacia cyclops*. Other weedy species found in the upper reaches of the estuary in 2012 were *Cynodon dactylon, Stenotaphrum*, en *Pennisetum* and *Gomphocarpus fruticosus*. The latter is an indigenous weedy species.

Table 24. Summary of how the macrophytes in the present condition have changed relative to the reference condition

Abiotic factors	***Changes***
⇩ Large and small floods	Stable sediment encourages macrophyte growth ⇧ 25% reeds and sedges ⇧ 10% intertidal salt marsh
⇩ Mouth closure	⇧ 10% intertidal salt marsh
⇧ Salinity	⇩ 10% reeds and sedges particularly in lower reaches ⇩ 13% intertidal salt marsh
⇧ Nutrients	⇧ 50% macroalgae, reeds
Causeway	⇩ 90% supratidal salt marsh ⇧ desertified salt marsh

Abiotic factors	*Changes*
Overall change	Macroalgae ⇧ 50%, submerged macrophytes 0%, reeds and sedges ⇧ 5%, intertidal salt marsh ⇧7%, supratidal salt marsh ⇩90%.

Table 25. Similarity scores of macrophytes in the present condition relative to the reference condition

Variable	*Change from natural*	*Score*
Species richness	Species have been lost because of the less dynamic environment. Under reference conditions there would be a diversity of macrophytes characterised by both primary colonisers and climax species at any one time. Die-back of less salt-tolerant species in response to increase in salinity. Invasive species potentially displaced some species. Confidence: Medium	50
Abundance	The largest change in area has been in the supratidal salt marsh area which has changed to desertified marsh with little vegetation cover. There have been smaller increases in macroalgae in response to nutrient increases. Reeds, sedges and intertidal salt marsh have increased in cover as a result of the decrease in floods and more stable sediment conditions. Confidence: Medium	67
Community composition	Brackish communities have been lost from the desertified salt marsh area which is now barren. This would include reeds, sedges and supratidal salt marsh. Macroalgae are now abundant as a result of nutrient enrichment. Confidence: Medium	63
Macrophyte health score (minimum score) Confidence: Medium		**50**
% of impact non-flow-related		50

3.9 Invertebrates

3.9.1 Invertebrate groups

Table 26. Classification of South African estuarine invertebrate fauna and the parameters influencing their abundance and distribution

Description	*Influencing factors*
Polychaetes – estuarine resident (e.g. *Ceratonereis keiskama*)	Medium to fine sediments; detritus; other edible invertebrates; predatory.
Polychaetes – marine (e.g. *Arenicola*)	Medium to coarse sediments; detritus; open mouth; saline water.
Amphipods	Finer sand/mud; shelter; detritus; POM; reduced salinity.
Isopods	Coarse sediments; higher salinity; dead matter.
Gastropods – marine dominated species (detritivores, scavengers and predators e.g. *Bullia*)	Detritus; open mouth; MPB; higher salinity.
Gastropods – resident sediment living grazers, detritivores and predators (e.g. *Hydrobia*; *Natica*)	Shelter; submerged macrophytes; MPB; detritus.
Gastropods – grazers associated with macrophytes	Shelter; submerged macrophytes; MPB.
Bivalves – estuarine resident	Medium-fine sediments; submerged macrophytes; Particulate organic matter (POM).
Bivalves – marine (e.g. *Donax/Tellina*)	Medium-coarse sediments; open mouth; POM.

Description	***Influencing factors***
Crabs – resident estuarine (e.g. *Spiroplax*)	Medium-fine sediments; (presence of prawns for *Spiroplax*).
Crabs – estuarine (e.g. *Hymenosoma*)	Open mouth; saline.
Carids – estuarine–marine (e.g. *Palaemon*)	Medium-fine sediments; detritus; open mouth; high salinity.
Carids – resident (e.g. *Betaeus*)	Medium-fine sediments; detritus; submerged macrophytes; prawns (*Betaeus*).
Saltmarsh inverts	Saltmarsh.
Insect larvae	Lower salinities.
Mudprawns (e.g. *Upogebia*)	Fine sand/mud; open mouth; POM.
Sandprawns (e.g. *Callichirus kraussi*)	Sand; not extended freshwater (>17 ppt to breed); POM.
Zooplankton – marine	Phytoplankton; open mouth.
Zooplankton – estuarine resident	Phytoplankton; current velocity; salinity.

The invertebrate fauna of the Orange Estuary is considered to be species poor and atypical of tidal estuaries along the west coast of South Africa. Those few species resident in the estuary are tolerant of a highly variable physic-chemical environment, although populations probably fluctuate significantly in terms of abundance and composition both within years (variations in seasonal flow) and between years (magnitude of floods and state of the mouth including breaching (artificial or natural).

When the three invertebrate groups are considered (zooplankton in the water column, hyperbenthos just above the substrate and the benthos on or in the bottom sediments), the group with highest biomass is usually linked to either the hyperbenthos or benthos. Under present state, tidal currents (when the mouth is open) and the associated low residence time of the water probably lead to significant export of biomass. Thus, the euryhaline zooplankton community (primarily linked to the water column) was particularly poor in terms of representation in the estuary (Table 26) and species that often dominate euryhaline mesozooplankton communities were absent (e.g. *Acartia longipatella*) or present in very low numbers (e.g. *Pseudodiaptomus hessei*). The absence of *A. longipatella* is probably linked to extreme fluctuations in salinity over relatively short time periods (tidal and lunar cycles that are further inter-linked with acyclic or cyclic river inflow volumes) and strong tidal currents present in the estuary.

In terms of the invertebrate community, abundance of species was maximal among species that are either resident in the benthos (polychaetes) or those that have a strong association with the substrate (mysids in the hyperbenthos). Abundance levels of hyperbenthic and benthic species (although species poor in the Orange) are more closely aligned to abundance levels recorded for other tidal west coast estuaries. Mysids (and other invertebrates), probably move actively between the marine nearshore and the estuary and are also able to avoid been washed out of the estuary because of greater or stronger swimming ability compared to typical zooplankton (e.g. copepods) higher up in the water column. Among the two polychaete species in the Orange, *Desdemona ornata* filter feeds from tough tubes at the surface of the substrate, while *Ceratonereis keiskama* is highly predaceous. Numerous polychaete larvae were also present in the plankton and were probably representative of these two species.

3.9.2 Factors affecting the invertebrate fauna

The main factors affecting the abundance of the different invertebrate groups found in the Orange estuary are summarised in Table 27.

Table 27. Effect of abiotic characteristics and processes, as well as other biotic components on invertebrate groupings

Abiotic factor
Affected categories
Mouth condition (provide temporal implications where applicable)
Under closed mouth conditions, residence time of the water is significantly increased. If salinity values are euhaline at the time of mouth closure, invertebrate composition and biomass will increase significantly and may even attain levels comparable with the richest estuaries along the west coast (biomass). The number of euryhaline species is also likely to increase following mouth closure. However, salinity will slowly decrease as river inflow dilutes the salinity levels in the estuary. As salinity approaches 4 – 7, the community will begin to be change and become dominated by freshwater species.
Retention times of water masses
Retention time of water masses will favour all three invertebrate groups, but particularly the zooplankton. Deeper areas will favour the hyperbenthos as these will hold pockets of more saline water that is retained for longer compared to the overlying water. In terms of the benthos, loss of larval stages will also be reduced, since species currently in the benthos have planktonic larvae. Refer to Technical Report 33 for more detail.
Flow velocities (e.g. tidal velocities or river inflow velocities)
Flow velocities impact all three invertebrate groups. Under current conditions, zooplankton is particularly affected, as individuals are flushed from the system relatively easily. Nearer the substrate, hyperbenthic species are still able to maintain populations in the estuary (e.g. mysids), but any increase in flow velocity compared to present will also impact the group in a manner similar to the zooplankton. Deeper areas are important for mysids for example, as they represent pockets of water less affected by overlying currents. This also suggests that the community, like the zooplankton, is ephemeral in the estuary and is linked to changes in the annual flow patterns. The bentic community is more resilient to flow velocities, but thresholds will also be reached when scouring removes surface sediment layers. Consequently, all three groups will benefit from reduced flow velocities, but thresholds will be unequal between them. Deeper areas of pocket water will also be important as refugia.
Total volume and/or estimated volume of different salinity ranges
The euhaline-euryhaline salinity range (ca 5 – 28) will benefit the invertebrate community directly. The greater the volume, the greater the habitat available to them.
Floods
Floods impact the invertebrate community directly, particularly through the flushing of communities from the estuary. However, floods will influence the three components (zooplankton, hyperbenthos and benthos) in disproportionate ways. The most sensitive will be the zooplankton. Tidal ebb and flow already stress communities and a permanent euryhaline component does not establish itself. Marine copepods particularly move in and out of the estuary with the tides (ephemeral), while a freshwater associated community is present near the head of the estuary and further upstream. Hyperbenthic and benthic species will also be sensitive to even small floods that are able to scour bottom

Abiotic factor
Affected categories
sediments.
Salinity Because of considerable variation in salinity along the estuary, only extremely tolerant estuarine species become established in the estuary. Again, the zooplankton is mostly linked to the freshwater group, while marine species move in and out of the estuary with the tidal plug.
Turbidity Only high turbidity levels will influence the invertebrates – those that are present in the estuary are adapted to high variability in the physic-chemical environment.
Dissolved oxygen If oxygen levels drop below about 50% saturation, most invertebrates will be negatively affected. However, species such as the polychaete worm *Desdemona* will survive much lower levels of oxygen concentration.
Subtidal, intertidal and supratidal habitat Observations in supratidal habitats indicate a low biomass of invertebrates, and those present are insects. No burrowing forms were observed. Subtidal and intertidal habitats are dominated by two species of polychaetes. *Dedemona ornata* is small (mm), while the predator *Ceratonereis keiskama* occurs in high numbers on exposed banks and subtidally.
Sediment characteristics (including sedimentation) Along the estuary channel, sediment characteristics are highly variable both on a temporal and spatial scale. Smothering will be an important factor impacting the benthos, but general observations of distribution along the estuary suggest that the two key benthic species are able to colonise a wide range of sediment types. *Desdemona* establishes a carpet of small tubes that almost smother the substrate.
Phytoplankton biomass Phytoplankton biomass probably provides a major component of the diet of the filter feeder, *Desdemona ornata* that carpets the bottom of the estuary. *Desdemona* is the proverbial 'wall of mouths' on the estuary floor, functioning in a similar manner to the polyps on coral reefs.
Benthic micro-algae biomass As above, providing an important component of the diet of *Desdemona.*
Zooplankton biomass Zooplankton a negligible component in the estuary foodweb, although their importance will increase upstream in freshwater habitats.
Aquatic macrophyte cover If other factors such as salinity are suitable, aquatic macrophytes will provide habitat for colonisation for invertebrates, but this is likely to be extremely patchy.
Fish biomass The foodweb linked to the invertebrate community is probably relatively simple, with fish targeting mainly the mysids in the hyperbenthos and polychaete worms in the substrate. Of the two components, the benthos probably represents the highest biomass that is available most consistently.

3.9.3 *Reference condition*

Under the reference condition, the estuary would have been extremely dynamic with much stronger water flows, with State 5 dominating the hydrological cycle. Under present-day conditions the 1:2 to 1:5 floods are reduced by 85% to 74% respectively.

Low flows (10 – 20 m^3/s) have increased eight times compared to the natural state. Thus, extremely dynamic water flow conditions (frequent floods) characterised the system under the natural state, leading to a river mouth state for much of the time. Although mouth closure occurred under natural conditions, salinity values probably remained too low for an estuarine community to become established.

In effect, the lower Orange River mouth area has moved along a trajectory originally described as a river mouth with occasional increases in salinity to a system where estuarine characteristics and associated biotic communities have become established.

3.9.4 *Health of the invertebrate component*

The current invertebrate community represents a simple complex of species that are able to survive in a dynamic physic-chemical estuarine environment. Water residence time in the estuary is low (a few days at most) and strong tidal currents. The most vulnerable group is the zooplankton and no real estuarine community has yet established itself, although during drought periods, some species may temporarily become established. The early colonisers currently present in the estuary are essentially pioneers, able to survive prevailing conditions. The hyperbenthos is able to survive in deeper pockets (stratified water column), depending on prevailing freshwater inflow volumes to the estuary. The benthos is probably the best represented of the three groups (zooplankton, hyperbenthos and benthos), despite only two species being present in any numbers. The two species represent a filter feeder and a predator.

Table 28. Similarity scores of invertebrates in the present state relative to the reference condition

Variable	*Change from reference condition*	*Score*
Species richness	The lower Orange River has moved along a trajectory originally representing a river mouth (freshwater) much of the time to a system more typical of an estuary (present-day). Invertebrates now present are represented by few extremely tolerant estuarine species, particularly in the benthos. Confidence: High	50
Abundance	Abundance levels fluctuate widely, linked to river inflows and degree of marine influence. However, average abundance increased due to more persistent estuarine conditions. Hyperbenthic species survive in deeper stratified pockets of water. When the estuary is flushed, mysids for example are able to recolonise the estuary from the marine environment where populations also occur naturally (*Mesopodopsis wooldridgei*). Sediments more stable under present-day conditions; they are less frequently eroded and benthic populations become better established and persist for longer. Confidence: High	45

Variable	*Change from reference condition*	*Score*
Community composition	As above, with high dominance. Confidence: High	45
Invertebrate health score (minimum score) **Confidence: High**		**45**
Degree to which deviation from natural is due to non-flow-related impacts Confidence: Medium		10

3.10 Fish

Table 29. Classification of South African fish fauna according to their dependence on estuaries (Adapted from 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.

Thirty-six species of fish representing 19 families have been recorded from the Orange Estuary (Brown, 1959; Day, 1981; Cambray, 1984; DWA, 1986; Morant and O'Callaghan, 1990; Harrison, 1997; Seaman and van As, 1998 and this study). Six of these, the estuarine round herring *Gilchristella aestuaria*, Cape silverside *Atherina breviceps*, barehead goby *Caffrogobius nudiceps*, commafin goby *Caffrogobius saldhana*, klipvis *Clinus superciliosus* and pipefish *Syngnathus temminckii* live and breed in estuaries. With the exception of *G. aestuaria*, these fish also have marine breeding populations. Three species, white steenbras *Lithognathus lithognathus*, leervis *Lichia amia* and the facultative catadromous flathead mullet *Mugil cephalus* are dependent on estuaries for at least their first year of life whereas another two, elf *Pomatomus saltatrix* and harder *Liza richardsonii* are partially estuarine dependent. Eight species such as west coast steenbras *Lithognathus aureti* and silver kob *Argyrosomus inodorus* are marine species that occasionally venture into estuaries whereas 15 species, such as largemouth yellowfish *Labeobarbus kimberleyensis*, river sardine *Mesobola brevianalis* and the introduced carp *Cyprinus carpio* are euryhaline freshwater species whose penetration into the estuary is determined by salinity tolerance. One catadromous species the longfin eel *Anguilla mossambica* has been recorded from the Orange River near Kakamas and it is assumed that recruitment occurred through the estuary notwithstanding the (more likely) possibility that it entered the system through one of the inter-basin transfer schemes that connect the catchment with rivers on the east coast of South Africa. Overall, 31% of the fish species recorded from the Orange Estuary are either partially or completely dependent on estuaries for their survival, 22% are marine and 47% freshwater in origin.

Two species of kob, silver kob *Argyrosomus inodorus* and Angolan kob *A. coronus* are known from the Orange Estuary, the latter only been caught by anglers in the mouth region. Interestingly, on the east coast of South Africa dusky kob *A. japonicus* are dependent on estuarine nursery areas whereas *A. inodorus* seldom if ever ventures into estuaries. On the west coast however, *A. inodorus* frequently (and predictably) occurs in the Berg, Olifants and Orange Estuaries whereas *A. coronus* is predominantly caught on the beaches immediately adjacent to the mouths of these rivers, and have only been recorded in estuaries during low oxygen conditions in the sea (Lamberth et al., 2008; Lamberth et al., 2010). Therefore, *A. inodorus* may show some degree of estuarine dependence on the west coast of South Africa. All three of the kob species mentioned prefer turbid waters such as that in the Orange Estuary. Further, towards the edge of the range of *A. inodorus*, *A. coronus* becomes the dominant kob species in the Kunene River Estuary over 1,500 km to the north. Silver and dusky kob both increase in abundance immediately adjacent to the mouth during the summer months which is most likely a response to avoid cool up-welled waters in the nearshore. Large aggregations of both species predictably occur up to two weeks before and during flood events, a circumstance that anglers take advantage of and plan their trips around.

Comparisons with other estuaries and biogeographical regions are difficult because the data collected in the Orange Estuary, and consequently the relative contribution of each estuarine-dependence category, varies according to the gear used in each study and the distance sampled from the mouth. Overall, species that breed in estuaries and/or estuarine residents comprise 10 – 22% of the Orange Estuary fish fauna as compared to 26 – 27% for the Berg and Olifants estuaries (400 – 500 km to the south) and 4 – 25% for estuaries on the south, east and KwaZulu–Natal coasts (Bennett, 1994; Lamberth and Whitfield, 1997). Entirely estuarine dependent species comprise 24 – 33% of the Orange Estuary fish fauna comparing well with the 26, 25 – 54, 22 and 9% recorded for the west, south, east and KwaZulu–Natal coasts respectively (Bennett, 1994; Lamberth and Whitfield, 1997; Harrison, 1997, 1999). Partially estuarine dependent species comprise 7 – 22% of the Orange fish fauna, which is lower than the 29 – 40% for the Berg and Olifants and 18 – 27% for estuaries from Cape Point to KwaZulu-Natal (Bennett, 1994; Lamberth and Whitfield, 1997). Non estuarine dependent marine species comprise 21% of the species recorded but at least two of these, *A. inodorus* and *L. aureti*, occur predictably according to season and weather conditions as opposed to being vagrants that occur randomly.

3.10.1 Factors affecting the fish community

The main factors affecting the abundance of the different fish groups found in the Orange Estuary are summarised in Table 30.

Table 30. Summary of fish responses to abiotic processes and biotic components

Abiotic factor
Affected categories
Mouth condition
During the summer months, open mouth conditions maintain a substantial warm, turbid plume that provides a refuge from cool up-welled water in the nearshore and cues for fish attempting to recruit into the estuary. Under closed mouth conditions increased phytoplankton and zooplankton production will favour growth of all species and spawning success, survival and population size of estuary breeders will increase. Populations of most of the latter will crash once breaching occurs. Prolonged mouth closure will likely see salinity levels decrease and freshwater species moving into the lower reaches of the estuary.
Retention times of water masses
Larval growth and survival, especially of estuary breeders, will increase provided that predation by zooplankton doesn't reach excessive levels. Increased retention time will favour phytoplankton and zooplankton production, providing a currently rare food source in the estuary, favouring the juveniles of most species as well as the adults of planktivorous fish such as *G. aestuaria* and *S. Temminckii.*
Flow velocities (e.g. tidal velocities or river inflow velocities)
During floods and high flows fish tend to find refuge in the shallow marginal areas on the floodplain and / or amongst saltmarsh and reed-beds. High flow velocities also generate numerous eddies that provide refuge and concentrate prey as well as standing waves that fish use to recruit into the estuary or move upstream. Most estuary associated fish are adapted to take advantage of both high and low flow velocities. If reduced flow velocities translate into increased phytoplankton and zooplankton production, fish will benefit from this abundant prey.
Total volume and/or estimated volume of different salinity ranges
The Orange is predominantly open so fish distributed according to their salinity preference in the system. However, in the Orange and other estuaries on the west coast of South Africa, temperature may sometimes be the deciding factor as to where and whether a fish occurs in the system. Oxygen may also play a key role. There are also the observations that aggregations of kob and west-coast steenbras are a predictable response to an impending flow event and the abundance of both freshwater and estuary-associated marine species greater during the summer high-flow season. The lower and upper reaches of the estuary-proper to the Sir Ernest Oppenheimer Bridge comprise 280 ha and 100 ha of water surface-area respectively. However, from the bridge to Brandkaros 20 km upstream there's a further 650 ha of water extensively used as an adult and nursery habitat by estuary-associated fish. Therefore, total effective estuary habitat available to fish is at least 1,030 ha. Persistent low or zero flows coupled with obstructions presented by the present and past bridge site may see the upstream reaches and associated habitat become inaccessible to fish.
Floods
Small to medium floods provide cues for fish to enter the estuary or move upstream. Fish will either find refuge in the marginal areas, upstream or be swept out to sea. This said, the abundance of kob and steenbras increases at the mouth before and during small and large floods. This may ultimately be a response to prey such as small fish being washed out of the estuary mouth. Freshwater fish also occur in the surf-zone at these times.
Salinities

Abiotic factor
Affected categories
As above, the Orange is predominantly open so fish are distributed according to their salinity preference in the system but temperature and oxygen may play a larger role in estuaries on the south and east coast of South Africa. Unlike the Berg and Olifants estuaries, the current fish assemblage of the Orange is typical of those in estuaries to the north and throughout the west coast of Africa in having a high proportion of freshwater species and freshwater tolerant estuary-dependent marine species. Those of the latter group in the Orange are also tolerant of prolonged mouth closure and hypersalinity, an arid-adapted character shared with fish assemblages to the south and east.
Turbidity
High turbidity provides refuge for small fish but also attracts predators in search of concentrated prey. Both kob *Argyrosomus* species prefer high turbidity and are physiologically adapted to survive high sediment loads from which most other fish are excluded. High turbidity also tends to favour fish such as *G. aestuaria* that have a more catholic diet and can switch between filter and selective feeding as the need arises over less versatile species such as *A. breviceps* that prefers clearer waters.
Dissolved oxygen
Low oxygen levels in the sea; especially during the summer upwelling months, is one of the drivers behind recruitment into the estuary. Fish will swim away from localised low oxygen levels in the estuary. If unable to escape, they will start surface breathing, a behavioural adaptation shared by estuary-associated and freshwater fish globally. Prolonged mouth closure and persistent low oxygen levels throughout the estuary could eventually see fish dying from exhaustion. However, most of the fish in the estuary are tolerant of low salinity and would probably escape upstream before this.
Subtidal, intertidal and supratidal habitat
Fish spend most of the time in the subtidal and forage in the intertidal during flood tide. Resuspended detritus as well as bird droppings flowing into the channels on the ebb-tide provide an important food source for mullet species. In summer, there may be a 10 – 15°C temperature difference between the estuary and sea. Shallow sun-warmed intertidal waters provide a refuge from cold seawater during the pushing tide.
Sediment characteristics (including sedimentation)
Caffrogobius nudiceps and *C. saldhana* are associated with muddy channel margins and both these fish and preferred habitat are rare in the estuary. The sediments are not extensively reworked by benthic invertebrates, smothering by sediment is fairly low and benthic diatoms remain an important food source for mullet species. Kob *Argyrosomus* species aggregate at times of high sediment loads and turbidity in the estuary and adjacent sea. Apart from harder *Liza richardsonii* that feed on benthic algae, benthic foraging species that feed on burrowing invertebrates such as white steenbras *Lithognathus lithognathus*, are also rare in the estuary. Excluding *L. richardsonii*, the fish assemblage is dominated by piscivores or planktivores that feed in the water column and not benthic feeders.
Phytoplankton biomass
At times when zooplankton are sparse, phytoplankton probably provide a major component of the diet of *G. aestuaria* and *A. breviceps.*
Benthic micro-algae biomass
Liza richardsonii contribute more than 90% of the fish biomass in the estuary and are reliant on benthic algae for most of the year. *Mugil cephalus, G. aestuaria* and *A. breviceps* also feed on benthic algae when phytoplankton and zooplankton are in short supply.
Zooplankton biomass
The juveniles of most fish species, including *L. richardsonii,* prefer to feed on zooplankton. Relatively low zooplankton biomass probably the reason that juveniles of species such as *M. cephalus* and *L. lithognathus* are usually rare in the estuary or further upstream in the freshwater reaches.

Abiotic factor	***Affected categories***
Aquatic macrophyte cover	Excluding reed-beds, aquatic macrophyte cover is limited to patches of *Ulva* in the lower reaches and filamentous algae in the freshwater backwaters. All pipefish *Syngnathus temminckii,* both *Caffrogobius* species and klipvis *Clinus spatulatus* were found exclusively with the *Ulva* patches. Limited macrophyte cover is probably a contributor to the low numbers of these species in the estuary. Mozambique tilapia *Oreochromis mossambicus*, banded tilapia *Tilapia sparrmanii,* three Barbus species and river sardine *Mesobola brevianalis* were associated with the algae in the freshwater reaches.
Fish biomass	The fish biomass is dominated by *Liza richardsonii* which in the Orange Estuary are mostly feeding (grazing) on benthic algae and invertebrates. Aside from *L. richardsonii*, the fish biomass is dominated by piscivores such as elf *P. saltatrix*, silver kob *A. inodorus* and leervis *Lichia amia*. With the exception of the freshwater species, benthic invertebrate feeders, both adults and juveniles, are rare.

3.10.2 Reference condition

Under reference conditions, fish species composition and abundance was likely seasonal and varied according to summer high-flow, winter low-flows and physico-chemical gradients between the estuary and sea. Abundance is expected to have been highest in spring and early summer, a combination of new recruits entering the system, marine species remaining before salinities are 'diluted' and freshwater species moving downstream in response to the first wet season flows. Winter low-flow numbers are expected to have been the lowest comprising a few estuarine, marine and freshwater species tolerant of higher salinities. Then, as now, fish numbers and biomass would have been dominated by the partially estuarine dependent *L. richardsonii* throughout the year. The fish assemblage in the summer high-flow season is also likely to have seen increased numbers of estuary-associated marine species especially silver kob *Argyrosomus inodorus* as well as the larger freshwater species *Labeobarbus kimberleyensis, Labeobarbus aeneus, Labeo capensis* and *Oreochromis mossambicus*. Estuary-associated species such as *L. richardsonii* and *M. cephalus* are 'facultative catadromous' species and, in the absence of any physical barriers, ventured hundreds of kilometres upstream. Under flood conditions, much of the estuary fish assemblage is likely to have found temporary residence or refuge in the sea. Floods would also have cued aggregations of *A. inodorus, A. coronus* and *L. aureti* in the surf-zone adjacent to the estuary mouth.

Freshwater dominance and high flows would have resulted in low retention times and low phytoplankton and zooplankton production. Coupled with scouring and limited benthic invertebrate prey, this would have seen low numbers of adult and juvenile benthic invertebrate feeders similar to that in the present-day. Consequently, with the exception of *L. richardsonii,* the remainder of the fish assemblage would have been predominantly estuary-associated piscivorous predators namely *P. saltatrix, A. inodorous* and *L. amia.* In contrast to the present, these three species would have been more abundant in the absence of high fishing pressure and their countrywide overexploited state.

The existence of a number of different size classes for many estuary-associated and resident species suggests that the Orange Estuary is being utilised as a juvenile nursery in the present-day. This is likely to have been even more so under reference especially for exploited species.

Under reference and the present-day, migration of marine and estuarine species up and down the west coast may be facilitated by the Orange and the two other large estuaries on the west coast. Throughout the year, but especially during the summer upwelling months, species such as P*omatomus saltatrix, Argyrosomus inodorus, Lithognathus lithognathus* and *Lithognathus aureti* tend to be distributed within the warmer-water areas along the west coast (Lamberth et al., 2008). These warm areas are limited and tend to be in shallow bays, estuaries or warm-water plumes in the vicinity of estuary mouths. Hypothetically, the southward distribution of Angolan dusky kob *Argyrosomus coronus* and west coast steenbras *L. aureti,* both non-estuarine marine species, to as far as Langebaan Lagoon, may depend on the availability of warm-water refugia offered by estuary mouths and plumes. Southward movement is most likely during anomalous years when the barrier presented by the Luderitz upwelling cell breaks down or when there is a southwards intrusion of warm water during Benguela Niño years - the nett result being warmer coastal waters (Van der Lingen et al., 2006). Once upwelling resumes, populations of these species that have penetrated south will be confined to the limited warm-water areas provided by estuaries and shallow bays. Consequently, a reduction in estuarine flow may influence the distribution of these species by reducing the extent and availability of these refugia. A similar process could facilitate exchange between South African, Namibian and Angolan stocks of *Argyrosomus inodorus, Pomatomus saltatrix* and *Lichia amia*. All three of these species as well as *Lithognathus lithognathus* and *L. aureti*, are important commercial and/or recreational fish in the region.

3.10.3 Health of the fish component

On the whole, the current fish assemblage and the presence of estuarine residents and juveniles of estuarine-associated species such as *G. aestuaria, C. nudiceps, L. richardsonii* and *P. saltatrix* suggests that the Orange Estuary functions as a viable nursery area and refuge for juvenile and adult estuarine fish though perhaps not as well as under reference conditions. Historically, it was likely that estuarine and freshwater fish escaped floods and high flows by either swimming upstream or moving onto the inundated floodplain and saltmarshes or even into the adjacent surf-zone. Nowadays obstructions such as the dykes and causeway have removed much of this temporary refuge and the chances of being flushed from the system are higher and may even occur at slightly lower flows. Reduced inundation of the marginal and channel areas of the saltmarsh are also likely to have seen a reduction in habitat and numbers of benthic species such as the gobies *Caffrogobius nudiceps* and *C. saldhana* and pipefish *S. temminckii*. This is also likely to have greatly reduced the intertidal foraging area of the dominant species in the estuary, *L. richardsonii*. Higher flows in the winter months may have reduced the residence time and/or numbers of marine and estuarine dependent species entering the system whereas lower flows during the summer months may have seen fewer fish escaping cold upwelling events in the sea. Higher winter flows are also likely to have resulted in the freshwater species persisting in the estuary throughout winter whereas previously they would have moved back into the upper reaches in response to increased salinity.

The above assumptions are supported by an apparent increase in species composition and abundance over the last decade following a reduction in hydroelectric releases during winter and the partial removal of the causeway, the latter restoring much of the intertidal habitat previously lost to fish in the estuary.

Table 31. Similarity scores of fish in the present condition relative to the reference condition

Variable	***Change from Reference condition***	***Score***
Species richness	The Orange Estuary was freshwater dominated under reference but less so in the present-day. However, the fish assemblage (36 species) is similar to reference characterised by half being freshwater species, the estuary- associated component dominated by the benthic algal feeder (grazer) *L. richardsonii* and piscivorous predators and rarity of benthic invertebrate feeders. Freshwater component has the addition of two alien invasive species. Confidence: Medium	60
Abundance	*L. richardsonii* dominate (>90%) by mass and numerically under reference and the present-day. Recruitment and aggregations of piscivorous predators are smaller and less frequent than under reference, most likely due to reduced flow, fewer floods and overexploitation throughout their range. Juvenile nursery habitat much reduced by causeways and other obstructions in the estuary. Confidence: Medium	50
Community composition	Community composition as under reference, dominated by freshwater tolerant *L. richardsonii,* piscivorous predators and freshwater species. Lower numbers of piscivores will have seen less predation on *L. richardsonii* and other small fish in the system in the present-day. Confidence: Medium	60
Fish health score (minimum score) **Confidence: Medium**		**50**
% due to non-flow-related impacts Overexploitation throughout ranges of the dominant species and the impact of causeway, bridges and other obstructions on the recruitment, foraging and survival of juveniles in the estuary. Confidence: Medium		40

3.11 Birds

This section summarises the information supplied in the specialist report on birds of the estuary from 1980 to the present (Technical Report 33), and uses this to derive scores of the present state of the bird community.

3.11.1 Bird groups

For the purpose of understanding the most likely potential factors driving patterns in community structure and abundance, the birds recorded in the latest count have been grouped according to nine broad foraging guilds (Table 32).

Table 32. Major bird groups found in the Orange 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 and white-breasted cormorant.
Piscivorous wading birds	This group comprises the egrets, herons, ibises and spoonbill. Loosely termed piscivores, their diet varies in plasticity, with fish usually dominating, but often also includes other vertebrates, such as frogs, and invertebrates. The ibises were included in this group, though their diet mainly comprises invertebrates and is fairly plastic. They tend to be tolerant of a wide range of salinities. Wading piscivores prefer shallow water up to a certain species dependant wading depth.
Herbivorous waterfowl	This group is dominated by species that tend to occur in lower salinity or freshwater habitats and are associated with the presence of aquatic plants such as *Potamageton* and *Phragmites*. The group includes some of the ducks (e.g. southern pochard), and all the rallids (e.g. redknobbed coot, African purple swamphen). Some herbivorous waterfowl such as Egyptian goose probably feed in terrestrial areas away from the estuary and floodplain as well as in the estuary.
Omnivorous waterfowl	This group comprises ducks which eat a mixture of plant material and invertebrate food such as small crustaceans - yellow-billed duck, Cape teal, red-billed teal and Cape shoveller. Although varying in tolerance, these species are fairly tolerant of more saline conditions.
Benthivorous waders	This group includes all the waders (e.g. flamingo, greenshank, curlew sandpiper). These species feed on benthic macroinvertebrates in exposed and shallow intertidal areas. Invertebrate-feeding waders forage mainly on exposed sandbanks and mudflats as well as shallow inundated areas. A few resident species occur such as white-fronted plover, chestnut-banded plover and black-winged stilt.
Piscivorous gulls and terns	This group comprises the rest of the charadriiformes, and includes all the gull and tern species using the estuary. These species are primarily piscivorous, but also take invertebrates. Most are euryhaline, but certain tern species on the estuary tend to be associated with low salinity environments. Gulls and terns can be very abundant and use the estuary primarily for roosting
Piscivorous kingfishers	Three species of kingfishers are known to occur on the estuary in low numbers. They breed and perch on the river banks and prefer areas of open water with adjacent vegetation.
Piscivorous birds of prey	At Orange Estuary the African fish eagle and osprey are the only species in this group. The fish eagle is however not confined to a diet of fish, also taking other vertebrates and invertebrates, the osprey however is.
Other birds of prey	The marsh harrier has been recorded on the estuary, and feeds on small vertebrates such as mice and frogs.

3.11.2 Baseline description

A total of 52 species of water bird were seen in the estuary during the three-day site visit. This was the same as the average number of species recorded per count since 1980 (Anderson, 2006). The numbers of species recorded in summer is usually slightly more (by <10) than in winter.

In the most recent count (November 2012), a total of 2,647 waterbirds were recorded on the estuary, though the total number of birds might have been slightly higher, since some parts of the lower estuary could not be covered. Birds were concentrated towards the mouth, with 56% in the mouth and associated island and saltmarsh areas, and 27% in the rest of the area below the bridge, and 18% above the bridge.

The avifauna is dominated by benthivorous waders, followed by piscivorous gulls and terns, with these groups together comprising 64% of the birds on the estuary in November 2012 (Figure 8). Nevertheless, the avifaunal composition is relatively even, and most of the other groups described also make up significant components of the avifauna. The most abundant species were sandwich tern (430), Egyptian goose (266), little stint (219), Cape cormorant (187) and lesser flamingo (152).

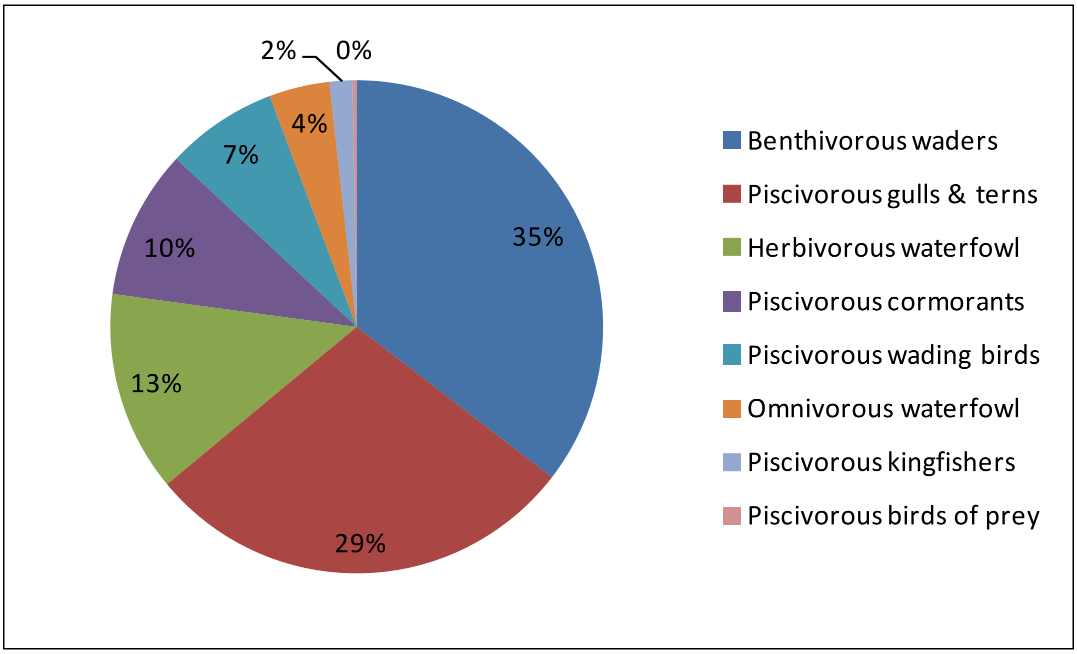


Figure 8. Avifaunal community structure in November 2012

3.11.3 Flow-related factors driving waterbird community structure and abundance

The community structure and abundance of birds in the estuary can be influenced by a range of abiotic factors which influence the suitability of the estuary according to the different feeding guilds of birds, these are summarised in Table 33. These factors are borne in mind, along with historical count data, in order to estimate the reference condition and predict changes under potential scenarios.

Table 33. Effect of flow-related abiotic characteristics and processes, as well as other biotic components on bird groupings

Abiotic factor	***Description***
Mouth condition	
	Cormorants and wading piscivores; Kingfishers and fish-eagle: Indirectly, through influence on water level and fish; closed mouth conditions affect availability of sandbanks and islands. Waterfowl: Indirectly, through influence on macrophytes. Waders, gulls and terns: Closed mouth conditions affect availability of sandbanks and islands.
Salinities	
	Waterfowl: Certain species of waterfowl prefer lower salinities.
Turbidity	
	Cormorants and wading piscivores: Negatively affects visibility for foraging. Kingfishers and fish-eagle: Negatively affects visibility for foraging. Waders, gulls and terns: Turbidity in the sea near the estuary mouth, determined by river flow, will negatively affect foraging by terns.
Intertidal area and saltmarsh	
	Waders, gulls and terns: Waders rely mostly on intertidal areas for feeding.
Sediment characteristics (including sedimentation)	
	Cormorants and wading piscivores: Islands in the mouth area are important habitat for cormorants and terns. Waders, gulls and terns: Most waders prefer medium to fine sand; a few prefer coarse sand.
Primary productivity	
	Cormorants and wading piscivores; Kingfishers and fish-eagle; Waterfowl; Waders, gulls and terns: Indirectly though influence on food supply.
Submerged macrophytes abundance	
	Waterfowl: Has positive influence on herbivorous waterfowl numbers
Abundance of reeds and sedges	
	Waterfowl: Has positive influence on some herbivorous waterfowl species
Abundance of zooplankton	
	Waterfowl: Assumed positive for some omnivorous species
Benthic invertebrate abundance	
	Waders, gulls and terns: Primary food source for invertebrate-feeding waders.
Fish biomass in the estuary	
	Cormorants and wading piscivores: Wading piscivores and certain cormorants will increase with increasing numbers of small to medium-sized fish.

3.11.4 Reference condition

Waterbird counts have been conducted at the estuary since 1980, but this post-dates most of the major dam developments that took place in the catchment area from 1938 to 1978. Since 1980, the number of species using the estuary has remained fairly stable (average 52), but the numbers of birds have decreased dramatically, particularly from 1980 to the early 1990s. Over 20,000 birds were recorded in summer counts in the 1980s (21,512 in January 1980 and between 20,563 and 26,653 in December 1985). Numbers fell below 10,000 in the mid-1990s, and fewer than 4,000 birds were recorded in the most recent count.

Counts suggest that current bird numbers are less than 25% of those in the 1980s. Given that freshwater inflows were already greatly reduced by then, and that marine fisheries had already had an impact on fish stocks along the west coast, it is likely that the numbers recorded in the 1980s were lower than in the reference condition.

3.11.5 Non-flow versus flow-related causes of changes since reference

Some of the observed declines in bird numbers are a result of external influences. The numbers of many species have declined globally, including common terns (Nisbet, 2002) and several species of Palearctic-breeding waders. At a regional scale, declines in the abundance of marine fish stocks are likely to have been responsible for declines in the populations of seabirds including cormorants and terns along the west coast of southern Africa. Nevertheless, physical habitat disturbance within the estuary is also likely to have contributed to the major declines in some species (Anderson et al., 2003), and decreased salinities as a result of reduced freshwater inflows are likely to have been responsible for declines in many species of waterfowl. The factors contributing to the changes in various waterbird groups are summarised in Table 34.

Table 34. Factors contributing to changes in major avifaunal groups

Change	*Flow-related causes*	*Other causes*
Loss of marine cormorants and terns	Regional population declines as a result of declines in marine fish stocks, also major disease events. Attracted to expanding breeding sites in Namibia.	Decrease in suitable island habitat near mouth, plus increased accessibility of the islands to predators, humans and livestock.
Decreased waterfowl		Change from freshwater dominated to estuarine. Open more in winter.
Decreased waders	Decreased productive intertidal and shallow water habitat as a result of causeway; reclamation. Global population declines. Human disturbance (minor).	Decreased productive intertidal and shallow water habitat as a result of bank stabilisation and colonisation by vegetation.
Increases of certain waterfowl		Regional population increases due to spread of anthropogenic habitats.

3.11.6 Health of the avifaunal component

Table 35. Similarity scores of birds in the present condition relative to the reference condition

Variable	*Change from natural*	*Score*
Species richness	Species richness has remained stable over 30 years; there is not likely to have been very much change instantaneous average species richness from the reference condition. Confidence: Medium	90

Variable	*Change from natural*	*Score*
Abundance	Numbers were at least four times higher in the 1980s, and are likely to have been even higher before that. Confidence: Medium	23
Community composition	Seabirds dominated the estuary in the past, using it as a roosting and breeding habitat; the proportion of these birds has diminished markedly. Waterfowl would have been relatively more common in the past than at present, because the system has changed from a freshwater dominated estuary to one which is more typically estuarine. Confidence: Medium	33
Bird health score (minimum score) **Confidence: Medium**		**23**
% impact due to non-flow-related impacts Global losses in numbers of migratory waders; regional decreases due to marine fish declines. In this case it is difficult to estimate to what extent some of the declines were caused by estuary changes verses external factors. Confidence: Low		65

3.12 Present ecological status

3.12.1 Overall estuary health score

The health scores allocated to the various abiotic and biotic health parameters for the Orange Estuary and the overall ecological conditions for the system under the present state are calculated from the overall health score (Table 36). The Orange Estuary has an overall health score of 51 relative to the natural condition, which translates into a *Largely modified* system with a PES of a D (summarised in Table 37). This is mostly attributed to the following factors:

- significant freshwater flow modification – both loss of floods and increase baseflows;
- lack of estuary mouth closure and resulting backflooding of saltmarshes with fresher water;
- road infrastructure such as the old causeway crossing the saltmarshes and old bridge supports;
- nutrient input from catchment downstream of Vioolsdrift;
- gill netting of indigenous fish species and considerable fishing effort at the mouth on both sides of the estuary;
- riparian infrastructure - levees preventing backflooding;
- mining activities;
- wastewater disposal (sewage and mining return flow).

The estuary health score for the Orange Estuary under present conditions and the study confidence levels are provided below in Table 36.

Table 36. The estuary health score for the Orange Estuary, the estimated estuary health score with non-flow-related impacts removed, and confidence levels

Variable	***Weight***	***Health score***	***Health score net of 50% of non-flow-related impacts***	***Confidence***
Hydrology	25	44	44	Low/Medium
Hydrodynamics and mouth condition	25	70	70	Low
Water quality	25	53.2	53.2	Medium
Physical habitat alteration	25	78	87	Medium
Habitat (abiotic) health score		**61**	**63**	**Medium**
Microalgae	20	40	46	Low
Macrophytes	20	50	75	Medium
Invertebrates	20	45	51	High
Fish	20	50	70	Medium
Birds	20	23	65	Medium
Biotic health score		**42**	**61**	**Medium**
Estuary health score		**51**	**62**	**Medium**
Present ecological status		**D**	**C**	

Table 37. Present ecological state scores and descriptions

Estuary health 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

3.12.2 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 62, which would raise the health status to a Moderately modified estuary - C category. This suggests that non-flow impacts have played a significant 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 freshwater flows to the estuary, specifically the increase in baseflows which is hindering mouth closure and elevated nutrient levels as a result of poor agricultural practises. Of the non-flow-related impacts, the road infrastructure (e.g. old cause way) crossing the saltmarshes, gill netting in the estuary and the levees were found to be the most important factors influencing the health of the system.

3.12.3 Overall confidence

Confidence levels were medium for most of the abiotic components. The fact that hydrology and hydrodynamics were of a medium level meant that they affected the confidence of all subsequent components. Four of the biotic components had enough data to yield medium to high confidence assessments. The overall confidence of the study was 'medium' (Table 36).

The implications of this are that:

- One has to be cautious and apply the precautionary principle in setting the environmental flow requirement for the Orange Estuary; and
- Efforts should be made to collect baseline and monitoring data that will help to address some key gaps in understanding.

The key gaps relate to the abiotic aspects of the estuary. The primary gap is caused by the lack of good hydrology data, mouth condition information and water quality information in the estuary.

3.13 Importance of the Orange Estuary

Following South Africa's accession to the Ramsar Convention, the Orange Estuary was designated a Ramsar Site, i.e. a wetland of international importance, on 28/06/1991 (Cowan, 1995). Namibia ratified the Ramsar Convention in 1995, after which the designated area was enlarged and the Namibian part of the wetland was designated too. In September 1995 the South African Ramsar Site was placed on the Montreux Record (a list of Ramsar Sites around the world that are in a degraded state) as a result of a belated recognition of the severely degraded state of the saltmarsh on the south bank (CSIR, 2001). The implication is that the Orange Estuary may lose its status as a Ramsar Site unless the condition of the saltmarsh can be restored.

The Namibian section of the Orange Estuary was recently included in the proclamation of the Sperrgebiet National Park in Namibia. However, the section in South Africa is still in the process of being formally protected through legislation. The Orange Estuary also forms part of the core set of estuaries in need of formal protection to achieve biodiversity targets in the region (Turpie et al., 2012, Van Niekerk and Turpie, 2012). The Orange Estuary is also one of only two estuaries on the Namibian coast, the other being the Kunene River mouth.

Turpie et al. (2002) ranked the Orange as the seventh most important system in South Africa in terms of conservation importance. The prioritisation study calculated conservation importance on the basis of size, habitat diversity, zonal type rarity and biodiversity importance.

Estuary importance is an expression of the value of a specific estuary to maintaining ecological diversity and functioning of estuarine systems on local and wider scales. The estuary importance score takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity importance and functional importance of the estuary into account. The biodiversity importance score is in turn based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices.

The rationale for selecting these variables, as well as further details on the estuary importance index, are discussed in Turpie et al. (2002) and updated in *Resource Directed Measures for protection of water resources; Volume 5: Estuarine component* (DWA, 2008).

The importance scores ideally refer to the system in its natural condition. The scores have already been determined for all South African estuaries, apart from the functional importance score, which is derived by specialists in a workshop (DWA, 2008). For this project, the functional importance score (see Table 38) was derived at a specialist workshop held in Stellenbosch in March 2013.

Table 38. Estimation of the functional importance score for the Orange Estuary

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

In this case, the functional importance of the estuary was deemed to be very high (100), since the sediment supply from the Orange River catchment feeds the beaches to the north of the mouth (Table 39). The sediment input from the river is also very important for flatfish in the nearshore environment in the vicinity of the mouth as it provides the habitat on which they depend.

The estuary importance for the Orange Estuary (Table 39), based on its present state, was estimated to be 99 out of 100 and is therefore rated as highly important (Table 40).

Table 39. The importance scores for the Orange Estuary

Criterion	***Weight***	***Score***
Estuary size	15	100
Zonal rarity type	10	90
Habitat diversity	25	100
Biodiversity importance	25	99
Functional importance	25	100
Estuary importance score		**99**

Table 40. Estuary importance scores and significance

Importance score	***Description***

81 – 100	**Highly important**
61 – 80	Important
0 – 60	Of low to average importance

3.14 Recommended ecological category

The 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 estuary health score (derived from the estuary health index), PES and minimum REC is set out in Table 41.

Table 41. Relationship between the estuary health score, PES and minimum REC

Estuary health score	***PES***	***Description***	***Minimum REC***
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 importance and the level of protection, or desired protection, of a particular estuary as shown below in Table 42.

Table 42. Estuary protection status and importance, and the basis for assigning a recommended ecological category

Protection status and importance	***REC***	***Policy basis***
Protected area Desired protected area	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 EC.
Important	PES + 1, min C	Important estuaries should be in an A, B or C EC.
Of low to average importance	PES, min D	Estuaries to remain in a D category.

* Best attainable state

The PES for the Orange Estuary is a D. The estuary is rated as 'highly important', it is a designated Ramsar Site, a Protected Area on the Namibian side; and a desired protected area in the South African Biodiversity Plan for the 2011 National Biodiversity Assessment (Turpie et al., 2012). The REC for the estuary is therefore an A or its best attainable state which is estimated as a category C.

Remedial actions required to improve the health of the system include:

- decreasing the winter baseflows sufficiently to allow for mouth closure and related backflooding of the saltmarshes with brackish water to reduce soil salinities;

- controlling the fishing effort on both the South African and Namibian side through increased compliance and law enforcements. This also required the alignment of the fishing regulations (e.g. size and bag limits) and management boundaries on both side of the transboundary estuary.
- removal of the remnant causeway that still transects the saltmarshes to improve circulation during high flow and floods events. This will also assist with increasing the water exchange into the lower marsh areas;
- decreasing nutrient input from the catchment (focussing on the river reach downstream of Vioolsdrift), through improved agricultural practices;
- reduce/control destruction of habitat (e.g. wind-blown dust from mining activities, grazing, reducing number of access roads);
- reduce/remove grazing and hunting pressures.

4 Flow scenarios

4.1 Description of the scenarios

The following scenarios (Sc) were evaluated as part of this study (Table 43).

Table 43. Summary of the scenarios evaluated in this study

Scenario	*MAR (Mm^3/a*)*	*% Remaining*	*Orange River drivers*	*Fish River drivers*
Sc OF 2	4 411.05	39	Metolong Dam, Tandjieskoppe, acid mine drainage (AMD) treated.	Neckartal Dam. Increase in Naute Dam irrigation.
Sc OF 3	4 418.26	39.1	Metolong Dam, Tandjieskoppe, AMD treated.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Sc OF 4	4 469.77	39.5	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Sc OF 5	3 837.16	33.9	Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released, Polihali Dam, Vioolsdrift Balancing Dam (small). Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.
Sc OF 6	2 326.26	20.6	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam. Increase in Naute Dam irrigation.
Sc OF 7	2 329.31	20.6	Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, Large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams.	Neckartal Dam with EFR release. Increase in Naute Dam irrigation.

Note that for simplicity sake, scenarios will here after only refer to the NUMBER and exclude OF. OF refers to the Orange Fish and indicates that each scenario includes drivers from both systems.

Flows and abiotic states under Sc 2, 3, 4, 6 and 7

A summary of the mean monthly flows is presented in Tables 44 to 50, and Figures 9 to 14. 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 44. Summary of the mean monthly flow (in m³/s) distribution under the various scenarios

Scenarios	Duration	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2	10%	141.0	259.1	267.2	514.8	1760.6	771.0	720.3	219.4	106.4	47.8	61.2	42.6
	20%	7.0	13.3	90.7	266.2	915.1	473.9	409.2	161.9	44.0	21.4	23.9	7.2
	30%	5.7	9.8	27.8	115.1	263.4	392.7	155.7	109.0	16.5	9.5	7.3	6.7
	40%	5.5	7.4	8.2	22.0	61.3	200.9	114.8	44.0	10.5	7.2	6.9	6.6
	50%	5.3	6.2	5.6	4.6	31.8	100.1	55.0	20.5	9.2	7.1	6.7	6.6
	60%	5.2	6.0	4.3	4.2	6.9	36.9	27.5	12.7	7.7	6.7	6.6	6.6
	70%	5.1	5.7	4.2	4.2	3.9	15.0	18.3	10.9	7.5	6.6	6.5	6.5
	80%	5.0	5.5	4.2	4.2	3.6	9.5	13.7	10.1	6.3	6.5	6.5	6.5
	90%	4.9	5.2	4.1	3.3	3.5	8.9	12.3	8.8	5.6	5.4	6.4	6.5
	99%	3.2	2.6	1.3	0.8	1.0	6.9	11.5	8.5	5.5	5.2	6.1	4.8
3	Duration	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	10%	141.0	259.1	269.1	517.0	1767.8	768.7	724.4	220.4	106.4	48.0	61.2	42.6
	20%	7.0	13.3	94.8	267.9	916.3	464.9	348.1	162.5	44.0	21.4	24.0	7.2
	30%	5.8	9.9	29.0	115.1	262.2	387.6	156.5	109.1	16.9	9.9	7.3	6.7
	40%	5.5	7.4	10.8	22.0	63.4	207.7	116.2	44.0	10.7	7.6	6.9	6.6
	50%	5.3	6.2	5.7	7.0	31.4	101.2	54.6	18.7	9.4	7.1	6.7	6.6
	60%	5.2	6.0	4.4	4.3	11.3	40.7	31.4	12.8	8.0	6.7	6.6	6.6
	70%	5.1	5.8	4.2	4.2	5.4	16.0	18.5	11.5	7.5	6.6	6.5	6.5
	80%	5.0	5.6	4.2	4.2	3.8	12.8	15.7	10.6	7.1	6.5	6.5	6.5
	90%	4.9	5.3	4.1	3.4	3.5	10.4	13.5	9.1	5.6	5.4	6.4	6.5
	99%	3.2	3.5	1.9	2.0	2.7	8.2	11.5	8.7	5.5	5.2	6.1	5.6
4	Duration	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	10%	54.8	258.4	151.1	518.2	1544.7	646.5	571.0	158.5	63.2	30.3	31.3	30.2
	20%	34.0	74.5	108.6	162.3	847.2	459.9	278.5	128.9	48.7	29.0	29.1	29.8
	30%	32.9	71.0	82.2	105.7	216.5	295.1	139.5	76.1	46.5	28.3	28.5	28.9
	40%	31.5	69.4	79.0	94.7	138.3	177.7	116.7	66.7	42.9	27.2	26.5	28.2
	50%	28.8	66.7	62.6	84.6	99.4	133.6	104.7	60.4	38.9	26.2	24.1	25.0
	60%	25.3	63.4	52.8	62.1	77.6	102.6	90.8	55.4	35.2	25.2	20.2	19.4
	70%	17.7	41.3	42.2	35.6	51.5	63.6	57.0	44.5	21.3	19.1	15.3	10.5
	80%	9.9	22.1	23.7	25.5	39.0	45.3	40.1	13.2	11.3	11.2	8.5	3.8
	90%	4.1	8.8	18.8	18.1	34.1	38.6	16.0	7.7	5.9	6.7	4.7	0.0

Scenarios													
	99%	0.0	0.0	11.0	9.6	29.2	28.4	8.2	5.9	4.3	3.8	2.6	0.0

5	Duration	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	10%	21.4	252.3	148.5	430.5	1309.1	625.3	403.8	139.7	54.3	25.5	19.8	14.6
	20%	20.6	54.9	82.9	128.2	731.2	385.1	271.2	85.0	42.9	23.5	17.7	13.8
	30%	18.2	53.2	64.1	83.3	163.6	256.3	107.9	68.4	40.9	22.8	17.1	13.5
	40%	15.9	49.8	55.7	68.2	113.3	161.2	101.3	60.3	37.5	21.8	16.0	12.6
	50%	12.0	46.3	43.0	56.4	79.5	112.5	87.7	54.1	34.4	20.7	13.4	11.2
	60%	5.7	39.5	29.8	35.9	58.3	73.2	79.4	49.1	30.2	19.7	11.7	5.6
	70%	0.0	20.5	23.3	13.9	30.7	49.2	45.7	36.7	15.7	13.6	8.4	0.8
	80%	0.0	7.7	6.2	5.7	21.2	30.6	28.8	22.7	8.2	8.7	5.4	0.0
	90%	0.0	0.5	1.7	1.1	15.8	24.2	6.8	2.6	2.3	2.1	0.3	0.0
	99%	0.0	0.0	0.0	0.0	9.8	17.1	1.7	0.0	0.0	0.0	0.0	0.0

6	Duration	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	10%	0.1	134.0	98.8	367.9	952.8	471.6	307.5	83.2	20.8	1.7	2.0	3.0
	20%	0.0	0.0	12.5	96.0	588.7	293.3	212.1	31.1	2.8	0.0	0.0	2.9
	30%	0.0	0.0	0.0	1.9	49.2	191.9	67.2	10.8	0.1	0.0	0.0	2.9
	40%	0.0	0.0	0.0	0.0	7.9	69.1	22.8	0.9	0.0	0.0	0.0	2.9
	50%	0.0	0.0	0.0	0.0	0.0	5.4	3.2	0.0	0.0	0.0	0.0	2.9
	60%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
	70%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
	80%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
	90%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
	99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1

7	Duration	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	10%	0.5	134.0	98.8	368.8	959.1	469.9	311.5	83.5	21.0	2.1	2.0	3.0
	20%	0.0	0.0	12.5	96.0	588.7	294.6	212.1	31.9	3.5	0.1	0.0	2.9
	30%	0.0	0.0	0.7	7.0	54.4	182.7	63.2	10.0	0.7	0.0	0.0	2.9
	40%	0.0	0.0	0.0	1.8	15.2	61.4	17.7	1.4	0.0	0.0	0.0	2.9
	50%	0.0	0.0	0.0	0.0	3.0	11.8	6.3	0.5	0.0	0.0	0.0	2.9
	60%	0.0	0.0	0.0	0.0	0.0	4.7	2.1	0.2	0.0	0.0	0.0	2.9
	70%	0.0	0.0	0.0	0.0	0.0	2.8	0.9	0.0	0.0	0.0	0.0	2.9
	80%	0.0	0.0	0.0	0.0	0.0	0.7	0.4	0.0	0.0	0.0	0.0	2.9
	90%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
	99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7

Table 45. Simulated mean monthly inflows (in m³/s) into the Orange Estuary under Sc 2

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Closed
1920	5.07	5.62	4.25	13.49	16.82	25.55	51.13	207.54	7.66	151.85	43.26	6.62	1
1921	5.21	8.47	4.37	4.26	4.91	8.38	13.68	10.64	7.49	6.58	6.50	6.59	3
1922	3.00	5.64	4.15	4.21	3.42	8.77	12.89	8.72	5.82	5.39	6.09	6.56	4
1923	4.92	8.07	28.83	1353.35	1031.28	582.14	329.74	155.67	49.33	7.07	24.88	6.75	1
1924	6.51	391.61	663.18	3.33	4.70	165.92	140.25	167.38	58.12	6.79	41.34	6.57	2
1925	5.03	6.04	4.25	4.21	3.71	67.46	73.03	167.04	34.44	6.69	6.62	7.15	3
1926	5.52	825.13	200.52	887.14	1397.52	261.99	13.86	10.75	7.49	6.58	6.52	6.55	0
1927	4.92	5.69	8.21	6.16	39.24	16.08	12.43	19.37	11.58	13.01	6.75	6.56	1
1928	5.24	2.85	8.04	171.98	1525.24	409.56	63.10	12.82	7.55	7.94	128.96	47.66	1
1929	7.50	191.53	121.98	6.17	31.69	43.36	319.31	191.87	43.97	6.64	6.54	6.84	0
1930	5.32	9.99	128.26	280.70	551.80	136.10	135.82	13.79	8.72	6.85	6.74	6.57	0
1931	5.30	5.07	4.15	4.21	44.93	145.72	48.88	28.47	10.68	6.90	7.10	6.55	2
1932	13.94	7.93	333.98	167.50	3.69	9.02	953.12	1249.61	304.83	399.26	147.70	37.51	1
1933	408.49	1715.8	1332.5	366.51	**2109.00**	463.62	25.10	10.86	42.06	7.64	6.93	6.61	0
1934	91.08	25.73	4.15	4.81	3.77	275.68	70.36	10.53	7.45	7.19	6.64	6.56	3
1935	5.68	5.70	4.15	4.24	4.06	22.28	46.93	21.54	9.44	6.62	6.54	6.98	3
1936	5.29	5.63	4.16	3.68	3.55	12.47	15.14	9.16	5.64	5.55	6.52	6.55	3
1937	5.23	5.46	5.42	3.50	15.98	924.00	737.94	41.30	7.85	6.69	6.57	6.55	1
1938	5.13	5.86	4.26	0.73	0.89	9.92	12.90	8.79	5.52	5.18	6.11	6.56	3
1939	4.96	5.11	4.16	4.21	47.18	339.97	522.96	834.80	201.83	54.79	208.10	18.15	3
1940	6.99	5.65	24.25	21.96	3.11	9.10	12.95	11.36	9.35	7.12	6.56	6.55	1
1941	5.25	5.23	4.15	4.21	61.34	95.41	13.25	8.75	5.52	85.92	33.98	6.60	2
1942	5.33	6.85	4.23	4.21	64.67	100.39	58.88	12.96	7.41	6.60	6.99	6.69	2
1943	5.13	7.12	43.02	18.61	1.01	712.22	592.05	48.75	9.34	7.08	6.78	6.58	1
1944	4.96	5.55	4.22	173.10	**2064.51**	504.24	155.04	64.67	10.47	8.70	6.99	6.69	2
1945	5.60	9.64	5.72	4.09	208.36	1249.20	724.76	113.63	10.47	6.68	6.60	6.55	1
1946	5.31	6.38	959.54	496.56	49.06	159.34	64.81	12.74	9.01	21.37	7.02	1579.1	0
1947	1581.6	408.43	90.68	863.26	185.62	9.00	46.38	201.40	91.24	6.56	6.50	6.55	0
1948	4.90	5.78	10.80	25.85	6.76	9.04	12.89	310.31	119.06	82.58	6.51	6.55	1
1949	5.10	6.10	4.45	4.33	70.04	200.90	114.76	44.86	9.57	6.69	7.08	6.55	2
1950	5.14	5.99	112.70	77.01	3.72	434.76	669.16	231.33	217.35	106.05	29.13	6.59	1
1951	4.91	11.02	38.25	4.25	946.84	321.89	18.00	87.67	10.96	7.24	7.42	6.92	2
1952	4.95	8.73	5.87	387.10	449.82	596.68	741.81	134.12	13.29	40.86	6.88	6.72	1
1953	5.59	103.81	94.06	4.29	3.54	141.64	250.63	8.79	5.63	5.21	6.38	7.71	2
1954	191.00	326.73	126.93	125.84	3.78	34.68	27.48	11.73	7.15	6.65	6.58	6.55	1

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1955	5.03	5.89	3.89	129.39	532.10	6.76	11.46	9.23	7.35	6.51	6.50	6.55	1
1956	5.12	5.32	4.18	266.15	1648.30	414.14	1242.54	656.98	276.65	33.49	6.94	6.65	1
1957	5.54	3.49	4.31	4.21	3.54	84.85	43.33	54.86	19.69	6.75	6.63	6.55	4
1958	5.25	2.03	0.73	4.24	23.54	14.76	22.19	15.23	8.34	6.67	6.66	6.55	3
1959	5.35	5.25	4.15	4.22	7.55	10.63	11.85	8.84	5.86	5.18	6.80	6.55	2
1960	3.32	5.99	5.21	2.07	5.82	9.50	14.72	11.94	7.64	14.01	9.32	6.62	2
1961	5.43	5.40	4.15	92.34	117.12	473.95	409.23	104.46	10.96	6.64	6.57	6.55	1
1962	4.96	5.53	4.15	4.21	23.38	36.87	30.70	13.34	7.50	7.22	6.59	6.58	3
1963	6.34	6.18	13.53	1173.12	**3640.63**	**2246.05**	636.67	148.54	58.42	12.65	143.57	10.20	0
1964	5.72	141.55	354.46	418.69	1991.65	839.84	285.29	28.81	10.11	10.30	6.69	6.59	0
1965	5.02	13.29	763.90	**2074.43**	**2898.77**	**3200.98**	1448.70	539.50	145.84	32.52	11.82	4.91	1
1966	705.51	531.34	43.97	104.30	871.94	829.80	146.27	36.75	7.81	5.88	6.28	6.43	0
1967	5.69	9.89	5.69	482.64	318.42	468.21	899.81	165.44	22.47	10.37	6.79	6.66	0
1968	5.80	5.49	4.17	4.06	40.83	27.37	12.03	8.64	6.19	7.16	65.93	65.30	2
1969	30.70	6.08	4.19	4.21	31.81	51.73	85.91	11.02	7.17	6.32	85.46	68.69	2
1970	15.52	12.07	6.12	27.11	365.72	375.78	18.69	44.04	93.79	6.53	180.05	101.99	0
1971	5.24	6.91	6.96	4.22	3.61	8.84	23.65	11.75	6.27	8.60	6.65	6.55	2
1972	5.54	5.78	1.53	4.38	3.55	8.87	11.49	10.13	6.02	5.18	6.00	6.59	3
1973	5.32	10.82	4.31	2.56	3.54	8.02	12.13	8.58	5.54	5.48	6.55	6.55	3
1974	5.47	5.92	4.15	3.23	2.92	8.89	14.00	8.73	5.52	5.18	6.49	6.55	3
1975	8.70	12.08	39.05	32.03	2.65	12.48	19.50	10.17	29.10	12.40	6.08	6.58	1
1976	5.46	6.04	4.15	4.21	1.75	6.97	11.57	8.47	5.52	5.39	6.09	83.78	3
1977	725.62	129.51	11.62	0.77	**3163.96**	**3428.50**	715.90	147.42	75.36	26.79	23.95	320.75	1
1978	199.26	162.33	373.62	533.13	1873.00	499.60	214.69	128.20	148.47	55.38	56.40	6.58	0
1979	4.93	6.15	11.76	4.25	6.43	243.73	489.14	161.93	37.86	33.73	6.52	6.55	2
1980	4.91	5.11	4.97	217.41	915.14	704.59	115.07	10.64	9.50	7.59	7.82	11.16	2
1981	612.80	361.61	35.57	2.99	3.54	7.02	11.57	8.67	5.52	5.20	6.52	6.72	2
1982	5.21	6.27	4.15	4.26	6.92	9.96	15.65	9.78	6.33	5.83	6.53	6.55	2
1983	6.08	7.38	4.20	14.01	186.79	99.86	156.35	42.10	7.49	7.08	6.53	6.55	1
1984	4.94	5.54	4.15	2.44	3.62	15.19	21.59	12.08	8.35	7.88	7.89	7.19	4
1985	5.84	8.32	26.70	725.68	1425.94	422.64	126.20	239.56	7.60	25.46	12.31	4.65	1

State 1 **0.00** **State 2** **0.0 – 5** **State 3** **5 – 20** **State 4** **20 – 50** **State 5** **>50** **Flood** **> 2000**

Table 46. Simulated mean monthly inflows (in m³/s) into the Orange Estuary under Sc 3

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1920	5.07	5.62	4.25	14.51	20.78	34.33	49.09	207.68	7.66	151.85	43.27	6.62	1
1921	5.22	8.48	4.37	4.26	4.91	9.22	14.32	10.64	7.50	6.58	6.50	6.59	3

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1922	3.00	5.64	4.15	4.21	3.97	9.54	13.27	8.72	5.82	5.39	6.09	6.56	4
1923	4.92	8.07	31.24	1337.5	1031.31	582.15	329.75	155.67	49.47	7.07	24.88	6.76	1
1924	6.51	391.62	663.90	5.15	11.31	170.94	142.56	168.46	58.28	6.79	41.34	6.57	0
1925	5.03	6.04	4.25	4.21	3.71	81.34	65.09	167.75	34.81	6.69	6.62	7.15	3
1926	5.52	825.13	200.52	889.41	1371.31	262.00	15.11	10.75	7.49	6.58	6.52	6.55	0
1927	4.92	5.69	8.21	16.36	42.41	16.44	15.70	15.55	11.13	13.09	6.75	6.56	1
1928	5.24	5.86	12.40	173.11	1514.98	399.39	63.12	13.06	7.99	8.47	129.28	47.66	0
1929	7.50	191.53	121.98	6.93	41.22	51.30	320.33	191.87	43.97	6.64	6.54	6.86	0
1930	5.65	9.99	128.26	281.07	553.00	136.64	135.82	13.79	8.72	6.85	6.74	6.57	0
1931	5.30	5.07	4.15	4.21	25.28	143.20	48.89	28.47	11.40	6.90	7.10	6.55	2
1932	13.94	7.93	337.63	172.04	5.40	11.35	958.81	1251.8	304.83	399.26	147.70	37.51	0
1933	408.49	1715.8	1337.5	369.79	**2098.01**	464.92	25.66	10.86	42.06	7.64	6.93	6.61	0
1934	91.08	25.73	4.15	4.81	3.77	275.68	70.44	10.63	7.45	7.19	6.64	6.56	3
1935	5.68	5.70	5.07	7.08	4.30	22.66	47.76	21.83	9.44	6.62	6.54	6.98	1
1936	5.29	5.63	4.16	3.68	3.55	12.77	17.00	9.43	5.64	5.55	6.52	6.55	3
1937	5.23	5.46	5.42	3.50	15.98	924.00	738.70	41.83	7.85	6.69	6.57	6.55	1
1938	5.13	5.86	4.26	1.91	2.76	15.38	17.91	9.18	5.65	5.31	6.11	6.56	3
1939	4.96	5.11	4.16	4.21	63.36	287.95	522.96	834.81	202.36	55.13	208.10	18.15	3
1940	6.99	5.66	24.25	21.96	7.08	13.40	13.39	11.69	9.37	7.13	6.56	6.55	0
1941	5.25	5.23	4.29	4.21	62.98	83.49	14.47	8.99	5.52	85.92	33.98	6.60	2
1942	5.33	6.85	4.23	4.21	63.38	100.40	58.90	13.62	7.41	6.60	6.99	6.69	2
1943	5.13	7.12	45.10	20.21	3.07	705.27	592.06	48.76	9.87	7.20	6.78	6.58	1
1944	4.96	5.55	4.22	181.15	**2072.81**	502.43	156.72	64.67	11.32	9.42	6.99	6.69	2
1945	5.60	9.87	6.99	9.52	182.98	1249.21	724.77	113.64	10.69	7.37	6.85	6.55	0
1946	5.31	6.38	959.54	497.60	53.83	152.31	64.83	12.75	9.42	21.42	7.02	1579.2	0
1947	1581.63	408.43	95.73	867.23	188.78	11.26	47.09	201.40	91.24	6.56	6.50	6.55	0
1948	4.90	5.78	10.80	25.85	7.36	10.39	13.80	310.31	119.06	82.58	6.51	6.55	1
1949	5.10	6.10	4.45	4.33	70.66	207.73	118.08	45.34	9.57	6.69	7.08	6.55	2
1950	5.14	5.99	112.70	77.01	3.72	435.08	671.95	233.19	218.07	106.15	29.13	6.59	1
1951	4.91	11.02	38.25	4.51	951.91	325.88	18.23	87.69	10.96	7.24	7.42	6.92	2
1952	4.95	8.73	5.87	398.72	397.64	596.69	741.81	134.13	13.54	40.86	6.88	6.72	1
1953	5.60	104.45	94.81	4.29	3.54	141.64	250.63	8.79	5.63	5.21	6.38	7.71	2
1954	191.00	326.73	126.93	125.84	4.15	37.66	31.44	12.50	7.15	6.65	6.58	6.55	1
1955	5.03	5.89	3.89	129.39	535.13	9.59	13.56	10.01	7.35	6.51	6.50	6.55	1
1956	6.02	6.31	4.20	267.86	1652.53	425.02	1253.7	658.48	277.65	33.49	6.95	6.66	1
1957	5.55	4.34	5.66	4.21	3.54	91.93	50.30	55.69	20.28	6.76	6.63	6.55	3
1958	5.25	2.03	2.09	4.24	31.01	23.02	24.35	15.29	8.34	6.67	6.66	6.55	3
1959	5.35	5.25	4.15	4.22	7.55	10.89	11.86	8.84	5.86	5.18	6.80	6.55	2

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1960	3.32	5.99	5.21	2.07	12.28	15.35	15.61	11.94	7.64	14.01	9.32	6.62	2
1961	5.43	5.40	4.15	103.31	128.83	436.13	348.10	104.47	11.22	6.64	6.57	6.55	1
1962	4.96	5.53	4.15	4.21	23.38	40.74	35.21	13.64	7.50	7.22	6.59	6.58	3
1963	6.34	6.18	13.53	1164.2	**3640.64**	**2246.06**	636.68	148.54	58.43	13.64	143.96	10.20	0
1964	5.72	141.55	354.62	420.54	1992.86	836.31	283.68	29.57	10.11	10.30	6.69	6.59	0
1965	5.02	13.29	763.90	**2074.17**	**2898.79**	**3200.99**	1448.7	539.51	145.84	32.53	11.83	6.08	0
1966	706.44	531.34	43.97	104.30	870.87	829.83	146.28	36.77	8.24	6.19	6.28	6.43	0
1967	5.69	9.89	5.69	482.64	331.81	454.59	899.83	165.68	22.48	10.37	6.79	6.66	0
1968	5.80	5.49	4.17	6.61	37.73	27.38	12.67	9.41	8.00	7.95	65.93	65.30	1
1969	30.70	6.08	4.19	4.21	31.81	55.81	77.89	11.66	7.17	6.32	85.46	68.69	2
1970	15.52	12.07	6.12	27.11	365.72	375.78	18.69	44.04	93.79	6.53	180.05	101.99	0
1971	5.24	6.91	6.96	4.22	3.61	8.84	23.65	11.75	6.27	8.60	6.65	6.55	2
1972	5.54	5.78	1.53	4.38	3.55	8.87	11.49	10.13	6.02	5.18	6.00	6.59	3
1973	5.32	10.82	5.19	2.86	3.54	12.43	15.81	8.89	5.54	5.48	6.55	6.55	2
1974	5.47	5.92	4.15	3.23	5.31	14.26	16.46	8.84	5.52	5.18	6.49	6.55	2
1975	8.70	12.08	41.86	34.05	3.88	15.58	22.87	10.86	29.21	12.40	6.08	6.58	1
1976	5.46	6.04	4.15	4.21	2.62	10.48	13.20	9.17	5.52	5.39	6.09	83.78	3
1977	725.62	129.51	11.62	2.60	**3170.74**	**3439.84**	723.95	148.18	75.36	26.79	23.95	320.76	1
1978	199.27	162.33	373.62	536.36	1883.16	505.41	215.51	128.70	148.48	55.38	56.40	6.58	0
1979	4.93	6.15	11.76	4.25	6.43	243.73	492.09	162.52	37.86	33.73	6.52	6.55	2
1980	4.91	5.11	4.97	217.41	916.33	707.61	116.18	10.69	9.50	7.59	7.82	11.41	2
1981	613.09	361.91	36.16	2.99	3.54	7.02	11.57	8.67	5.52	5.20	6.52	6.72	2
1982	5.21	6.27	4.15	4.26	6.92	11.10	18.37	11.31	6.33	5.83	6.53	6.55	2
1983	6.08	7.38	4.20	14.27	192.53	101.94	156.36	42.10	7.49	7.08	6.53	6.55	1
1984	4.94	5.54	4.15	2.44	3.62	15.19	21.59	12.08	8.35	7.88	7.89	7.19	4
1985	5.84	8.32	26.70	726.87	1439.44	428.51	126.96	240.09	7.62	25.46	12.31	4.65	1

State 1	**0.00**	**State 2**	**0.0 – 5**	**State 3**	**5 – 20**	**State 4**	**20 – 50**	**State 5**	**>50**	**Flood**	**> 2000**

Table 47. Simulated mean monthly inflows (in m³/s) into the Orange Estuary under Sc 4

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Closed
1920	12.85	8.64	17.94	86.57	90.19	81.14	143.38	74.95	25.52	29.08	29.14	8.82	0
1921	22.00	68.95	28.78	17.43	101.94	69.13	13.92	6.05	5.40	6.96	2.65	19.00	1
1922	0.00	22.11	24.38	0.00	24.22	19.51	3.73	6.15	4.00	3.50	2.58	0.00	7
1923	0.00	78.30	113.08	804.34	618.67	550.12	319.86	149.09	48.65	28.38	29.36	19.00	1
1924	32.23	330.22	664.52	31.30	45.07	137.68	112.16	161.07	54.54	25.48	29.27	29.10	0
1925	9.14	12.26	23.71	62.10	51.50	140.22	105.28	154.12	48.30	26.63	20.50	0.00	1
1926	31.50	822.35	176.85	616.71	1371.76	257.02	28.38	7.73	9.80	11.17	5.66	0.00	1
1927	8.14	0.00	60.68	94.66	153.41	66.16	91.20	67.29	50.08	28.16	28.69	21.65	1
1928	33.33	47.63	80.07	104.28	912.09	357.22	62.03	49.69	38.16	29.43	117.43	32.11	0
1929	33.35	188.95	119.13	27.89	77.63	152.82	117.47	128.90	47.94	26.54	17.81	30.05	0
1930	30.61	73.30	125.42	277.46	412.48	131.66	125.94	46.94	8.00	24.27	20.20	21.00	0
1931	31.53	11.89	18.56	92.65	130.28	264.43	119.08	61.65	23.58	18.72	28.67	28.59	0
1932	33.07	70.14	114.13	100.67	35.52	50.60	513.36	1282.50	331.00	425.50	100.00	26.00	0
1933	400.00	1691.1	1327.20	371.01	**2098.69**	459.94	48.47	13.90	26.40	28.16	25.05	29.90	0
1934	72.98	62.81	17.69	16.27	39.99	269.44	94.01	39.96	36.35	19.32	4.00	0.00	2
1935	4.14	8.20	17.86	103.08	119.88	108.09	83.58	75.57	48.61	25.74	4.00	0.00	3
1936	32.72	64.63	23.68	25.47	52.25	45.36	82.39	55.38	35.15	25.20	10.39	29.81	0
1937	32.14	53.42	81.45	91.57	82.44	499.74	278.48	58.25	19.12	5.11	3.70	0.00	2
1938	19.18	16.30	17.69	28.41	37.83	47.38	20.25	44.67	21.27	17.83	4.20	0.00	2
1939	21.64	69.19	82.81	68.24	97.43	343.04	386.95	288.30	51.16	30.10	93.00	30.05	0
1940	14.71	8.52	79.01	93.50	45.54	45.25	54.21	45.92	36.66	26.33	19.30	25.50	0
1941	33.96	63.18	20.96	30.98	138.33	107.22	19.92	10.10	20.53	74.89	30.96	29.46	0
1942	20.78	65.38	48.60	21.96	194.14	201.23	112.54	66.67	35.92	17.73	10.73	8.19	0
1943	30.12	63.45	80.46	55.56	96.29	486.89	377.18	65.10	35.41	18.80	8.20	0.00	1
1944	4.14	34.98	41.28	141.38	1170.25	497.44	146.47	62.38	43.15	28.53	11.47	0.00	2
1945	25.60	67.72	72.86	57.55	264.82	939.44	714.90	107.07	45.74	26.11	12.10	3.51	1
1946	31.00	69.39	820.85	498.82	65.71	138.28	90.77	13.14	15.14	29.09	29.25	1365.0	0
1947	1500.00	409.12	96.42	868.07	189.46	37.08	83.20	120.96	87.56	25.73	4.10	25.60	1
1948	4.14	67.49	81.48	64.87	44.64	40.07	109.94	76.64	49.26	28.96	28.65	11.82	1
1949	31.50	68.43	82.32	73.92	95.59	124.32	95.69	60.71	39.72	25.74	28.40	28.81	0
1950	35.50	68.12	109.38	82.55	36.37	177.74	515.23	226.62	214.41	102.95	23.62	15.64	0
1951	10.00	73.20	82.74	38.48	847.17	320.86	43.14	64.28	21.58	10.80	5.30	9.11	0
1952	4.14	70.75	49.14	257.31	398.32	591.52	731.94	127.56	42.32	29.14	28.96	28.20	1
1953	25.40	77.00	75.85	81.72	36.90	119.97	150.61	36.05	31.37	27.47	27.60	28.94	0
1954	72.91	327.90	124.08	127.07	38.30	46.13	104.07	57.60	44.57	27.23	27.68	21.00	0

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1955	29.00	24.75	19.03	104.93	238.91	37.49	13.37	6.99	5.88	7.01	5.27	0.00	1
1956	9.86	15.90	59.90	154.54	1649.84	419.78	1243.8	668.20	278.00	30.29	27.60	22.50	0
1957	10.00	65.92	38.37	16.75	31.90	102.68	98.66	95.27	54.33	26.93	16.56	25.00	0
1958	4.14	8.87	52.78	18.70	52.99	140.86	119.28	71.31	46.53	25.19	19.60	3.76	2
1959	33.40	55.37	61.00	26.40	40.87	34.37	10.67	6.34	4.80	7.20	17.03	28.44	1
1960	33.10	53.89	76.85	88.14	101.38	44.60	113.19	71.81	42.89	26.63	25.18	12.50	0
1961	0.00	0.00	0.00	131.83	166.21	220.39	190.04	79.03	42.40	21.82	14.00	6.90	3
1962	25.00	28.93	19.19	14.84	90.43	65.05	53.02	9.70	11.30	5.35	28.89	28.47	0
1963	34.40	30.00	64.16	1161.23	**2681.30**	**2241.05**	626.80	141.97	54.77	27.77	170.00	26.00	0
1964	4.14	157.09	355.28	421.20	1993.42	830.46	273.72	61.85	41.59	28.45	25.41	28.60	1
1965	34.08	73.00	572.92	**2073.85**	**2893.42**	**3191.47**	1438.5	549.70	142.18	39.91	27.20	30.96	0
1966	600.00	545.00	45.55	101.95	875.12	824.53	135.62	55.40	37.52	25.98	16.93	29.58	0
1967	33.20	64.52	47.23	450.44	261.16	336.00	889.95	162.30	46.53	27.41	26.50	29.80	0
1968	35.00	19.36	82.29	37.48	75.26	59.51	12.50	45.24	44.66	30.28	29.40	29.87	0
1969	36.00	65.34	47.13	57.55	121.89	102.63	75.96	7.57	5.80	6.44	74.02	53.18	0
1970	27.40	64.80	58.93	102.82	140.63	206.70	40.07	58.54	48.18	26.96	30.39	30.29	0
1971	19.00	29.00	59.32	33.77	33.16	34.52	116.72	71.29	41.63	27.99	21.80	25.00	0
1972	31.32	70.75	20.97	16.06	32.04	33.25	11.54	14.17	21.30	28.83	28.61	19.40	0
1973	27.00	71.80	81.40	89.93	33.51	39.65	22.76	57.86	19.15	17.53	24.55	29.29	0
1974	25.30	27.37	22.28	21.07	125.58	76.35	18.17	5.75	8.20	10.94	8.46	0.00	1
1975	28.50	71.31	108.59	106.40	51.55	43.32	24.84	13.15	45.61	20.55	25.56	29.77	0
1976	36.64	74.50	43.03	25.44	34.73	40.97	44.19	10.14	5.90	9.37	23.66	29.89	0
1977	29.00	76.00	82.04	72.54	**2275.98**	**3434.83**	714.08	141.61	71.70	28.89	25.14	220.00	0
1978	190.00	163.02	374.22	537.54	1883.33	500.37	205.59	139.00	175.60	52.18	54.87	21.00	0
1979	14.34	71.22	71.46	48.63	38.95	135.53	396.85	155.95	46.70	28.80	28.19	28.59	0
1980	8.14	0.00	23.40	162.25	917.00	701.39	106.30	10.80	10.50	19.45	20.20	32.04	1
1981	525.00	350.00	52.78	21.01	32.27	33.42	11.07	6.22	4.50	5.79	8.36	13.40	1
1982	16.32	70.72	24.64	17.56	59.95	43.63	53.67	44.26	8.29	4.80	8.00	3.32	2
1983	32.18	69.69	68.81	106.80	159.31	80.30	91.72	56.34	5.50	18.55	20.50	8.21	0
1984	6.14	0.00	16.98	19.93	32.94	62.22	59.75	38.42	13.80	4.00	14.01	8.80	2
1985	27.40	70.31	85.93	726.51	1439.58	394.32	117.08	60.09	40.47	37.48	31.71	28.00	0

State 1	**0.00**	**State 2**	**0.0 – 5**	**State 3**	**5 – 20**	**State 4**	**20 – 50**	**State 5**	**>50**	**Flood**	**> 2000**

Table 48. Simulated mean monthly inflows (in m³/s) into the Orange Estuary under Sc 5

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1920	0.29	0.00	0.00	57.61	73.12	68.11	132.07	68.61	19.81	23.65	17.56	0.80	4
1921	9.50	51.94	11.44	0.45	79.71	56.08	4.93	0.00	0.00	0.76	0.00	0.00	7

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1922	0.00	5.34	6.23	0.55	11.07	13.18	1.80	0.00	0.00	0.00	0.00	0.00	8
1923	0.00	39.55	42.53	807.00	594.23	472.49	294.03	78.50	42.95	22.89	17.79	10.11	1
1924	17.69	323.05	509.02	11.67	25.76	124.70	88.00	68.27	41.80	20.00	17.70	13.06	0
1925	0.00	1.16	5.81	23.81	32.82	127.25	93.96	164.41	42.60	21.14	11.87	0.00	3
1926	11.73	811.79	164.80	409.01	981.33	212.67	17.10	3.89	6.12	8.68	3.08	0.00	3
1927	0.00	0.00	28.99	55.10	136.56	53.08	79.92	60.95	44.44	22.71	17.12	11.62	2
1928	20.74	30.62	62.65	82.66	939.61	277.49	52.71	41.49	32.47	23.97	110.95	24.08	0
1929	20.82	181.46	106.37	6.41	60.37	139.93	106.17	68.13	42.23	21.08	11.23	14.11	0
1930	15.99	54.24	119.92	259.52	272.90	73.21	93.69	40.62	8.18	18.79	11.65	9.54	0
1931	17.94	0.94	0.00	66.14	113.28	251.42	107.77	55.32	17.88	13.23	17.10	12.60	2
1932	20.56	53.14	132.27	78.94	18.49	37.55	281.20	830.12	284.43	395.74	138.40	17.58	0
1933	434.42	1704.23	1307.38	336.42	**2067.05**	439.80	37.14	29.58	42.71	22.67	13.51	13.92	0
1934	67.26	45.75	0.24	0.00	17.19	261.14	82.71	33.63	30.64	13.87	1.40	0.00	4
1935	0.00	0.00	0.90	49.52	101.53	95.09	72.32	69.41	42.92	20.26	2.95	0.00	5
1936	11.33	47.63	6.26	5.65	33.11	32.31	71.09	49.08	29.45	19.71	6.81	13.83	0
1937	19.58	36.37	64.07	69.88	65.58	564.11	271.48	51.91	13.41	5.62	0.00	0.00	2
1938	0.00	2.91	0.00	8.69	14.57	21.79	10.22	37.15	15.56	12.34	3.15	0.00	5
1939	0.00	41.60	65.39	46.54	80.53	330.10	375.30	278.16	45.45	24.61	17.97	14.09	1
1940	0.01	0.00	49.71	71.79	28.51	32.18	42.90	39.60	30.95	20.84	12.72	9.48	2
1941	21.36	46.13	3.71	10.56	119.78	94.14	8.65	22.68	14.84	69.47	19.39	13.45	1
1942	0.00	46.50	31.16	3.61	173.44	188.15	101.32	60.33	30.22	12.24	7.16	0.17	3
1943	17.54	46.48	63.12	33.84	79.24	474.04	365.91	58.80	29.71	13.31	0.28	0.00	2
1944	0.00	15.08	13.44	110.83	1062.15	287.69	85.25	56.05	37.48	23.06	7.90	0.00	2
1945	0.00	43.47	55.51	35.89	247.83	814.58	432.32	83.88	40.03	20.62	5.52	0.00	2
1946	13.05	52.42	623.05	405.14	48.72	113.74	79.45	9.37	9.52	23.59	17.71	1402.27	0
1947	1445.97	360.05	82.89	707.48	153.85	24.00	71.89	85.00	76.26	20.24	5.99	11.63	0
1948	0.00	38.78	64.18	43.18	27.67	27.03	98.65	70.38	43.55	23.48	17.07	3.79	2
1949	16.85	51.39	64.92	52.21	78.57	111.31	84.39	54.43	34.02	20.26	16.89	12.78	0
1950	15.91	51.11	114.98	60.86	19.30	164.86	271.23	96.92	208.80	96.99	17.06	5.61	0
1951	0.00	40.90	65.33	16.77	731.25	300.31	31.83	57.93	15.88	6.75	0.27	1.08	3
1952	0.00	40.57	31.70	128.15	346.67	581.53	709.87	116.37	36.63	23.66	17.41	12.17	1
1953	2.81	55.55	55.72	59.97	19.84	106.89	97.24	29.71	25.70	21.98	16.05	12.92	1
1954	21.46	333.70	110.78	109.21	21.22	33.06	92.90	51.26	38.87	21.84	16.11	13.74	0
1955	12.36	7.74	1.58	83.25	125.23	24.39	5.03	0.32	0.00	1.22	0.00	0.00	6
1956	0.69	4.54	28.76	205.08	1193.63	375.68	1221.79	644.65	269.96	26.23	16.03	11.45	2
1957	0.01	39.54	20.92	0.13	9.73	89.20	87.42	88.98	48.63	21.43	9.98	11.01	2
1958	0.00	0.00	20.99	1.67	24.76	127.84	108.10	65.00	40.83	19.70	11.39	0.00	4

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1959	16.88	38.33	43.56	6.44	21.93	21.26	1.41	0.00	0.00	1.23	0.00	3.12	6
1960	19.35	19.64	59.37	66.49	84.43	31.52	101.95	65.51	37.21	21.17	13.22	0.00	1
1961	0.00	21.43	29.07	59.73	101.74	196.76	178.77	70.29	36.70	16.33	8.96	0.00	2
1962	3.58	11.87	1.74	0.00	65.83	52.07	41.84	22.95	7.63	2.89	17.33	13.44	4
1963	11.73	16.95	46.87	1141.34	**2095.50**	**2198.70**	609.33	142.63	46.40	22.27	139.70	13.83	0
1964	0.00	89.87	315.01	392.27	1711.55	762.25	259.83	55.51	35.92	22.99	15.83	13.57	1
1965	18.46	54.13	511.98	1857.38	**2946.31**	**3252.33**	1435.68	521.40	124.35	34.46	20.62	14.95	0
1966	682.19	535.17	28.11	83.44	845.62	804.64	114.39	49.13	31.82	20.49	10.35	13.57	0
1967	20.61	47.55	29.85	451.93	248.31	194.07	863.56	153.97	40.83	21.93	14.96	13.81	0
1968	19.18	4.19	63.09	15.76	58.28	46.41	3.94	36.33	38.96	24.83	17.88	13.84	2
1969	20.41	48.36	29.69	35.86	104.91	89.70	64.64	1.37	1.98	4.95	67.47	45.22	3
1970	14.73	47.83	41.52	81.20	123.79	161.20	28.76	52.25	42.49	21.47	18.97	14.26	0
1971	7.22	15.87	41.95	12.02	16.12	21.45	105.51	64.94	35.94	22.56	15.22	8.89	0
1972	18.78	53.72	3.55	0.00	9.80	19.22	3.10	20.90	32.45	23.36	17.03	4.41	4
1973	14.45	54.86	64.02	68.19	16.44	26.59	11.53	51.55	13.45	12.04	13.03	13.26	0
1974	8.64	8.63	4.94	3.94	58.00	60.57	8.53	0.04	3.17	5.15	0.00	0.00	6
1975	0.00	53.32	91.34	84.76	34.47	30.25	14.51	7.87	39.93	15.06	14.00	13.75	1
1976	21.07	55.29	25.58	5.66	15.55	27.90	32.89	7.42	1.83	0.00	13.39	13.99	2
1977	21.41	55.14	64.65	50.80	1559.78	**3367.58**	697.98	136.74	60.05	23.40	17.57	270.78	0
1978	164.90	128.38	399.32	531.43	1909.85	485.75	196.83	107.95	137.80	35.90	45.53	8.97	0
1979	0.00	49.85	54.02	26.92	21.96	122.51	279.51	134.93	41.06	23.31	16.62	12.56	1
1980	0.00	0.00	5.61	94.14	888.05	669.15	102.94	21.67	9.04	13.96	11.60	16.11	2
1981	510.89	333.14	35.39	3.04	11.03	20.40	2.80	0.00	0.00	0.00	2.36	3.36	7
1982	5.75	53.71	7.19	0.49	37.80	30.56	42.38	37.93	2.61	1.35	5.42	0.00	4
1983	14.59	52.68	51.44	85.21	142.41	67.30	80.39	49.99	7.78	13.07	11.91	0.18	1
1984	0.00	0.00	0.00	2.35	10.29	27.59	48.43	32.15	8.09	3.13	7.44	0.78	6
1985	14.79	53.34	68.65	628.56	1424.57	385.10	106.60	53.78	34.76	32.10	20.16	11.96	0

State 1	**0.00**	**State 2**	**0.0 – 5**	**State 3**	**5 – 20**	**State 4**	**20 – 50**	**State 5 >50**	**Floods**	**> 2000**

Table 49. Simulated mean monthly inflows (in m³/s) into the Orange Estuary under Sc 6

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1920	0.00	0.00	0.00	0.00	0.00	5.01	19.69	0.29	0.00	0.05	0.04	2.96	10
1921	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1922	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1923	0.00	0.00	0.00	746.66	588.66	380.95	212.08	55.37	8.41	0.22	5.96	3.10	5
1924	0.12	289.64	498.59	0.00	0.00	0.00	0.13	0.10	0.00	0.00	0.00	2.91	10
1925	0.00	0.00	0.00	0.00	0.00	0.00	23.16	146.49	22.79	0.00	0.00	2.89	9

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1926	0.00	765.19	155.02	393.88	726.11	35.37	0.06	0.00	0.00	0.00	0.00	2.89	7
1927	0.00	0.00	0.00	0.00	9.63	0.00	0.00	10.42	2.81	0.00	0.00	2.89	10
1928	0.00	0.00	3.40	0.64	839.40	285.94	47.95	1.92	0.00	0.00	101.76	33.15	7
1929	0.00	158.57	96.57	0.00	6.82	7.31	0.05	0.00	0.00	0.00	0.00	2.89	8
1930	0.00	0.00	32.68	247.71	264.58	5.81	93.94	0.00	0.00	0.00	0.00	2.89	7
1931	0.00	0.00	0.00	0.00	36.67	129.68	22.83	19.31	2.77	0.00	0.00	2.89	8
1932	0.00	0.00	25.48	44.39	0.00	0.00	240.80	404.36	31.29	272.89	57.05	26.62	4
1933	152.65	734.93	485.13	254.50	1917.48	293.26	0.00	0.00	10.45	0.00	0.00	2.89	5
1934	61.34	1.36	0.00	0.00	0.00	181.85	50.73	0.00	0.00	0.00	0.00	2.89	9
1935	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1936	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1937	0.00	0.00	0.00	0.00	0.00	469.06	269.69	0.00	0.00	0.00	0.00	2.89	10
1938	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1939	0.00	0.00	0.00	0.00	7.90	227.28	376.98	281.50	46.22	0.06	0.04	2.97	7
1940	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1941	0.00	0.00	0.00	0.00	13.57	73.33	0.10	0.00	0.00	0.00	0.55	2.89	10
1942	0.00	0.00	0.00	0.00	46.85	86.65	7.10	0.86	0.00	0.00	0.00	2.89	9
1943	0.00	0.00	0.00	3.13	0.00	385.91	302.90	11.20	0.52	0.00	0.00	2.89	9
1944	0.00	0.00	0.00	0.00	993.08	287.78	9.66	1.23	2.17	1.42	0.00	2.89	9
1945	0.00	0.00	0.00	0.00	137.79	764.27	392.03	21.91	2.43	0.00	0.00	2.89	8
1946	0.00	0.00	549.36	267.25	0.00	69.10	48.65	2.43	0.00	0.00	0.00	946.2	7
1947	783.91	109.52	68.04	389.89	27.50	0.00	13.89	0.00	0.00	0.00	0.00	2.89	6
1948	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1949	0.00	0.00	0.00	0.00	0.00	0.00	1.52	0.04	0.00	0.00	0.00	2.89	12
1950	0.00	0.00	12.46	47.25	0.00	143.85	267.41	32.06	24.11	70.60	16.52	2.89	4
1951	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1952	0.00	0.00	0.00	7.22	159.27	412.60	669.11	71.79	0.03	0.08	0.07	2.98	7
1953	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1954	0.00	229.24	100.98	96.01	0.00	3.79	5.37	0.00	0.00	0.00	0.00	2.89	8
1955	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1956	0.00	0.00	0.00	108.45	912.57	200.13	687.13	608.95	227.10	0.05	0.04	2.97	6
1957	0.01	0.00	0.00	0.00	0.00	0.00	0.00	31.08	7.74	0.00	0.00	2.89	10
1958	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1959	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1960	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1961	0.00	0.00	0.00	0.00	51.47	234.77	178.63	8.69	0.00	0.00	0.00	2.89	8
1962	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1963	0.00	0.00	0.00	1043.73	1899.93	1224.28	310.65	77.67	18.77	1.95	31.52	2.21	5

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1964	0.00	0.00	215.61	377.78	1540.37	474.22	215.78	11.28	2.01	0.00	0.00	2.89	6
1965	0.00	0.00	458.10	1453.23	**2544.90**	**3225.7**	1399.48	479.97	82.53	19.04	2.80	1.21	4
1966	501.64	472.10	14.27	70.28	741.47	705.22	70.00	11.44	0.00	0.00	0.00	2.73	4
1967	0.00	0.00	0.00	358.00	227.81	205.97	585.16	107.62	7.36	2.04	0.00	2.89	6
1968	0.00	0.00	0.00	0.00	35.96	18.46	0.00	0.00	0.09	0.00	0.00	2.89	10
1969	0.00	0.00	0.00	0.00	0.00	15.82	64.31	0.73	0.00	0.00	0.00	53.66	9
1970	0.00	0.00	0.00	0.00	93.30	183.63	0.00	0.00	0.00	0.00	2.86	2.89	10
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1973	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.82	0.00	0.00	0.00	0.00	2.89	12
1975	0.00	0.00	0.00	16.41	0.00	2.81	4.90	1.04	0.00	0.00	0.00	2.89	11
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1977	0.00	0.00	0.00	0.00	883.27	1728.77	304.27	22.74	13.02	10.76	1.16	22.27	5
1978	109.59	103.42	24.61	315.66	1852.37	433.27	162.41	64.86	96.13	0.00	0.00	2.89	3
1979	0.00	0.00	0.00	0.00	0.00	0.00	108.20	88.63	0.00	0.00	0.00	2.89	10
1980	0.00	0.00	0.00	0.00	589.57	627.91	52.68	0.00	0.00	0.00	0.00	2.00	9
1981	326.06	270.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	10
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1983	0.00	0.00	0.00	0.00	4.01	8.74	0.00	0.00	0.00	0.00	0.00	2.89	11
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1985	0.00	0.00	0.00	581.88	1404.49	377.52	104.82	31.88	0.00	13.32	1.05	0.85	6

State 1	**0.00**	**State 2**	**0.0 – 5**	**State 3**	**5 – 20**	**State 4**	**20 – 50**	**State 5**	**>50**	**Flood**	**>2000**

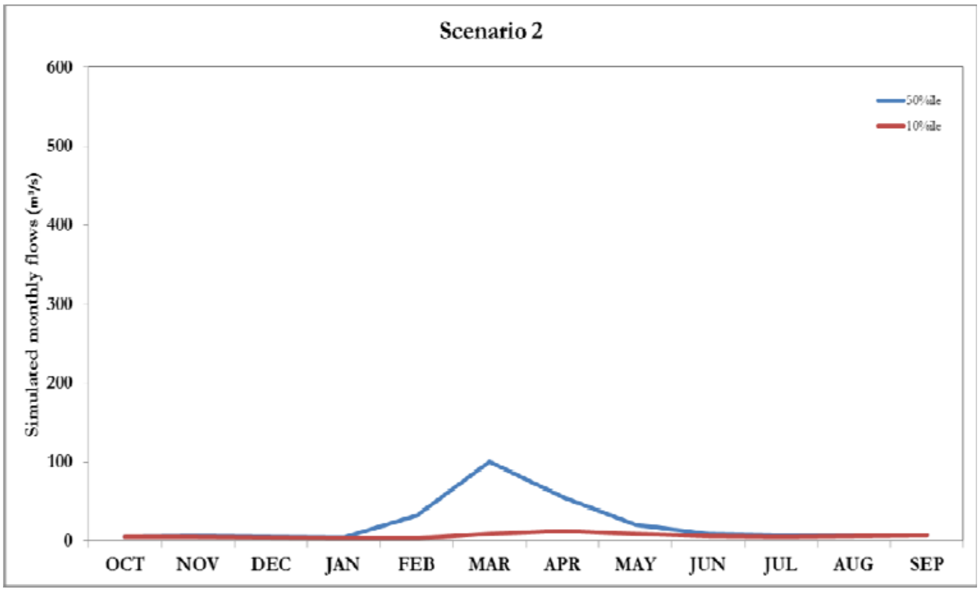
Table 50. Simulated mean monthly inflows (in m³/s) into the Orange Estuary under Sc 7

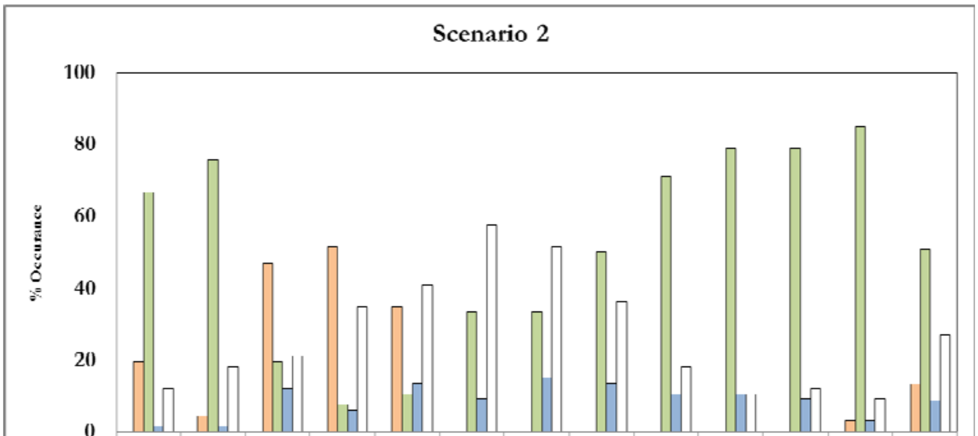
Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1920	0.00	0.00	0.00	0.00	0.76	13.78	17.66	0.43	0.00	0.05	0.04	2.97	10
1921	0.01	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.00	2.89	12
1922	0.00	0.00	0.00	0.00	0.00	0.73	0.20	0.00	0.00	0.00	0.00	2.89	12
1923	0.00	0.00	0.00	730.86	588.68	380.96	212.09	55.38	8.55	0.22	5.96	3.10	5
1924	0.13	289.65	499.30	0.16	6.18	3.95	2.44	1.18	0.08	0.00	0.00	2.91	9
1925	0.00	0.00	0.00	0.00	0.00	12.78	15.23	147.21	23.15	0.00	0.00	2.89	8
1926	0.00	765.19	155.02	396.15	699.90	35.38	1.31	0.00	0.00	0.00	0.00	2.89	7
1927	0.00	0.00	0.00	6.66	12.80	0.33	1.85	6.60	2.36	0.01	0.00	2.89	9
1928	0.00	0.00	7.77	1.77	829.14	275.77	47.97	2.15	0.29	0.46	102.08	33.15	6
1929	0.00	158.57	96.57	0.75	16.35	15.25	1.08	0.00	0.00	0.00	0.00	2.91	8
1930	0.30	0.00	32.68	248.08	265.78	6.35	93.94	0.00	0.00	0.00	0.00	2.89	7

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1931	0.00	0.00	0.00	0.00	17.01	127.17	22.84	19.32	3.48	0.00	0.00	2.89	8
1932	0.00	0.00	29.13	48.93	1.19	2.29	246.49	406.55	31.29	272.89	57.05	26.62	4
1933	152.65	734.93	490.09	257.77	1906.49	294.56	0.38	0.00	10.45	0.00	0.00	2.89	5
1934	61.34	1.36	0.00	0.00	0.00	181.85	50.80	0.03	0.00	0.00	0.00	2.89	9
1935	0.00	0.00	0.90	2.84	0.00	0.35	0.65	0.22	0.00	0.00	0.00	2.89	12
1936	0.00	0.00	0.00	0.00	0.00	0.00	1.69	0.21	0.00	0.00	0.00	2.89	12
1937	0.00	0.00	0.00	0.00	0.00	469.06	270.45	0.47	0.00	0.00	0.00	2.89	10
1938	0.00	0.00	0.00	0.00	0.00	3.31	3.39	0.32	0.00	0.07	0.00	2.89	12
1939	0.00	0.00	0.00	0.00	24.08	175.27	376.98	281.50	46.75	0.39	0.05	2.97	7
1940	0.01	0.00	0.00	0.00	2.65	4.27	0.26	0.26	0.00	0.00	0.00	2.89	12
1941	0.00	0.00	0.13	0.00	15.22	61.41	1.31	0.18	0.00	0.00	0.55	2.89	10
1942	0.00	0.00	0.00	0.00	45.55	86.67	7.11	1.53	0.00	0.00	0.00	2.89	9
1943	0.00	0.00	0.71	4.74	0.00	378.96	302.91	11.21	1.04	0.04	0.00	2.89	9
1944	0.00	0.00	0.00	4.51	1001.37	285.97	11.35	1.23	3.01	2.14	0.00	2.89	9
1945	0.00	0.04	1.25	3.24	112.41	764.28	392.04	21.92	2.65	0.63	0.20	2.89	8
1946	0.00	0.00	549.36	268.29	4.24	62.08	48.66	2.44	0.26	0.00	0.00	946.21	7
1947	783.91	109.52	73.09	393.86	30.66	2.22	14.60	0.00	0.00	0.00	0.00	2.89	6
1948	0.00	0.00	0.00	0.00	0.08	0.63	0.74	0.00	0.00	0.00	0.00	2.89	12
1949	0.00	0.00	0.00	0.00	0.00	4.68	4.84	0.52	0.00	0.00	0.00	2.89	12
1950	0.00	0.00	12.46	47.25	0.00	144.17	270.20	33.92	24.82	70.71	16.52	2.89	4
1951	0.00	0.00	0.00	0.26	1.88	3.70	0.00	0.00	0.00	0.00	0.00	2.89	12
1952	0.00	0.00	0.00	18.85	107.09	412.61	669.12	71.79	0.28	0.08	0.07	2.99	7
1953	0.03	0.48	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1954	0.00	229.24	100.98	96.01	0.00	6.77	9.33	0.71	0.00	0.00	0.00	2.89	7
1955	0.00	0.00	0.00	0.00	0.00	0.68	0.48	0.32	0.00	0.00	0.00	2.89	12
1956	0.69	0.51	0.00	110.16	916.79	211.02	698.31	610.45	228.10	0.06	0.05	2.97	6
1957	0.01	0.00	1.33	0.00	0.00	4.93	5.56	31.91	8.33	0.00	0.00	2.89	9
1958	0.00	0.00	0.00	0.00	4.28	6.11	0.55	0.00	0.00	0.00	0.00	2.89	11
1959	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	2.89	12
1960	0.00	0.00	0.00	0.00	3.26	3.69	0.71	0.00	0.00	0.00	0.00	2.89	12
1961	0.00	0.00	0.00	7.43	63.18	196.95	117.50	8.70	0.18	0.00	0.00	2.89	7
1962	0.00	0.00	0.00	0.00	0.00	1.72	2.89	0.24	0.00	0.00	0.00	2.89	12
1963	0.00	0.00	0.00	1034.79	1899.95	1224.29	310.66	77.68	18.78	2.95	31.91	2.21	5
1964	0.00	0.00	215.77	379.63	1541.57	470.69	214.16	12.04	2.01	0.00	0.00	2.89	6
1965	0.00	0.00	458.10	1452.97	**2544.92**	**3225.68**	1399.49	479.97	82.53	19.05	2.81	2.38	4
1966	502.56	472.10	14.27	70.28	740.39	705.25	70.01	11.45	0.28	0.00	0.00	2.73	4
1967	0.00	0.00	0.00	358.00	241.19	192.36	585.18	107.86	7.37	2.05	0.00	2.89	6
1968	0.00	0.00	0.00	1.85	32.86	18.47	0.00	0.45	1.90	0.73	0.00	2.89	10

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Closed*
1969	0.00	0.00	0.00	0.00	0.00	19.89	56.29	1.37	0.00	0.00	0.00	53.66	9
1970	0.00	0.00	0.00	0.00	93.30	183.63	0.00	0.00	0.00	0.00	2.86	2.89	10
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1973	0.00	0.00	0.00	0.00	0.00	2.26	2.06	0.03	0.00	0.00	0.00	2.89	12
1974	0.00	0.00	0.00	0.00	0.00	4.48	3.28	0.04	0.00	0.00	0.00	2.89	12
1975	0.00	0.00	2.80	18.43	0.00	5.91	8.26	1.73	0.00	0.00	0.00	2.89	9
1976	0.00	0.00	0.00	0.00	0.00	1.36	0.01	0.38	0.00	0.00	0.00	2.89	12
1977	0.00	0.00	0.00	0.00	890.04	1740.10	312.32	23.49	13.02	10.76	1.16	22.27	5
1978	109.60	103.42	24.61	318.89	1862.54	439.08	163.23	65.35	96.14	0.00	0.00	2.89	3
1979	0.00	0.00	0.00	0.00	0.00	0.00	111.14	89.22	0.00	0.00	0.00	2.89	10
1980	0.00	0.00	0.00	0.00	590.75	630.93	53.78	0.00	0.00	0.00	0.00	2.25	9
1981	326.35	271.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	10
1982	0.00	0.00	0.00	0.00	0.00	1.10	1.60	1.23	0.00	0.00	0.00	2.89	12
1983	0.00	0.00	0.00	0.00	9.74	10.81	0.00	0.00	0.00	0.00	0.00	2.89	10
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.89	12
1985	0.00	0.00	0.00	583.08	1417.99	383.39	105.58	32.42	0.00	13.32	1.05	0.85	6

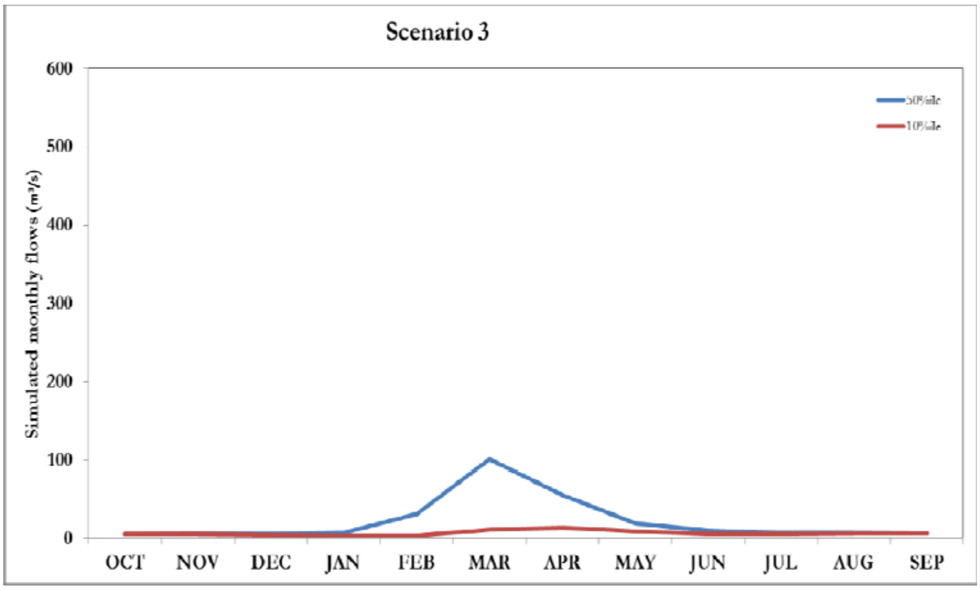
State 1	**0.00**	**State 2**	**0.0 – 5**	**State 3**	**5 – 20**	**State 4**	**20 – 50**	**State 5**	**>50**	**Floods**	**>2000**

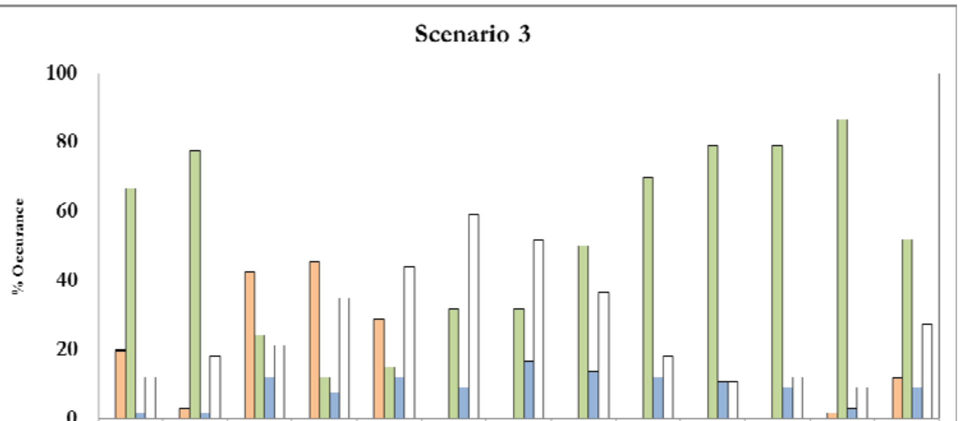




	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	20	5	47	52	35	0	0	0	0	0	0	3	13
State 3	67	76	20	8	11	33	33	50	71	79	79	85	51
State 4	2	2	12	6	14	9	15	14	11	11	9	3	9
State 5	12	18	21	35	41	58	52	36	18	11	12	9	27

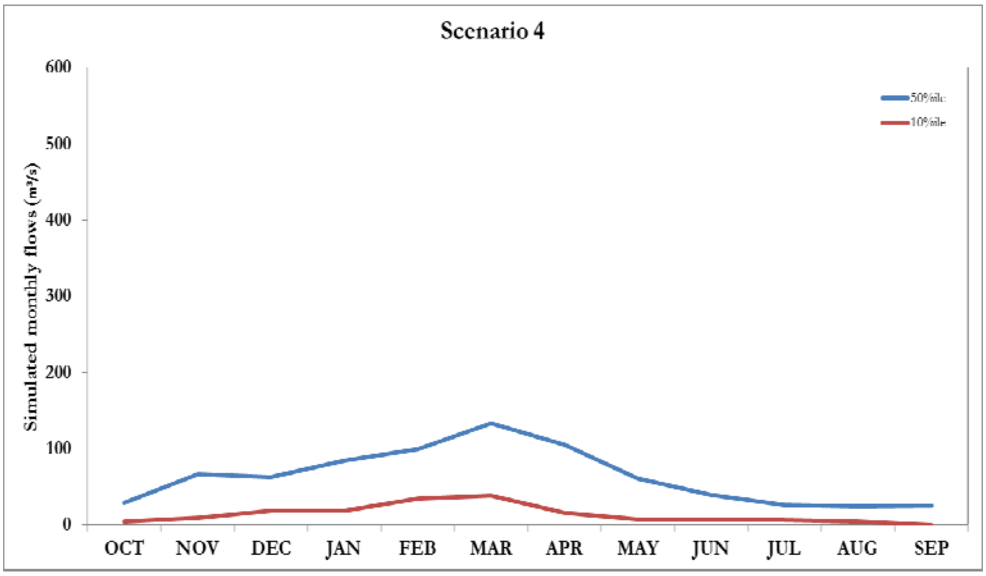
Figure 9. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) and a summary of the percentages monthly and annual occurrences of the various abiotic states for Sc 2.

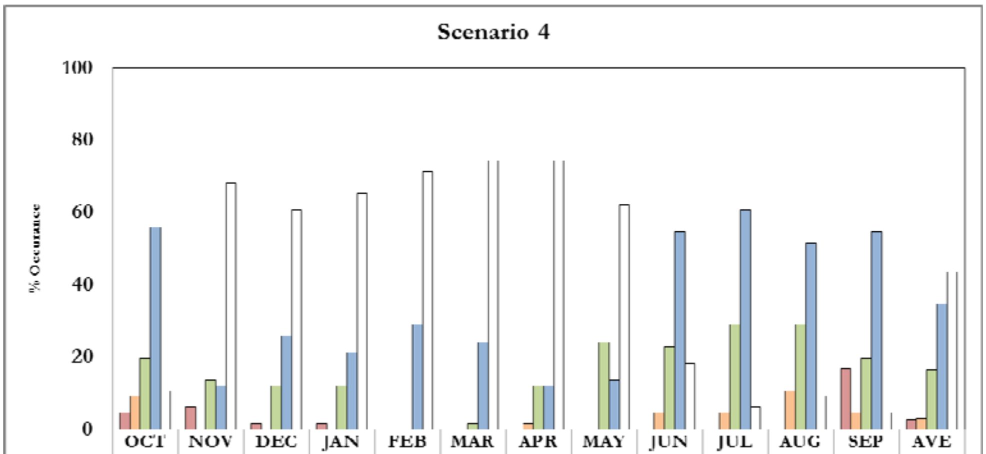




	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	20	3	42	45	29	0	0	0	0	0	0	2	12
State 3	67	77	24	12	15	32	32	50	70	79	79	86	52
State 4	2	2	12	8	12	9	17	14	12	11	9	3	9
State 5	12	18	21	35	44	59	52	36	18	11	12	9	27

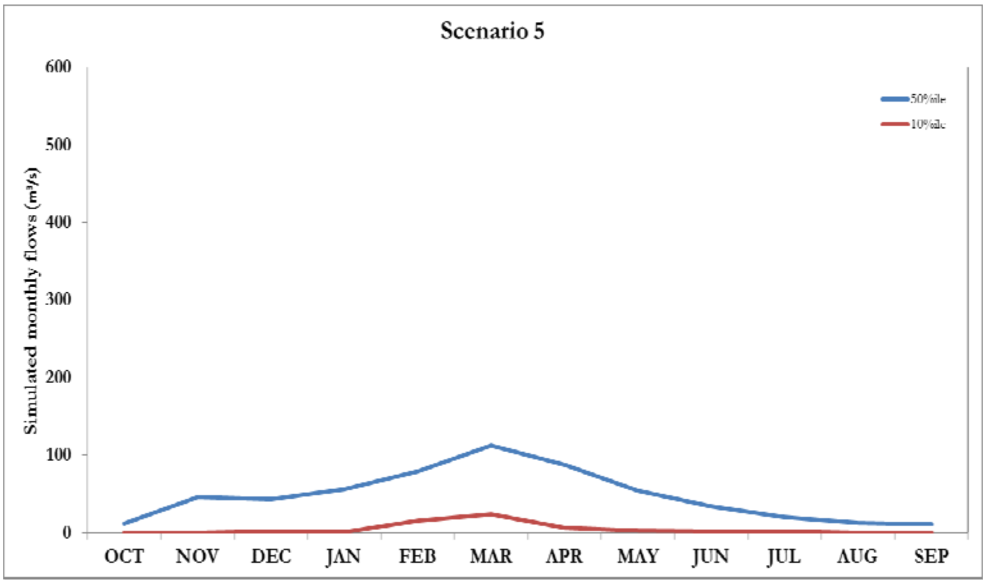
Figure 10. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) and a summary of the percentages monthly and annual occurrences of the various abiotic states in for Sc 3

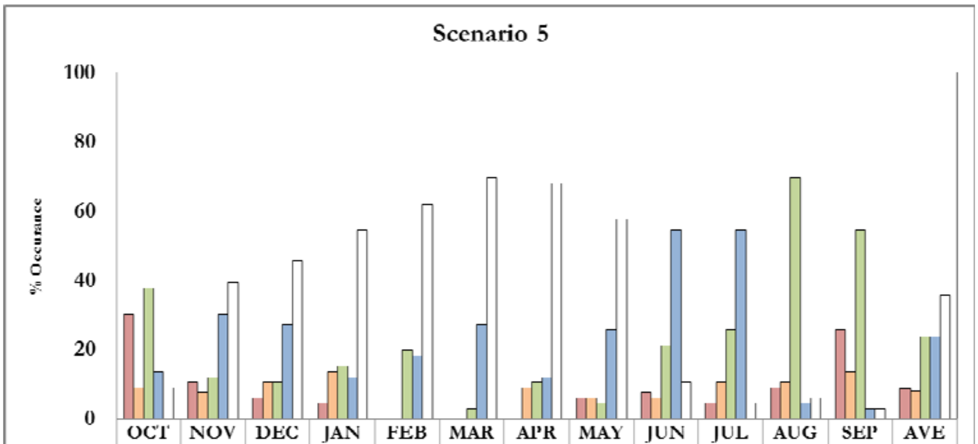




	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
State 1	5	6	2	2	0	0	0	0	0	0	0	17	3
State 2	9	0	0	0	0	0	2	0	5	5	11	5	3
State 3	20	14	12	12	0	2	12	24	23	29	29	20	16
State 4	56	12	26	21	29	24	12	14	55	61	52	55	35
State 5	11	68	61	65	71	74	74	62	18	6	9	5	44

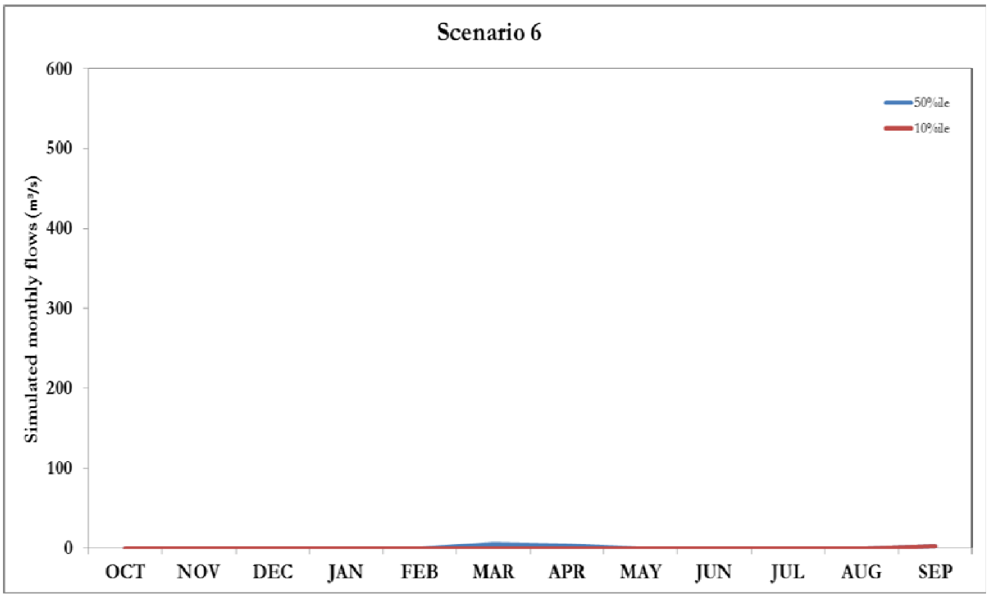
Figure 11. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) and a summary of the percentages monthly and annual occurrences of the various abiotic states in for Sc 4

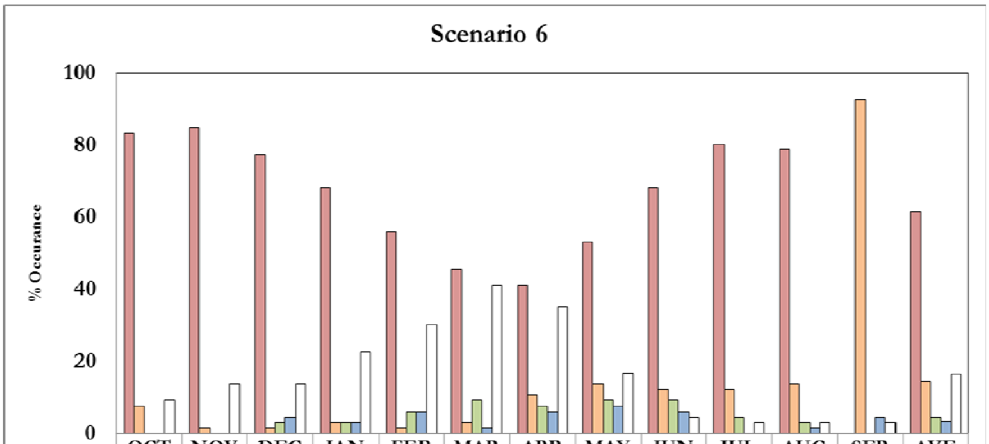




	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
State 1	30	11	6	5	0	0	0	6	8	5	9	26	9
State 2	9	8	11	14	0	0	9	6	6	11	11	14	8
State 3	38	12	11	15	20	3	11	5	21	26	70	55	24
State 4	14	30	27	12	18	27	12	26	55	55	5	3	24
State 5	9	39	45	55	62	70	68	58	11	5	6	3	36

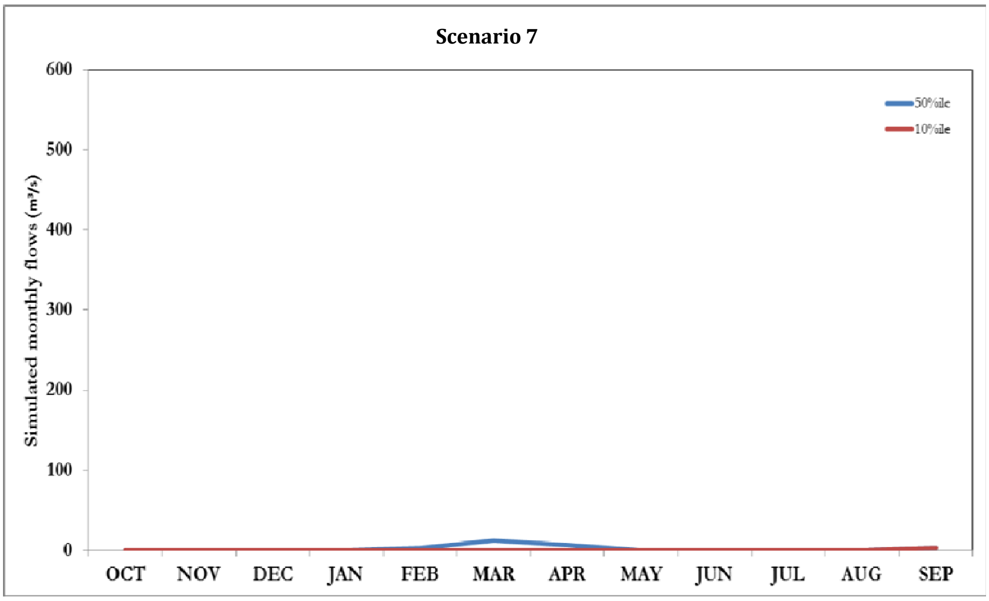
Figure 12. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) and a summary of the percentages monthly and annual occurrences of the various abiotic states in for Sc 5

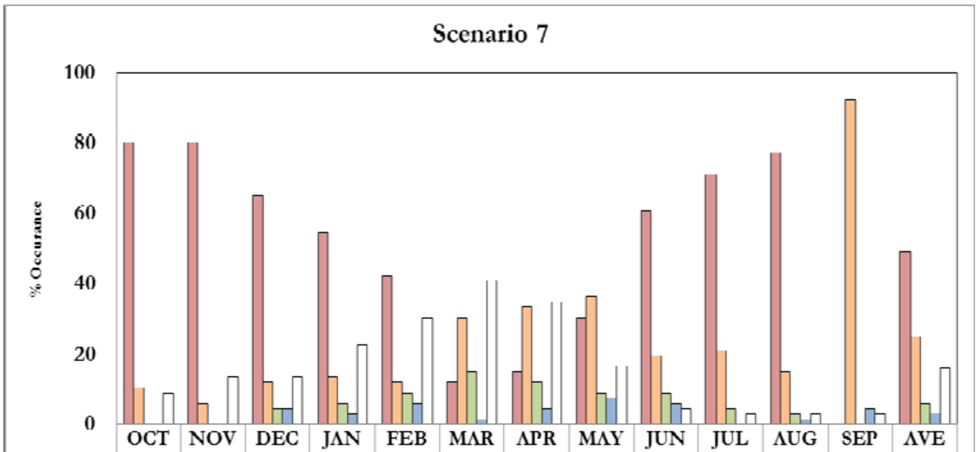




	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
State 1	83	85	77	68	56	45	41	53	68	80	79	0	61
State 2	8	2	2	3	2	3	11	14	12	12	14	92	14
State 3	0	0	3	3	6	9	8	9	9	5	3	0	5
State 4	0	0	5	3	6	2	6	8	6	0	2	5	3
State 5	9	14	14	23	30	41	35	17	5	3	3	3	16

Figure 13. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) and a summary of the percentages monthly and annual occurrences of the various abiotic states in for Sc 6





	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
State 1	80	80	65	55	42	12	15	30	61	71	77	0	49
State 2	11	6	12	14	12	30	33	36	20	21	15	92	25
State 3	0	0	5	6	9	15	12	9	9	5	3	0	6
State 4	0	0	5	3	6	2	5	8	6	0	2	5	3
State 5	9	14	14	23	30	41	35	17	5	3	3	3	16

Figure 14. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) and a summary of the percentages monthly and annual occurrences of the various abiotic states in for Sc 7

4.2 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.

4.2.1 Hydrology

The modelled changes in hydrology are summarised in Table 51 and scored in Table 52.

Table 51. Summary of changes under the different scenarios

Parameter	***Scenarios 2 – 7***
Low flows	

Flows below 50 m^3/s are seen as low flows to the Orange Estuary. To provide an overview of change in this flow range a frequency analysis were conducted on the 66-year period simulated data.

Flow (m^3/s)	Natural	Present	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7
0 – 10	5.7	3.2	53.7	51.6	11.7	23.1	77.8	76.8
10 – 20	6.2	48.9	10.6	12.0	10.0	17.4	2.5	3.7
20 – 30	6.1	11.0	3.5	3.8	18.2	10.6	1.4	1.3
30 – 40	4.3	5.2	2.4	2.5	9.8	6.6	1.3	1.3
40 – 50	5.1	2.3	2.9	2.8	6.6	6.4	0.8	0.8
>50	72.7	29.5	26.9	27.3	43.7	35.9	16.3	16.3

This analyse indicate that low flows (< 50 m^3/s) have significantly increased under the present state, Sc 2 and Sc 3. Under the present state the majority of flows occur in the 10 – 20 m^3/s flow range, while under Sc 2 and 3 it is in the 0 – 10 m^3/s flow range. Sc 4 represents an improvement on the present. While Sc 5 ranks between Sc 4 and Sc 2 and 3, in terms of increase in low flow conditions. Sc 6 and 7 represent a drastic reduction in all flow ranges, with inflows zero most of the time.

Changes in the occurrence of major floods for the 66-year period

No detailed flood analysis were conducted for this study for floods to the Orange Estuary, but monthly flow volumes higher than 5,000 Mm^3 (represented by a flow rate of 1,867 m^3/s in the simulated mean monthly flow tables) were seen as indicative of resetting events that influence the physical processes in the estuary. Under reference conditions this type of event occurred 25 times in the simulated flow period of 66 years. Under the present state and Sc 2 their occurrence has been reduced to eight times, under Sc 3 and 4 they occur nine times, while under Sc 5 they have been reduced to six times for the same simulation period. Under the worst case Sc 6 and 7 they only occur twice.

Parameter	***Scenarios 2 – 7***

Monthly flows (Mm³)	Natural	Present	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7
>5,000	25	8	8	9	9	6	2	2
>6,000	11	6	6	6	6	3	2	2
>7,000	9	5	5	5	5	3	1	1
>8,000	8	3	3	3	3	2	1	1
>9,000	7	1	1	1	1	1	0	0
>10,000	3	0	0	0	0	0	0	0
>11,000	1	0	0	0	0	0	0	0
>12,000	1	0	0	0	0	0	0	0
>13,000	0	0	0	0	0	0	0	0

Table 52. Similarity scores for hydrology relative to the reference condition

Variable								
	Present	***Sc 2***	***Sc 3***	***Sc 4***	***Sc 5***	***Sc 6***	***Sc 7***	***Confidence***
a: % similarity in the occurrence of low flows from reference condition to present state for the 66-year simulation period								
	52	48	48	71	63	28	29	Medium
b:% similarity in the occurrence of major floods from the reference conditions to the present state for the 66-year simulation period								
	32	32	36	36	24	8	8	High
Hydrology score[1]	52	48	48	71	63	28	29	

1 Score = (0.6*a) + (0.4*b)

4.2.2 Hydrodynamics and mouth condition

Table 53. Estimated occurrence of State 1 and 2 under reference condition, present state and scenarios

Variable								
	Natural	***Present***	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7
Years the flows decreased below < 5 m³/s and the mouth could have closed								
	21	0	54	48	26	44	66	66
% years of the years the mouth could close								
	32	0	82	73	39	67	100	100
Occurrence of State 1 and 2								
	3	0	13	12	5	17	76	74

Years within which flows decrease sufficiently for mouth closure to potentially occur decreased from 32% under reference to 0% under the present state. Under Sc 2, 3, 4 and 5 years within which the estuary can close occur for 82%, 73%, 39% and 67% of the time respectively. Under Sc 6 and 7 the mouth could close every year. Also note that under Scenario a and 7 mouth closure is a persistent state lasting for months to years at a time as can be seen by the aggregates occurrence of State 1 and State 2.

Table 54. Similarity scores for hydrodynamics in the Present condition relative to the reference condition

Variable								
	Present	**Sc 2**	**Sc 3**	**Sc 4**	**Sc 5**	**Sc 6**	**Sc 7**	***Confidence***
a. Mouth condition and abiotic states	70	50	60	90	60	0	0	Low
Hydrodynamics and mouth conditions score	70	50	60	90	60	0	0	**Low**

4.2.3 Water quality

Scoring of scenarios in respect of salinity, DIN/DIP, suspended solids, turbidity/transparency, dissolved oxygen and toxic substances, followed a similar approach as described earlier for the present state (assuming a similarity of 85%). 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 55. Details on the change in the axial salinity gradient, DIN/DIP, suspended solids, dissolved oxygen, and toxic substances are provided in Table 56.

Table 55. Summary of changes in the percentage frequency of different abiotic states under the different scenarios

State	***Reference***	***Present***	***Sc 2***	***Sc 3***	***Sc 4***	***Sc 5***	***Sc 6***	***Sc 7***
1	1.8	0.0	0.0	0.0	2.5	8.7	61.4	49.1
2	1.4	0.0	13.4	11.7	2.9	8.1	14.4	25.3
3	8.7	52.0	50.9	51.9	16.3	23.7	4.5	6.1
4	15.4	18.4	8.8	9.1	34.6	23.6	3.4	3.3
5	72.7	29.5	26.9	27.3	43.7	35.9	16.3	16.3

Table 56. Estimated changes in water quality in different zones of the Orange Estuary under reference, present, scenarios

Zones in Estuary	***Volume weighting***	***Reference***	***Present***	***Sc 2***	***Sc 3***	***Sc 4***	***Sc 5***	***Sc 6***	***Sc 7***
Estimated salinity concentration based on distribution of abiotic states									
Zone A	0.15	3	11	14	14	7	12	32	30
Zone B	0.15	1	0	1	1	1	4	23	20
Zone C	0.4	11	22	23	23	18	21	35	33
Zone D	0.3	1	3	5	4	2	6	24	21
Estimated DIN concentration (µg/ℓ) based on distribution of abiotic states									
Zone A	0.15	64	211	211	212	204	195	114	127
Zone B	0.15	51	159	161	160	188	172	109	121
Zone C	0.4	88	229	220	221	239	219	117	130

Zones in Estuary	*Volume weighting*	*Reference*	*Present*	*Sc 2*	*Sc 3*	*Sc 4*	*Sc 5*	*Sc 6*	*Sc 7*
Zone D	0.3	51	159	161	160	188	175	109	121
Estimated DIP concentration (µg/ℓ) based on distribution of abiotic states									
Zone A	0.15	13	39	40	40	36	35	21	24
Zone B	0.15	10	29	29	29	33	31	20	23
Zone C	0.4	18	43	41	42	43	40	22	24
Zone D	0.3	10	29	29	29	33	31	20	23
Estimated turbidity (NTU) based on distribution of abiotic states									
Zone A	0.15	79	40	36	36	56	47	25	25
Zone B	0.15	80	51	47	48	60	53	28	29
Zone C	0.4	75	37	34	35	49	42	25	25
Zone D	0.3	80	51	47	48	60	53	28	29
Estimated DO concentration (mg/ℓ) based on distribution of abiotic states									
Zone A	0.15	6	6	6	6	6	6	6	6
Zone B	0.15	6	6	6	6	6	6	6	6
Zone C	0.4	6	6	6	6	6	6	4	5
Zone D	0.3	6	5	5	5	6	5	4	4

Table 57. Expected changes in axial salinity gradient, DIN/DIP, turbidity, DO, and toxic substances in the Orange Estuary under the present and flow scenarios

Parameter	*Summary of changes*
Changes in longitudinal salinity gradient and vertical stratification	
	Salinity has increased from reference conditions due to the decrease in baseflows (State 1 and 2). Sc 2 and 3 are very similar to the present state, while Sc 4 represents a decrease in salinity (more similar to reference conditions). Scenario 6 and 7 shows a significant increase in salinity due to the total loss in baseflows.
DIN/DIP in estuary	
	⇧ due to nutrient enrichment from catchment especially during State 5, as well as stronger marine influence also introducing nutrient (upwelling) to lower estuary. The 'improvement' in Sc 6 and 7 is primarily related to a further, marked reduction in State 5 (effectively reducing nutrient loading from the catchment into the estuary)
Suspended solids/Turbidity/Transparency in estuary	
	⇩due to a marked reduction in high flows (decrease in State 5)and stronger influence of clear marine waters in the lower reaches (increase in State 3). A further reduction in turbidity under Sc 6 and 7 is primarily related to a further, marked reduction in State 5 effectively reducing turbid conditions in the estuary originating from the catchment. Also a stronger influence of clear, marine water intrusion contribute to this
DO in estuary.	
	No marked changes. The water column is relatively shallow and exposed to strong wind mixing. State 1 (closed) seldom occurs. Lower DO concentrations predicted for Sc 6 and 7 is linked to an increase in the occurrence of closed states (State 1 and 2).

Parameter	***Summary of changes***
Toxic substances in estuary	
	⇧ of toxic input associated with agricultural activity in catchment.

Table 58. Summary of changes and calculation of the water quality health score for the various scenarios

Variable	***Present***	***Sc 2***	***Sc 3***	***Sc 4***	***Sc 5***	***Sc 6***	***Sc 7***	***Confidence***
1 Salinity								
Similarity in salinity	54	56	58	76	51	26	28	Medium
2 General water quality in the estuary								
a N and P concentrations	52	53	53	50	53	75	70	
b Water turbidity	71	68	68	83	76	50	51	Medium
c DO concentrations	98	96	96	99	97	90	91	
d Toxic substances	85	85	85	85	85	80	80	
Water quality score[1]	**51.6**	**54.2**	**55**	**60.4**	**52.2**	**40.4**	**41.8**	

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

4.2.4 Physical habitat alteration

Scenarios 2, 3 and 4 are very similar to each other and also to the present state, in terms of physical habitat alteration, because the river flow and flood regime and coastal processes/dynamics are very similar to the present state. Only the smaller floods occurring less than 1 in 5 years show a small increase in occurrence under Sc 3 and 4, but the impacts thereof are not considered to be sufficient to affect the scoring relative to the present state (or Sc 2).

Scenario 5 is a bit worse than Sc 2 to 4, in that the MAR is reduced by another 3% to about 36% of Natural. However, the occurrence of smaller floods (less than 1 in 10 year events) is significantly reduced again from the already reduced occurrences under Sc 2 to 4. Yet, it seems that larger floods (from about 1 in 10 year events and upwards) have about the same occurrence as Sc 2 to 4 (which are much less than under Natural). Thus, the expected physical habitat alteration under Sc 5, is significantly worse than under the present state. In the long-term, this is considered to result in a relatively consistent change (impact) over all three 'sub-domains' of the intertidal areas, subtidal areas and sediment composition, in relation to the present state.

Scenarios 6 and 7 are considered to be very similar to each other in terms of physical habitat alteration. Under these two scenarios the MAR is reduced by 80% from reference. Overall, floods and especially large floods are crucial in maintaining the long-term dynamic equilibrium with respect to the sediment regime in the Orange Estuary. On an occurrence basis, 'reference/natural' floods in the order of 1 in 2 to 5 years occurred about 5 to 13 times more frequently than under these scenarios (i.e. they would occur on average only about 1 in 33 years), while 'reference/natural' 1 in 10 year floods would not occur even once in 66 years under these scenarios (according to the simulated 66 year hydrology). These very large changes in the flood regime are considered to be hugely significant for the estuarine habitat.

Under these scenarios (6 and 7) there are no large/resetting floods to scour out estuarine sediments. Thus, there will probably be a net accumulation of sediments, both riverine and marine. The mainly braided channels in the upper estuary could change to a mostly meandering nature. More permanent and larger mud-/sandbanks will occur throughout the estuary. Due to the net sediment build-up, the estuary (and intertidal areas) could eventually reduce significantly in size. Due to the significantly reduced riverine sediment inputs, with some amount of ongoing marine sediment intrusion (and in the absence of major flushing), marine sediments (coarser and non-cohesive) will eventually constitute a significantly larger proportion of estuarine sediments than during reference or present conditions. The subtidal area, e.g. basin and lower channels, will become smaller and shallower. The morphological character of the braided channels is also likely to change substantially.

Changes and scores are summarised in tables 59 and 60 respectively.

Table 59. Summary of changes in physical habitats under the different scenarios

Parameter	***Changes***
Scenarios 2, 3 and 4	
Similarity in intertidal area exposed	Similar to the present status, because river flow regime and coastal processes/dynamics are very similar to the present state.
Similarity in sand fraction relative to total sand and mud	Similar to the present status, because river flow regime and coastal processes/dynamics are very similar to the present state.
Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	Similar to the present status, because river flow regime and coastal processes/dynamics are very similar to the present state.
Scenario 5	
Similarity in intertidal area exposed	A bit worse than the present status due to significant further reduction in smaller floods (<1:10 year events). The smaller floods are considered to be important in redistributing sediments deposited by large floods. Thus, there will probably be more accumulation of sediments, both riverine and marine, but especially in the upper estuary. Sediments will have longer periods over which they can be compacted/consolidated, and vegetation will have longer periods to stabilise. Overall this zone will become less dynamic.
Similarity in sand fraction relative to total sand and mud	The cohesive sediments (clays) will be subject to greater compaction/consolidation making them more resistant to scouring. Marine sediment intrusion (coarser and non-cohesive sediments) into the lower estuary will increase due to reduced number of flood events washing some of these sediments back out to sea.
Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	Similar to the intertidal areas, there will probably be more accumulation of sediments, both riverine and marine, but especially in the upper estuary. Sediments will have longer periods over which they can be compacted/consolidated, and vegetation will have longer periods to stabilise. Overall this zone will also become less dynamic.
Scenarios 6 and 7	
Similarity in intertidal area exposed	Under these scenarios there are no large/resetting floods to scour out estuarine sediments. Thus, there will probably be a net accumulation of sediments, both riverine and marine. The mainly braided channels in the

Parameter	*Changes*
	upper estuary could change to a mostly meandering nature. More permanent and larger mud-/sandbanks will occur throughout the estuary. Due to the net sediment build-up, the estuary (and intertidal areas) could eventually reduce significantly in size.
Similarity in sand fraction relative to total sand and mud	Due to the significantly reduced riverine sediment inputs, with some amount of ongoing marine sediment intrusion (and in the absence of major flushing), marine sediments (coarser and non-cohesive) will eventually constitute a significantly larger proportion of estuarine sediments than during reference or present conditions.
Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	Similar to the above, this zone will become smaller and shallower. The morphological character of the channels is likely to change substantially.

Table 60. Similarity scores for physical habitats under different scenarios

Variable	*Present*	*Sc 2*	*Sc 3*	*Sc 4*	*Sc 5*	*Sc 6*	*Sc 7*	*Confidence*
1a: % similarity in present to reference intertidal area								
	65	65	65	65	50	10	10	Medium
1b: % similarity in in present to reference sand fraction relative to total sand and mud								
	85	85	85	85	70	20	20	Medium
2: Resemblance of subtidal estuary to reference condition: Depth, bed and channel morphology								
	80	80	80	80	65	10	10	Medium
Physical habitat score[1]	78	78	78	78	63	13	13	

1 Score = $\frac{\text{mean (1a + 1b) +2}}{2}$

4.3 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.

4.3.1 Microalgae

Background: Changes could be described for the different groups i.e. cyanophytes, dinoflagellates, chlorophytes, diatoms and flagellates. Changes and scores are summarised in Tables 61 and 62 respectively.

Table 61. Summary of how the microalgae change relative to the reference and/or present condition under the different scenarios

Scenario	Summary of changes
2	Salinity is likely to increase slightly (~2 ppt), with a slight increase in nutrients supporting a slight increase in biomass and contributions from flagellates and dinoflagellates relative to diatoms and chlorophytes (Phytoplankton: 1% decrease from present, and MPB: 4% decrease).
3	Similar to Sc 2.
4	Salinity likely to decrease slightly (~4 ppt) with a slight decrease in nutrients. Favours slight increase in diatoms and chlorophytes relative to flagellates and dinoflagellates (4% increase from present).
5	Slight reduction in river flow and smaller floods favours the intrusion of nutrient-rich upwelled coastal water and consolidation of sediment.
6	Drastic increase in salinity (~20 ppt) and extended mouth closure likely to favour flagellates relative to all other groups (12% increase in phytoplankton biomass and 28% increase in MPB biomass). Loss of intertidal zone.
7	Drastic increase in salinity (~18 ppt) and extended mouth closure likely to favour flagellates relative to all other groups (11% increase in phytoplankton biomass and 26% increase in MPB biomass). Loss of intertidal zone.

Table 62. Similarity scores of microalgae under the different scenarios

Component	Present	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Confidence
Phytoplankton								
Species richness	60	60	60	60	55	50	50	Low
Abundance	40	39	39	40	37	28	29	Low
Community composition	80	80	80	80	37	28	29	Low
Benthic microalgae								
Species richness	70	65	65	70	65	40	40	Low
Abundance	64	60	60	68	59	36	38	Low
Community composition	60	60	60	65	60	35	35	Low
Microalgae score	**40**	**39**	**39**	**40**	**37**	**28**	**29**	**Low**

4.3.2 Macrophytes

This section describes the changes in macrophytes for the different run-off scenarios. Scores and changes are summarised in Tables 63 and 64 respectively.

Low flows have significantly increased under present state, Sc 2 and 3, while Sc 4 represents a significant improvement on the present. For Sc 5 there is an increase in baseflow but a decrease in the frequency of floods. Scenario 6 and 7 represent a drastic reduction in all flow ranges, with inflows zero most of the time (Van Niekerk et al., 2013). The supratidal salt marsh area changed radically from the reference condition for all scenarios therefore community composition remains fairly similar for the different scenarios (Sc 2, 3, 4). Species richness and abundance are more similar to the reference condition for Sc 4. There is a drastic decrease in species richness, abundance and community composition for Sc 6 and 7. There is a loss in area cover of all macrophyte habitats except macroalgae which would survive the low flow, saline conditions. For Sc 6 and 7 the dry saline environment would result in loss of vegetated areas. The mouth area is expected to become a barren salt pan with some macroalgae surviving in the shallow waters.

For Sc 2, 3 and 5 there is an increase in closed mouth conditions compared to the reference state. This would cause die-back of intertidal salt marsh, reeds and sedges as they are sensitive to prolonged mouth closure. The mouth closes more frequently for Sc 2.

For Sc 4 large floods are similar to the present condition. The overall decrease in the dynamic sediment environment will result in the expansion of reeds, sedges and intertidal salt marsh in the lower reaches. There is a decrease in salinity compared to the Present Conditions and it is now more similar to the reference state thus promoting macrophyte growth. However there has still been an overall increase in salinity compared to reference conditions which decreases macrophyte growth. Supratidal salt marsh would increase in cover compared to the present state as a result of the increase in closed mouth conditions and decrease in salinity. This would lower groundwater salinity which the dominant species are dependent on. **For Sc 5** floods are removed because of the Vioolsdrift balancing weir and Polihali Dam. Stable sediment conditions would encourage macrophyte growth

Scenario 4 comparison with reference conditions (percentage change in abundance measured as area cover)

Abiotic Factors	*Changes*
⇩ large and small floods	Stable sediment encourages macrophyte growth. ⇧ 25% reeds and sedges. ⇧ 5% intertidal salt marsh.
⇧ salinity	⇩ 5% reeds and sedges particularly in lower reaches. ⇩ 5% intertidal salt marsh.
⇧ nutrients	⇧ 50% macroalgae.
Causeway	⇩ 80% supratidal salt marsh ⇧ desertified salt marsh
Overall change	Macroalgae ⇧ 50%; submerged macrophytes 0%; reeds and sedges ⇧ 20%; intertidal salt marsh 0%; supratidal salt marsh ⇩80%.

Scenario 5 comparison with reference conditions (percentage change in abundance measured as area cover)

Abiotic Factors	*Changes*
⇩ large and small floods	Stable sediment encourages macrophyte growth. ⇧ 35% reeds and sedges. ⇧ 8% intertidal salt marsh.
⇧ salinity and mouth closure	⇩ 25% reeds and sedges particularly in lower reaches. ⇩ 5% intertidal salt marsh.
⇧ nutrients	⇧ 50% macroalgae.
Causeway	⇩ 70% supratidal salt marsh ⇧ desertified salt marsh.

Overall change	Macroalgae ⇧ 50%; submerged macrophytes 0%; reeds and sedges ⇧ 25%; intertidal salt marsh 0%; supratidal salt marsh ⇩70%.

Sc 6 and 7 represent the worst case scenario where there are no resetting floods to scour out estuarine sediments. More permanent and larger mud-/sandbanks will occur throughout the estuary and over time these would be colonised by macrophytes. However due to zero freshwater inflow the salinity increases within a range from 20 to 30 ppt and the drier more saline environments would decrease macrophyte growth. Only salt tolerant macroalgae would grow under these conditions. The estuary water column and subtidal areas would become smaller and shallower resulting in a loss of submerged macrophyte area. The mouth would close annually inundating the intertidal salt marsh and reeds and sedges with saline water and causing die-back.

Table 63. Summary of how the macrophytes change relative to the reference condition under the different scenarios

Scenario	***Summary of changes***
2	Decrease in salinity compared to present but ⇧ mouth closure (82% compared with reference 32%). These conditions would result in flooding and some loss of intertidal salt marsh, reeds and sedges as they are sensitive to prolonged inundation. Floods would be similar to present with no beneficial effects on supratidal salt marsh. Species have been lost because of the less dynamic environment and high salinity conditions. The average species richness is similar to present condition, although salinity has improved slightly, mouth closure would reduce species richness. The average species richness per sampling event is 50% of the average expected during the reference condition considering only original species. Abundance (area cover): Macroalgae ⇧ 50%; submerged macrophytes 0%; reeds and sedges ⇩5%; intertidal salt marsh ⇩5%; supratidal salt marsh ⇩90%.
3	Compared with Sc 2 the mouth closes less frequently (72%) but there is still a ⇧ mouth closure compared to reference conditions. These conditions would result in flooding and some loss of intertidal salt marsh, reeds and sedges as they are sensitive to prolonged inundation. Slight increase in floods compared to Sc 2 due to EFR release which results in slight decrease in salinity compared with Sc 2 and present conditions. The average species richness is similar to present condition, although salinity has improved slightly, mouth closure would reduce species richness. Abundance (area cover): Macroalgae ⇧ 50%; submerged macrophytes 0%; reeds and sedges ⇩3%; intertidal salt marsh ⇩3%; supratidal salt marsh ⇩90%.
4	⇩ Salinity compared to present and similar to reference due to significant increase in low flow, mouth closure similar to reference. There is an improvement in conditions compared to the present state. The average species richness will improve slightly from present conditions. Resetting floods are still absent reducing the dynamic nature of the estuary would promote species richness. Abundance (area cover): Macroalgae ⇧ 50%; submerged macrophytes 0%; reeds and sedges ⇧ 20%; intertidal salt marsh 0%; supratidal salt marsh ⇩80%.
5	Slight improvement in low flow conditions compared to present but not as high as that in Sc 4. Floods are reduced compared to all other scenarios excluding Sc 6 and 7. This results in shallowing in the upper reaches which would encourage reed and salt marsh growth. Mouth closure is similar to Sc 3 (67%), these conditions would result in flooding and some loss of intertidal salt marsh, reeds and sedges as they are sensitive to prolonged inundation. There is an increase in salinity compared to present conditions which would reduce plant growth nutrients are similar to present conditions which would promote macroalgal growth. Abundance (area cover): Macroalgae ⇧ 50%; submerged macrophytes 0%; reeds and sedges ⇧

Scenario	*Summary of changes*
	10%; intertidal salt marsh ⇧3%; supratidal salt marsh ⇩70%.
6 and 7	⇩ Large and small floods, significant sedimentation and shallowing which encourages macrophyte growth, however due to the low water level and increase in salinity an expected die-back of all macrophyte habitats is expected. Extensive loss of species due to complete change in abiotic characteristics of the estuary. ⇧ Salinity due to 0 flows, range from 20 to 35 ppt, the drier more saline environment would decrease macrophyte growth. ⇧ mouth closure, occurs nearly every year, this would lead to loss of intertidal salt marsh and reeds and sedges due to inundation with saline water, the only group that would grow would be salt tolerant macroalgae. Abundance (area cover): Macroalgae ⇧ 100%; submerged macrophytes ⇩50%; reeds and sedges ⇩90%; intertidal salt marsh ⇩90%; supratidal salt marsh ⇩95%.

Table 64. Similarity scores of macrophytes under the different scenarios

Variable	*Present*	*Sc 2*	*Sc 3*	*Sc 4*	*Sc 5*	*Sc 6*	*Sc 7*	*Confidence*
Species richness	50	50	50	55	48	10	10	Medium
Abundance	67	65	65	75	62	6	6	Medium
Community composition	63	62	63	67	58	18	18	Medium
Macrophyte score	**50**	**50**	**50**	**55**	**48**	**10**	**10**	**Medium**

4.3.3 Invertebrates

This section describes the changes in invertebrates for the different run-off scenarios. Changes and scores are summarised in Tables 65 and 66 respectively.

Table 65. Summary of how the invertebrates change under the different scenarios

Scenario	*Summary of changes*
2	The key factor influencing the invertebrate community under this scenario is the increase in a closed mouth state. Increased frequency and duration of mouth closure (particularly in summer) would lead to a significant increase in species richness, abundance and community composition within all euryhaline invertebrate groups, particularly the zooplankton. This is because the tidal flushing effect is removed at times of mouth closure. Under this scenario, the invertebrate community would also reflect extremely high variability within and between years as state of the mouth, tidal current effects (refer to present state scenario) and floods impact the estuary. There is also the likely-hood that salinity will extend further upstream, extending available habitat for the euryhaline community. Along the salinity gradient established, optimal conditions for specific species will become available.
3	Similar to the above scenario.
4	Under this scenario, the increase in baseflows will lead to the estuary moving along a trajectory more representatives of natural conditions. The estuarine zooplankton community will disappear, while the hyperbenthos will be present during dry phases only. Mud- and sand-banks will become more extensive (at least initially), providing habitat for intertidal benthic species such as the popychaete *Ceratonereis keiskama*. However, compared to the natural state the role played by re-setting floods will disappear and open banks will slowly become vegetated.
5	Floods reduced in terms of present state. The mouth closes for 2 – 3 months during dry years (7 times in 10 years, ca 3 – 4 times under natural). Salinity values similar to present, but extending

Scenario	Summary of changes
	further upstream (higher compared to previous scenario). Increased mouth closure will lead to zooplankton and hyperbenthic populations becoming well established (also due to flood reduction). Within-year variance high in terms of abundance of invertebrate communities. Increased dominance because of populations persisting for longer (Closed mouth conditions).
6	Under this scenario, salinity will increase significantly (ca 20) and the mouth will remain closed for extended periods. Compared to Sc 2 and 3, variability in the physic-chemical environment will decrease and this will lead to the invertebrate community establishing itself and initially remaining at high biomass levels. Species richness will decrease as freshwater associated species disappear.
7	As above.

Table 66. Similarity scores of invertebrates under the different scenarios

Variable	Present	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Confidence
Species richness	50	40	40	70	60	35	35	Medium
Abundance	45	35	35	70	55	10	10	Medium
Community composition	45	35	35	70	55	10	10	Medium
Invertebrate score	**45**	**35**	**35**	**70**	**55**	**10**	**10**	**Medium**

4.3.4 Fish

This section describes the changes in fish for the different run-off scenarios. Changes and scores are summarised in Tables 67 and 68 respectively.

Table 67. Summary of how the fish change under the different scenarios

Scenario	Summary of changes
2 and 3	An increase in the frequency (72 – 82% of years) and duration of mouth closure relative to the reference (32% of years). Closure may be severe for the fish assemblage as it is most likely to occur during spring and early summer, the peak recruitment period for the juveniles and larvae of estuary-dependent species. Closure is also of longer duration compared to reference, favouring a fish assemblage typical of temporarily open closed estuaries and would result in the loss of marine vagrant species. A 50% increase in macroalgae will favour benthic species such as *C. nudiceps* and *S. temminckii* whereas increased zooplankton production will favour the juveniles of all species. However, a possible increase in the diversity and abundance of benthic species such as *L. lithognathus* would be negated by the impact of poorly timed and prolonged mouth closure on recruitment. A slight decrease in benthic diatoms, the principal food of *L. richardsonii* would be easily compensated by a switch to feeding on zooplankton. Mouth closure during spring and summer will also reduce the availability of the warm water refuge to fish attempting to escape cold up-welled water in the nearshore. A slight increase in floods (Sc 3) would favour aggregations of *L. aureti, A. japonicu*s and *A. inodorus* in the adjacent surf-zone and facilitate recruitment of the latter species into the estuary. Increased floods will also enhance recruitment cues for estuary-associated fish.
4	The frequency of mouth closure under Sc 4 (39% of years) is similar to that of reference (32% of years). However, the possibility of closure, and by inference duration, is greater than reference over the entire spring-early-summer peak recruitment period for most estuary-associated marine species. As with Sc 2 and 3, this would favour a fish assemblage typical of temporarily open closed estuaries and result in the loss of marine vagrant species.

Scenario	***Summary of changes***
	Similar to Sc 2 and 3, a 50% increase in macroalgae and more extensive mud-banks will favour benthic species such as *C. nudiceps* and *S. Temminckii*. However, the loss of zooplankton production will maintain the current low diversity and abundance of benthic species such as *L. lithognathus* that would already have been exacerbated by the impact of poorly timed and prolonged mouth closure on recruitment. A slight increase in benthic diatoms, may favour *L. richardsonii* the dominant fish in the system. Again, mouth closure during spring and summer will also reduce the availability of the warm water refuge to fish attempting to escape cold up-welled water in the nearshore. Floods are similar to the present-day and favour aggregations of *L. aureti, A. japonicus* and *A. inodorus* in the adjacent surf-zone and facilitate recruitment of the latter species into the estuary. Floods also enhance recruitment cues for estuary-associated fish. This said, magnitude and occurrence of floods and associated surf-zone aggregations and recruitment would all have been greater under reference.
5	Sc 5 is similar to Sc 4 (which is closer to ref than present) but with much reduced floods and an increase in the frequency and duration of mouth closure. 67% versus 32% and 39% under reference and Sc 4 respectively. The possibility of closure, and by inference duration, is greater than reference over the entire spring-early-summer peak recruitment period for most estuary-associated marine species. As with Sc 2, 3 and 4 this would favour a fish assemblage typical of temporarily open / closed estuaries and result in the loss of marine vagrant species. Salinity levels of 4-21 PSU well within preference of estuary-associated species but with the exception of salt tolerant *O. mossambicus,* most freshwater fish restricted to upper and freshwater reaches. Slight decrease in benthic diatoms but close enough to Sc 4 to favour *L. richardsonii* the dominant fish in the system. Loss of intertidal foraging habitat for this and other species. Again, mouth closure during spring and summer will much reduce the availability of the warm water refuge to fish attempting to escape cold up-welled water in the nearshore. Much reduced floods and high turbidity pulses will translate into the reduction of aggregations of *A. inodorus* and other species in the nearshore.
6 and 7	Under Sc 6 and 7 the estuary mouth is likely to close every year and for prolonged periods, perhaps throughout some years. Recruitment is likely to become an inter-annual event and restricted to the rare occasions when opening and peak recruitment periods coincide. The dominant fish in the system would be estuary residents (*G. aestuaria, A. breviceps*) and the two species (*L. richardsonii, M. cephalus*) that frequently recruit during high seas and over-wash events. The occurrence of the three abundant piscivorous fish, *A. inodorus, P. saltatrix* and *L. amia* is likely to become patchy or extremely rare. Numbers of benthic invertebrate feeders will remain low irrespective of whether habitat and prey abundance became suitable or not. *L. richardsonii* will respond to a drop in benthic diatom biomass by switching to macroalgae, zooplankton and other invertebrate prey. Persistent low flows as well as a 90% reduction in floods translate into a > 90% loss of recruitment cues for estuary-associated fish. Aggregations of *L. aureti, A. japonicus* and *A. inodorus* in the adjacent surf-zone in response to floods will become rare or non-existent. Mouth closure during spring and summer will remove the availability of the warm water refuge to fish attempting to escape cold up-welled water in the nearshore. The absence of large resetting floods will see a reduction in sediment scouring and loss of shallow intertidal habitat and foraging area for fish. Coupled with low flows channels are likely to become incised and the proportion of coarse, non-cohesive marine sediments higher. Pipefish *S. temminckii* and both *Caffrogobius* species have a preference for muddy habitat but its loss may be compensated by a 100% increase in macroalgae biomass in the system. All, estuary residents, especially juveniles, will benefit from an increase in this macroalgae refuge provided that night-time respiration and algal decay don't reduce oxygen to lethal levels.

Scenario	Summary of changes
	Increased salinity levels (20 – 35 PSU) will see most freshwater fish move into the river reaches. The exception will be Mozambique tilapia *O. mossambicus* that is tolerant of low oxygen and will often move into areas where levels drop. In addition, coarse sands provide ideal nesting sites and macroalgae abundant food for this herbivorous species.

Table 68. Similarity scores for fish under the different scenarios

Variable	Present	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Confidence
Species richness	60	60	60	60	50	40	40	Medium
Abundance	50	40	45	50	40	40	40	Medium
Community composition	60	60	60	60	55	50	50	Medium
Fish score	50	40	45	50	40	40	40	

4.3.5 Birds

This section describes the changes in birds for the different run-off scenarios. In order to remove the complication of past non-flow-related influences, the scenarios are predicted on the basis of the estimated present-day avifaunal community and the changes in influencing factors relative to present-day. The main parameters used to estimate these changes are summarised in Table 69, and scores have been reworked to express change relative to present. Changes and scores are summarised in Figure 15 and Tables 69 to 70 respectively.

Table 69. Summary of the main parameters used to estimate changes in the bird community, expressed as percentage of present state

Parameters	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7
Islands in mouth	100	100	100	50	25	25
Intertidal area	100	100	100	77	15	15
Salinity (‘freshness’)	104	107	141	94	48	52
Vegetation abundance	100	108	115	95	9	9
Invertebrate abundance	78	78	156	122	22	22
Fish abundance	80	90	80	80	70	70

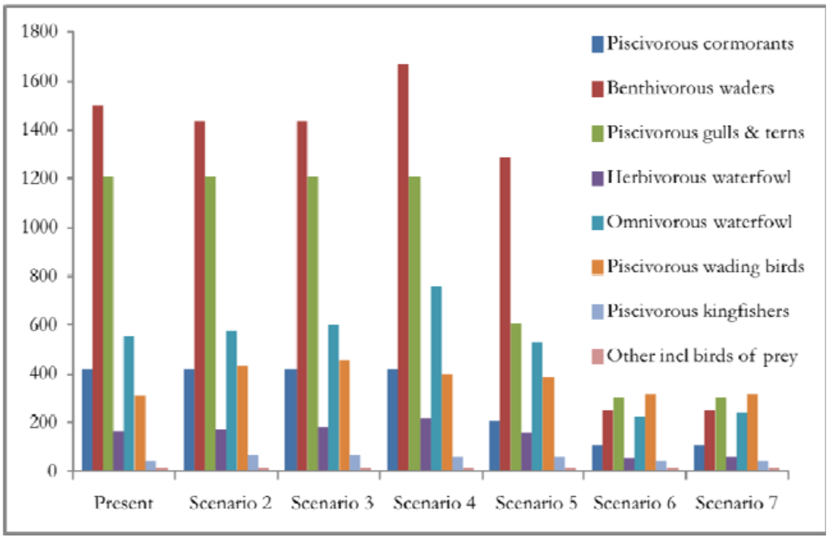


Figure 15. Summary of predicted changes under different scenarios from an approximated present state

Table 70. Similarity scores for birds under the different scenarios

Variable	*Present*	*Sc 2*	*Sc 3*	*Sc 4*	*Sc 5*	*Sc 6*	*Sc 7*	*Confidence*
1. Species richness	90	88	88	90	85	60	60	Medium
2 Abundance	23	23	24	26	18	7	7	Medium
3. Community composition	37	38	38	41	30	13	13	Medium
Bird score	**23**	**23**	**24**	**26**	**18**	**7**	**7**	

4.4 Ecological categories associated with runoff scenarios

The individual health scores, as well as the corresponding EC under different scenarios, are provided in the following table. The estuary is currently in a D category. It would deteriorate slightly under Sc 2, 3 and 5, but would likely remain in a D category. The estuary would improve under Sc 4 (decrease baseflows) to a C/D category. Under Sc 6 and 7 the estuary would significantly decline in health to an F category.

Scenario 4 minus anthropogenic impacts (indicated as Sc 4 – Anth) provides an evaluation of the contribution of non-flow-related impacts – removal of the causeway, reduction in baseflows to allow for mouth closure, a 50% decrease in nutrients, decreasing fishing effort. It suggests that if some of these are achieved in conjunction with the flow regime of Sc 4, the estuary condition could be raised to a C category.

The final scenario represents a combination of Sc 5 with a significant decrease in baseflows (similar to Sc 4 and indicated as Sc 5 – rehab & baseflows) in conjunction with some remedial/rehabilitation actions. Under this scenario the estuary would remain in a C/D category.

The health score and corresponding EC under the runoff scenarios are provided below in Table 71.

Table 71. Estuary health score and corresponding ecological category under the various runoff scenarios

			Scenarios							
Component	***Weight***	***Present***	***2***	***3***	***4***	***5***	***6***	***7***	***4 – Anth***	***5 – rehab & baseflows***
Hydrology	25	44	48	48	57	47	20	21	57	52
Hydrodynamics and mouth condition	25	70	50	60	90	60	0	0	90	90
Water quality	25	53	54	55	60	52	40	42	68	68
Physical habitat alteration	25	78	78	78	78	63	13	13	82	67
Habitat health score		**61**	**57**	**60**	**71**	**56**	**18**	**19**	**74**	**69**
Microalgae	20	40	40	39	40	37	28	29	40	40
Macrophytes	20	50	50	50	55	48	6	6	70	65
Invertebrates	20	45	35	35	70	55	10	10	80	50
Fish	20	50	40	45	50	40	30	30	60	50
Birds	20	23	23	24	26	18	7	7	43	38
Biotic health score		**42**	**38**	**39**	**48**	**40**	**16**	**16**	**59**	**49**
Estuary health score		**51**	**48**	**49**	**60**	**48**	**17**	**18**	**66**	**59**
Ecological category		**D**	**D**	**D**	**C/D**	**D**	**F**	**F**	**C**	**C/D**

4.5 Recommended ecological flow requirement for the Orange Estuary

For a high-confidence study, the 'recommended environmental 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 REC. Where any component of the health score is less than 40, modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. Based on this assessment, the best attainable state for the estuary is a C category.

None of the flow scenarios presented as part of this study meet the REC of C based solely on river inflow. Therefore, the recommended EFR is Sc 4 in conjunctions with the following mitigation measures:

- decreasing the winter baseflows sufficiently to allow for mouth closure and related backflooding of the saltmarshes with brackish water to reduce soil salinities;
- controlling the fishing effort on both the South African and Namibian side through increased compliance and law enforcement. This also requires the alignment of fishing regulations (e.g. size and bag limits) and management boundaries on either side of the transboundary estuary;

- removal of the remnant causeway that still transects the saltmarshes to improve circulation during high flow and floods events. This will also assist with increasing the water circulation into the lower marsh areas;
- decreasing nutrient input from the catchment downstream of Vioolsdrift, through improved agricultural practices;
- controlling windblown dust and wastewater from mining activities;
- reduce/remove grazing and hunting pressures.

The flow requirements for the estuary are the same as those described for Sc 4. A summary of the monthly flows for the scenario is presented in Table 72.

Table 72. Summary of the mean monthly flow (in m³/s) distribution under Sc 4

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
10%	54.8	258.4	151.1	518.2	1,544	646.5	571.0	158.5	63.2	30.3	31.3	30.2
20%	34.0	74.5	108.6	162.3	847.2	459.9	278.5	128.9	48.7	29.0	29.1	29.8
30%	32.9	71.0	82.2	105.7	216.5	295.1	139.5	76.1	46.5	28.3	28.5	28.9
40%	31.5	69.4	79.0	94.7	138.3	177.7	116.7	66.7	42.9	27.2	26.5	28.2
50%	28.8	66.7	62.6	84.6	99.4	133.6	104.7	60.4	38.9	26.2	24.1	25.0
60%	25.3	63.4	52.8	62.1	77.6	102.6	90.8	55.4	35.2	25.2	20.2	19.4
70%	17.7	41.3	42.2	35.6	51.5	63.6	57.0	44.5	21.3	19.1	15.3	10.5
80%	9.9	22.1	23.7	25.5	39.0	45.3	40.1	13.2	11.3	11.2	8.5	3.8
90%	4.1	8.8	18.8	18.1	34.1	38.6	16.0	7.7	5.9	6.7	4.7	0.0
99%	0.0	0.0	11.0	9.6	29.2	28.4	8.2	5.9	4.3	3.8	2.6	0.0

4.6 Recommendations for the estuary management plan

It should be noted, however, that some of these proposed mitigation measures, such as the reduction in fishing pressure, would be difficult to achieve in the short-term. It is therefore strongly recommended that the estuary management plan currently being developed for the Orange Estuary prioritise these actions for future implementations. It is also recommended that the management plan proactively addresses potential issues stemming from estuary mouth closure:

- determining the water level (relative to mean sea level) at which critical infrastructure and developments will be inundated if mouth closure occurs (e.g. by means of a Lidar survey of both South African and Namibian estuary floodplains);
- investigating the protection of the aforementioned infrastructure (e.g. golf course on the Namibian side);
- development of an mouth breaching protocol based on 'Guidelines for the mouth management of the Orange Estuary' (Van Niekerk and Huizinga, 2005);
- monitoring of water quality during the closed period.

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