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 2: Orange Estuary EFR: Supporting Information

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

Technical Report 33
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UNDP-GEF
Orange-Senqu Strategic Action Programme

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

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0	Initial draft draft for review	Aug 2013	LvN, DL
1	Second draft including recommendations	Oct 2013	LvN, DL

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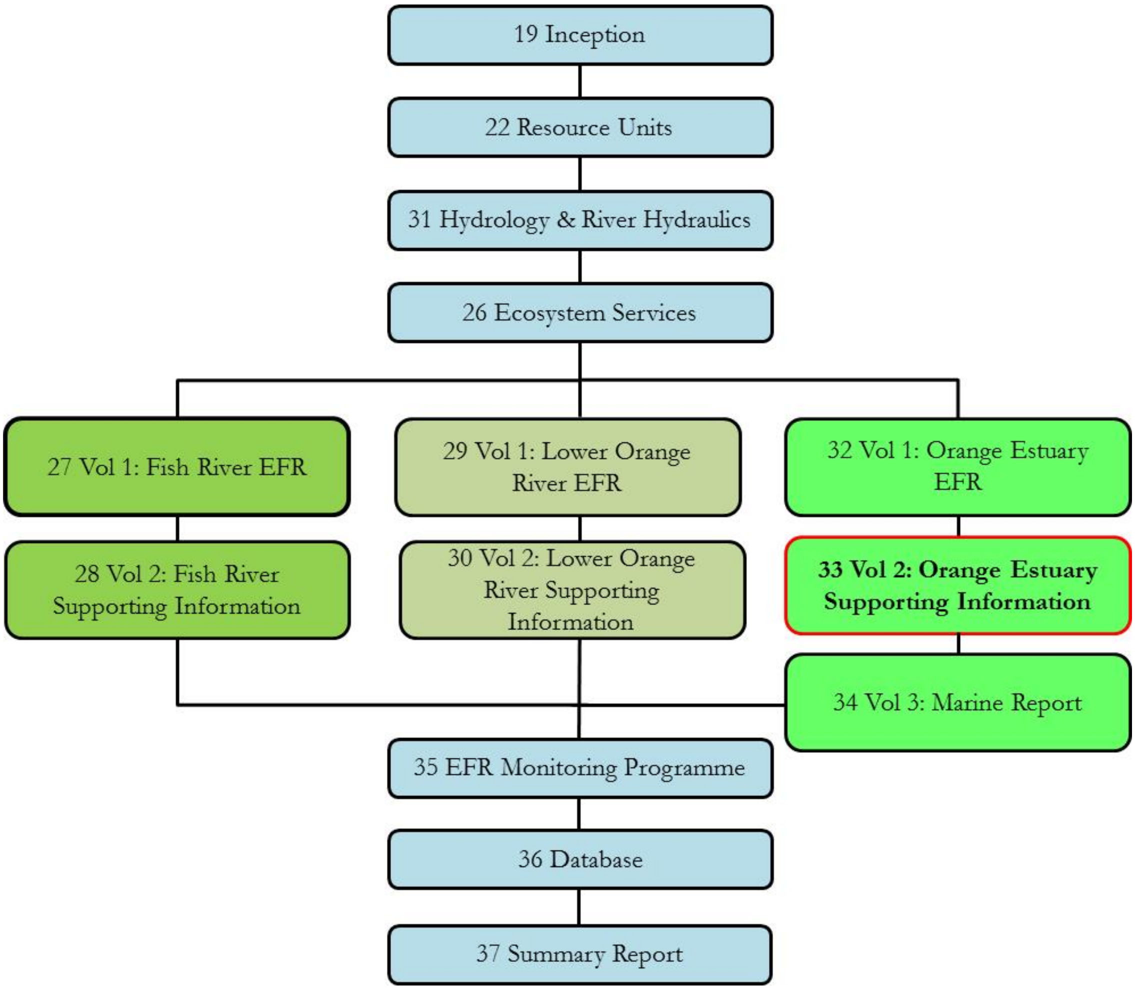
Report list

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
36	Database, Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth

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

Bold indicates current report.



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Contents

List of tables

List of figures

Abbreviations

BCLME	*Benguela Current Large Marine Ecosystem*
BAS	*Best attainable state*
CSIR	*Centre of Scientific and Industrial Research*
CWAC	*Co-ordinated Waterbird Counts*
DAFF	*Department Agriculture, Forestry and Fisheries*
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*
EFR	*Environmental flow requirements*
HWL	*High water level*
IWRM	*Integrated water resources management*
IUCN	*International Union for Conservation of Nature*
LWL	*Low water level*
MAR	*Mean annual run-off*
MSL	*Mean sea level*
ORASECOM	*Orange-Senqu River Commission*
PSU	*Practical salinity units*
PES	*Present ecological state*
RDM	*Resource Directed Measures*
REI	*River-estuary interface*
SAEON	*South African Environmental Observation Network*
TP	*Total phosphorus*
WOMS	*Wet overburden mining system*

1. Introduction

1.1 Background

The Orange-Senqu River riparian states (Botswana, Lesotho, Namibia and South Africa) are committed to address threats to the shared water resources of the basin. This is reflected in bilateral and basin-wide agreements between the riparian states and led to the formation of the Orange-Senqu River Commission (ORASECOM) in 2000. The UNDP-GEF Orange-Senqu Strategic Action Programme Project supports ORASECOM in developing a basin-wide Strategic Action Programme for the management and development of water resources, based on integrated water resources management (IWRM) principles.

The water resources of the Orange-Senqu River are utilised extensively and the system is highly regulated by 23 major dams and six inter-basin water transfer schemes within its basin.

Environmental flow requirements (EFR) of the ephemeral but nevertheless significant Fish River, and the Orange River, from its confluence with the Fish River to the Orange River mouth were not covered in any detail by the 2009–2010 study. This section of the river is the subject of this research project. The importance of completing the EFR study is becoming increasingly urgent due to the fact that two large dams, one in the lower Orange River (Vioolsdrift Dam) and one in the lower Fish River (Neckartal Dam), are at an advanced stage of planning.

One of the focus areas of this larger project is the Orange-Senqu River mouth (the Orange Estuary) and the adjacent marine environment.

1.2 Objectives of the study

The Orange Estuary study focuses on sediment and hydrodynamics, water quality, microalgae, vegetation, invertebrates, fish and birds. For this the following was 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 conducts an assessment regarding the role of freshwater inflows and associated fluxes and potential effects on the coastal marine ecosystems. This is done in order to recommend allowable changes to the inflow of freshwater into the marine environment.

1.3 Orange Estuary

The Orange Estuary (28°38' S; 16°27' E) is situated just north of the coastal town of Port Nolloth in the Northern Cape and forms the border between South Africa and Namibia.

The estuary comprise an (almost) permanently open mouth, a deeper tidal basin, a braided channel system (located between sand banks covered with pioneer vegetation) and a severely degraded saltmarsh on the south bank (Cowan, 1995). Previous freshwater requirement studies indicated that the Orange Estuary extends from the mouth as far as the Sir Ernest Oppenheimer Bridge, approximately 11 km upstream (CSIR, 2004). Tidal variations of a few centimetres are observed during springtide at this bridge (Figure 1).

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. The marine water interchange is limited to the lower section of the estuary under normal flow conditions.

In the past the location of the mouth was determined by natural or artificial breaching. The artificial mouth breachings have been undertaken on the north and south sides of the river by Namdeb and Alexcor respectively. The objective of these breachings has been to protect low-lying infrastructure from being flooded.

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

1.4 Report structure

The EcoClassification and EFR determination of the Orange Estuary and Marine Environment are part of Task 9 of the project plan and the results are contained within three reports:

- Technical Report 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
- Technical Report 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.
- Technical Report 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.

Technical Report 33 is a collection of supplementary technical reports which includes data collected during field surveys undertaken in January and August 2012, unpublished historical data collected by specialists on the Orange Estuary and literature surveys. This volume provides supporting information and background to Technical Report 32 and each specialist contribution forms a chapter of this volume and should be viewed as individual documents.

The report consists of the following chapters:

Chapter 1: Preface
This chapter provides an overview of the study area and objectives of the study.

Chapter 2: Abiotic components
Outlines the estuarine water quality, hydro- and sediment dynamics characteristics of the Orange Estuary in response to freshwater input.

Chapter 3: Estuarine microalgae
This chapter summarises the microalgae in the Orange Estuary and predicted responses to managed freshwater inputs.

Chapter 4: Estuarine macrophytes
This chapter provides an overview of the macrophytes (plants) of the Orange Estuary.

Chapter 5: Estuarine invertebrates
This chapter summarises the findings of the estuarine invertebrate assessment of the Orange Estuary in relation to freshwater flows.

Chapter 6: Estuarine fish
This chapter assess the condition of the fish of the Orange Estuary and evaluate their responses to freshwater flow.

Chapter 7: Estuarine birds
This chapter summarises the overall status and responses of the birds of the Orange Estuary.

Chapter 8: References

Appendix A: Hydrodynamic modelling of salinity distributions in the Orange Estuary under a range of river inflow scenarios
The approach and methods to hydrodynamic moelling is discussed in this chapter.

2. Abiotic components

2.1 Hydrodynamics processes

2.1.1 The role of river inflow

The main driving force of all estuaries is the river flow in all its variability entering the estuary. The catchment of the Orange River is approximately one million square kilometres (DWA, 1990) and the natural mean annual runoff (MAR) is estimated at 11,306 Mm^3. It is estimated, that by 1989 the MAR had been reduced to about 50% of the natural MAR (DWA, 1990) and at present to about 40%.

Besides the significant reduction in river flow, the variability in the Orange River flow has also been strongly reduced due to water resource development, and related major dam contruction, in the catchment. Low flows (dry season) are elevated and flood peaks are reduced or captured by the dams. Some aspects are:

- occurrence of large floods – The occurrence and magnitude of large floods has been somewhat reduced. Floods in the Orange system normally occur during the summer months.
- occurrence of small floods – The occurrence and magnitude of smaller floods with return periods of 1:1 to 1:10 years, also during the summer months, have been greatly reduced. Resulting in a considerable reduction in the occurrence of flooding of the salt marsh near the mouth during the summer months. These floods would probably have lasted for periods of a few weeks.
- occurrence of periods of low flow – The occurrence of very low flow during the winter months, causing mouth closure and back-flooding in the past, has been significantly reduced, because of agricultural return flow and releases from the dams. These releases are undertaken for the generation of electricity and for irrigation purposes.

2.1.2 Interaction between river flow and mouth conditions

As a result of local conditions, considerable differences exist between estuaries in terms of the river flow required to keep an estuary mouth open. The Great Brak Estuary mouth, for example, tends to stay open if a river flow of 0,5 m^3/s is maintained for a few days over neap tide (CSIR, 1994). However, the mouth of the Umgeni Estuary near Durban closes occasionally at river flows of 7 m^3/s even at springtide (CSIR, 1990). Estuary specific data on river flow and mouth closures are therefore required to determine the flow conditions under which the estuary mouth will close and, unfortunately, such data are not available for the Orange Estuary.

In order to quantify the river inflow permitting mouth closure for the Orange Estuary, measured inflow at the Vioolsdrift gauging station (D8H003) were adjusted for evaporative losses and irrigation demand, and then correlated with the three documented mouth closure events (CSIR, 2004). These events were the prolonged mouth closure of spring 1993, and two brief mouth closure events during December 1994 and December 1995, recorded by the permanent water level recorder (D8H012) near Alexander Bay.

Unfortunately, there are no measured data (water levels and river inflow) for 1993 indicating the precise flows at which the Orange Estuary closed. From 6 August to 31 December 1993, however, flows of less than 5 m^3/s occurred for 148 consecutive days. Daily flows of below 10 m^3/s occurred for 70% of the calendar year, while flows less than 5 m^3/s occurred for about 50% of the year. The adjusted measurements of low flows support statements regarding mouth closure for this period. Because of irrigation demand and evaporation losses between Vioolsdrift and the Orange River mouth, which range from 5 m^3/s in September to 10 m^3/s in December, it is likely that minimal flow reached the estuary during this period.

The permanent water level recorder (D8H012) installed near Alexander Bay indicates a brief period of mouth closure from 1 to 3 December 1994. In the 45 days preceding the mouth closure the median river inflow was 15 m^3/s, with a minimum flow of 3 m^3/s and a maximum flow of 25 m^3/s.

The water level recorder also indicates a brief period of mouth closure from 1 to 6 December 1995. Mean measured inflows of less than 5 m^3/s were recorded from August to December 1995 for close to 100 consecutive days, with the average inflow estimated at 1 m^3/s. Daily flows below 10 m^3/s occurred for 50% of the calendar year, while flows less than 5 m^3/s occurred for 36% of the time. Once again it should be noted that there was only a brief mouth closure event of a few days, registered on the water level recorder as the river inflow picked up substantially after the low flow period.

The surface water area of the Orange Estuary from the mouth to the bridge was estimated to be between 2 Mm^2 and 6 Mm^2. If a conservative amount of the surrounding flood plain area is included in this calculation, as is the case under at higher water levels, the surface water area can be increased to about 12 Mm^2. Through the correlation of the water levels recorded by the Department of Water Affairs, South Africa (DWA) in December 1994 and 1995 and the estimated surface area, it was determined that related flows required to keep the mouth open was between 8 and 30 m^3/s, and 30 and 70 m^3/s for the 1994 and 1995 mouth closure events respectively. The higher values estimated for 1995 were supported by the fact that for the period preceding 1 December 1995, Viooldrift gauging station was recording flows in the order of 5 m^3/s or less. On 1 December 1995, however, the gauging station (about 280 km upstream from the mouth) recorded a significantly higher flow of about 120 m^3/s. This increased flow caused the breaching of the mouth on 6 December 1995.

Although the above data implies that the Orange Estuary probably only closes at flows of 5 m^3/s or less, low confidence in the measured inflow data (the gauging station can be out by as much as 70% during the low flow period) requires that a precautionary approached be followed and that mouth closure for the purpose of this study be set at flows of 5 m^3/s. At higher flows, the water level will continue to increase till breaching occurs and the mouth will therefore remain closed for only a limited period. However, the berm can build up to levels of +3.0 m MSL in a short time and extensive backflooding can take place.

The Orange Estuary mouth can close at higher flows, e.g. 10 – 20 m^3/s, but after closure the water level in the estuary will increase rapidly.

At low flows (<5 m^3/s), the water level will initially increase, but could then remain constant or even drop again, based on the balance between the flows and the losses, mainly through seepage and evaporation. The mouth would then remain closed until the river flow starts increasing again. Tidal flows through the mouth will then not occur and seawater will only enter the estuary in limited ways for example overwash by waves at high springtides.

2.1.3 Tidal variation

The mean tidal range at the mouth of the Orange Estuary is approximately 0,4 m and can be as much as 1,0 m during spring tides (Figure 2). A water level recorder installed at the old bridge about 6 km from the mouth shows a tidal range similar to that of the mouth region. The tidal influence in the estuary is very limited above the old bridge. The results from the water level recorder installed at the Sir Ernest Oppenheimer Bridge, 9,5 km upstream, show limited tidal variation (less than 2 cm) at spring tides when the river flow is low.

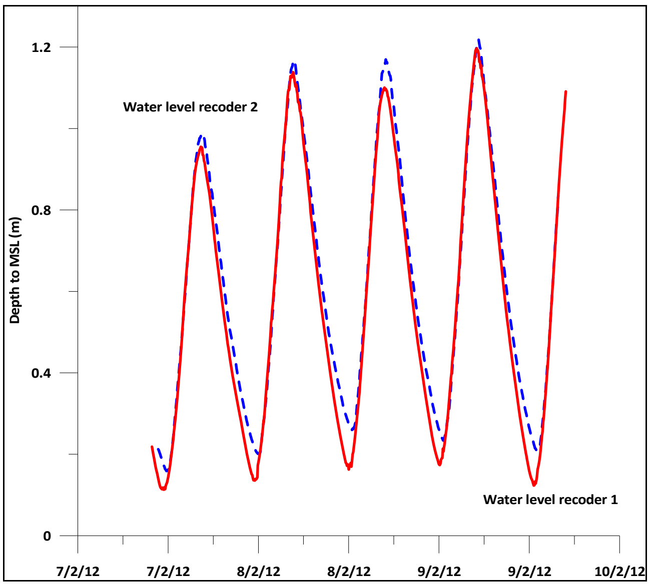


Figure 2. Water variation in the Orange Estuary in February 2012 at 2,7 km (water level recorder 1 – solid red line) and 6,0 km (water level recorder 2 – dashed blue line) from the mouth

Field observations also showed that tidal variation in the re-opened area behind the berm on the southern side is very dependent on its connectivity with the main water body. During the 2004 and 2005 surveys there were a well-established (50 m wide) connection to the main system, with tidal exchange estimated between 0,5 and 1,0 m (for example, a small boat with a 30 cm draft could clear the entrance channel on any tide). Intertidal salt marshes re-established themselves and flourished under these conditions.

During the 2012 field surveys this area was perched, with very little tidal variation observed (20 – 30 cm) through a very constricted channel (Figure 3 – left). A sediment sill (Figure 3 – right) had formed in the entrance to the side channel and had raised the water level in the re-opened area significantly. According to local fishermen this constriction developed during the 2010/11 floods. They indicated that initially the channel was even more constricted with water level variation in 2011 estimated at less than 10 cm. The tidal flows had over the last 2 years, slowly started widening and deeping the connection between the longshore area and the main water body again. The lack of tidal exchange is further supported by the loss of intertidal area and marshes in this biologically important area.

Figure 3. Photographs showing the restricted re-opened southern channel (left) and sediment sill that restricts tidal exchange in the re-opened area (right)

2.1.4 *Circulation features and salinity*

Circulation features

The Orange Estuary is characterised by highly dynamic, complex mixing processes that result from the interaction between: 1) the variability in river inflow; 2) the position of the mouth; and 3) the braided channel configuration and depth of the system. See Appendix A for more detail.

Depending on the river inflow, the estuary fluctuates between relatively well mixed at lower flows (<20 m^3/s) to highly stratified under higher flow condition (>50 m^3/s). Under intermediate flow conditions (20 – 50 m^3/s) the system tends to be well mix on the flood tide and stratified on the ebb tide.

The location of the mouth has a major influence on the salinity of the water reaching the salt marsh and the re-opened long-shore channel area on the southern bank. When the mouth is located at the southern position, considerable amounts of seawater enter the adjacent salt marsh and the longshore channel area at spring tides. However, the salinity of the water entering is much lower if the mouth is located at the northern bank.

The bathymetry also plays an important role in the mixing processes. While the central channels are relatively deep (1,5 – 3,0 m) and remain connected to the main body of water during all tides, side channels can become partially cut-off, or completely isolated, during low tides as a result of shallow bathymetric features that develop during succeeding floods.

In the following section salinity is used to demonstrate some of these features.

Salinity

Salinity data on the estuary were available from the following sources (Table 1):

- 13 – 14 January 1979 (CSIR, 1984);
- 25 August 1987 (CSIR, unpublished data);
- September 1993 (Harrison, 1997);
- conductivity measurements in March/April 1993, July 1993, September 1993 and January 1994 (Seaman and Van As, 1998);
- 10 February 2004, 2 August 2004 and 7 February 2005 (Benefit/ Benguela Current Large Marine Ecosystem (BCLME) study);
- 9 February and 23 – 24 August 2012 (this study).

Brown (1959) recorded salinities of 34,7 PSU from surface to bottom during high tide and 4,5 PSU at low tide surveyed during an open mouth state.

High and low tide surface salinity measurements recorded in January 1979 (Eagle and Bartlett, 1984) shows that the estuary was river-dominated with the mouth being situated closer to the Namibian bank (Table 1). Day (1981) observed that in the years that the river mouth closed, saline water extended as far as 8 km upstream from the mouth.

Table 1. Historical salinity data collected in the Orange Estuary during January 1979, August 1987 and September 1993

Position	***Estimated distance from mouth in km (Relative depth in m)***									
	0 (1.0)	***0.5 (4.5)***	***1.0 ( )***	***1.5 ( )***	***2 (3.3)***	***2.5 (1.3)***	***3 (<1)***	***3.5 (<1)***	***5.0 (<1)***	***7 (<1)***
January 1979 (Average measured flow ~ 300 m^3/s)										
Surface	<2.85*	<2.85*	–	–	–	<2.85*	<2.85*	<2.85*		
Bottom	–	–	–	–	–	–	–	–	–	
August 1987 (Average measured flow ~ 30m^3/s)										
Surface	6–10	2	–	–	0	0	–	–	–	
Bottom	33.5	31.5	–	–	30.5	0	–	–	–	

Position	***Estimated distance from mouth in km (Relative depth in m)***									
	0 (1.0)	***0.5 (4.5)***	***1.0 ( )***	***1.5 ( )***	***2 (3.3)***	***2.5 (1.3)***	***3 (<1)***	***3.5 (<1)***	***5.0 (<1)***	***7 (<1)***
26 March – 12 April 1993 (Average measured flow ~ 15m³/s)										
Water column**	–	9–36	–	–	–	6–36	–	–	–	0
September 1993 (Average measured flow ~1 m³/s)										
Surface	–	14.1	–	–	–	–	9.2	–	3.0	–
Bottom	–	29.3	–	–	–	–	22.2	–	16.5	–
30 September 1993 (Average measured flow ~1 m³/s)										
Surface**	–	–	36	30	–	35	20	–	–	–
Bottom**	–	–	36	36	–	35	19	–	–	–

* Minimum value that could be measured by the salinometer used at the time, salinity was probably ~ 0 Practical salinity units (PSU).
** Using the following conversion: Conductivity (mS/cm) x 100 x 8/1000 ~ Salinity (PSU).

In August 1987 measurements show that salt water penetrated about 2,0 km upstream at high tide until it encountered shallower water in the vicinity of the golf club. The mouth was then located further south towards the South African side, about 600 – 700 m west from the 1971 survey. During this sampling session salt water appeared to occur in an 'elongated triangular area' against the right bank. The controlling factor for salinity penetration was that the bottom topography shoaled rapidly near the islands which formed an oblique sill across the lower estuary.

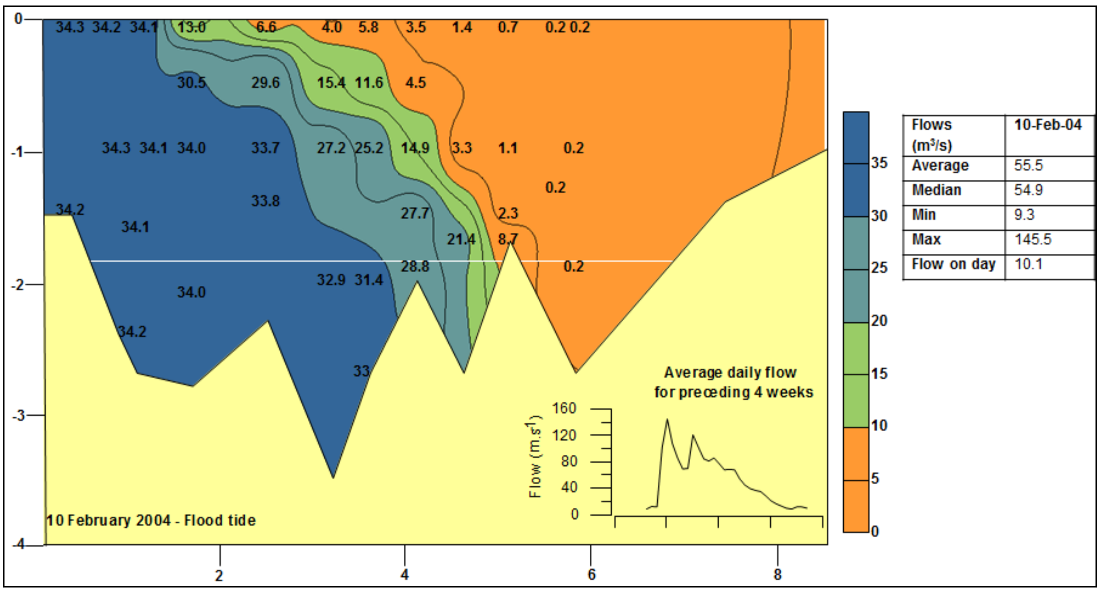


Figure 4. Orange Estuary flood tide salinity penetration, 10 February 2004

During the 10 February 2004 survey (Figure 4), saline water penetrated about 5,5 km during high tide. The system was only partially stratified on the flood tide, with salinity between 35 and 30 PSU recorded in the lower 2,0 to 4,0 km of the system at the surface and bottom respectively. Brackish waters between 20 and 10 PSU were measured at 2,5 km on the surface and at 5 km on the bottom. The average river inflow for the preceding four weeks was 56 m^3/s, with a minimum flow of 9 m^3/s and a maximum flow of 146 m^3/s.

During this field survey the mouth was situated near the Namibian side, with a clear front hugging the northern bank during the peak of the tide. A relatively large mixing eddy tended to form about 500 m from the mouth on the Namibian side, while more turbid water was observed at the same distance from the mouth on the South African side.

During August 2004, the lower entrance (near the mouth) of the channel (near the launching site) on the southern side was estimated to be 1,5 to 2,0 m deep, while the upper entrance was less than 0,5 m deep at high tide. A plug of saline water with a bottom salinity of 30 PSU was observed pushing into this side channel at high tide. On the receding tide the channel became isolated from the main estuary (~12 PSU or less in the vicinity of the channel) as the shallowness of the top entrance prevented the ebb tide from flushing the saline plug from the system. The net result was that this side channel consistently had a body of saline water (surface salinity 20 – 22 PSU, bottom salinity 30 PSU) regardless of the state of the tide, while the main estuary channel was subjected to larger variations in salinity.

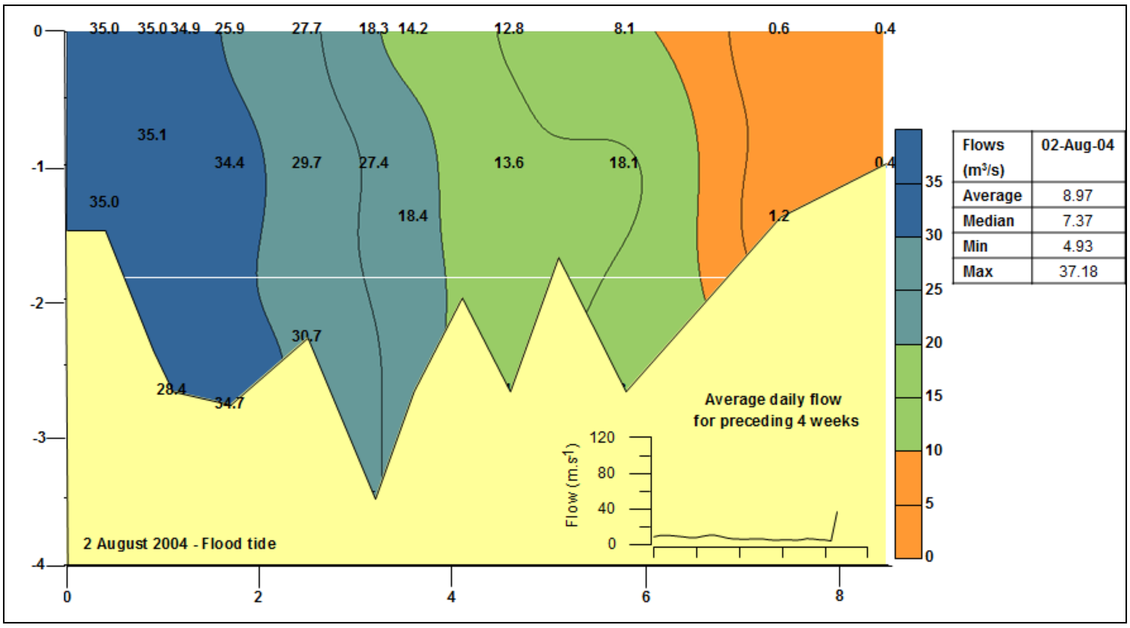


Figure 5. Orange Estuary flood tide salinity penetration, 2 Augustus 2004

During the 2 August 2004 survey (Figure 5), saline water penetrated about 7 km at high tide. The system was relatively well mixed on the flood tide, with salinity between 35 and 30 PSU recorded in the lower 2,5 km of the system. Brackish waters between 20 and 10 PSU were measured at 4 km from the mouth. The well mixed nature of the system reflected the relatively low flow that preceded this survey. During this period the average river inflow for the preceding four weeks was 9 m^3/s, with minimum and maximum flows for the same period between 5 and 37 m^3/s.

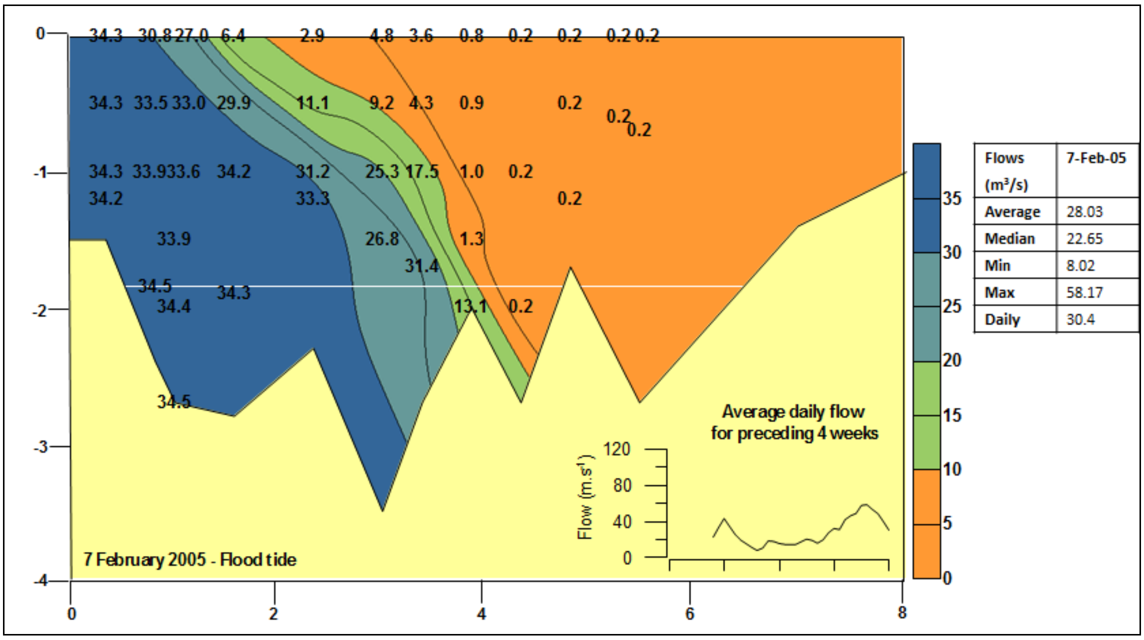


Figure 6. Orange Estuary flood tide salinity penetration, 7 February 2005

During the 7 August 2005 survey (Figure 6), saline water penetrated about 4,0 km at high tide. The system was relatively well mixed on the flood tide, with salinity between 35 and 30 PSU recorded in the lower 1,0 km (surface) to 3,0 km (bottom) of the system. Brackish waters between 20 and 10 PSU were measured at 1,5 to 4,0 km from the mouth on surface and bottom respectively. The estuary was partially stratified. During this period the average river inflow for the preceding four weeks was 28 m³/s, with minimum and maximum flows for the same period between 8 and 58 m³/s.

During the 9 February 2012 flood tide survey (Figure 7), saline water penetrated about 5,5 km on the late ebb tide. The system was highly stratified at a depth of 1,5 to 2,0 m, with salinity between 35 and 30 PSU only recorded in a plug of bottom water observed in a deeper section between 1,0 to 3,5 km from the mouth. Similarly, saline water between 30 and 20 PSU were only recorded in the bottom waters of the lower reaches up to 6 km from the mouth at depths below 2 m. Brackish waters between 20 and 10 PSU were present as a stratified layer (~0,5 m deep) between 0,0 and 5,5 km from the mouth. During this survey the surface of the estuary was nearly fresh with salinity between 6 and 8 PSU recorded at the mouth and less than 5 PSU measured at 3,0 km from the mouth. The related average river inflow for the preceding four weeks was 27 m³/s, with minimum and maximum flows for the same period between 0,2 and 95 m³/s.

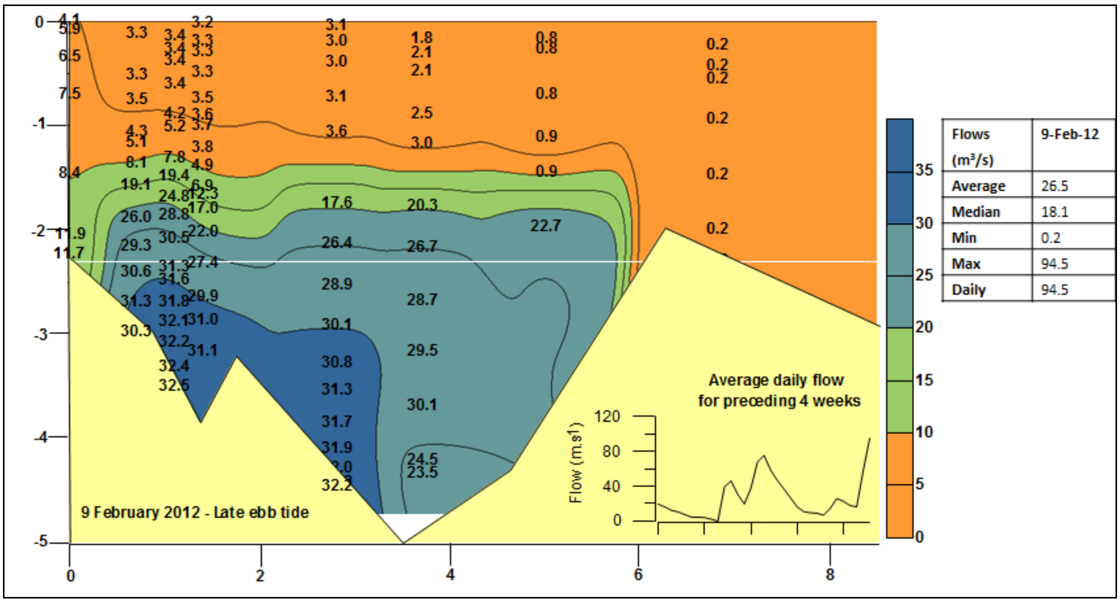
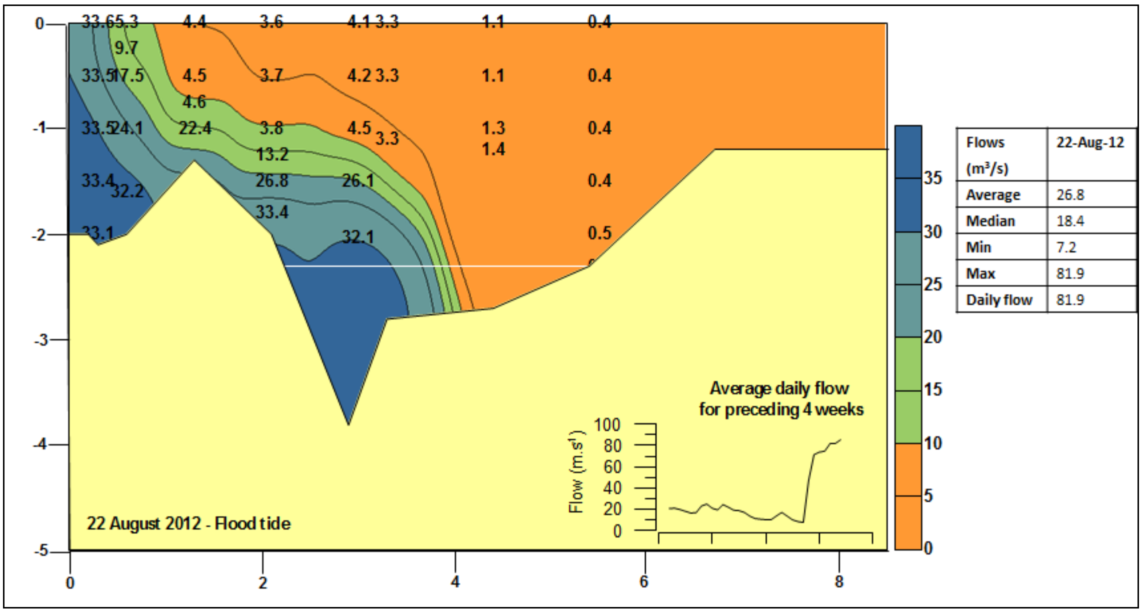


Figure 7. Orange Estuary ebb tide salinity penetration, 9 February 2012

During the 22 and 23 August 2012 flood tide surveys (Figure 8), saline water penetrated about 5,5 km at high tide. The system was relatively stratified on the flood tide at a depth of about 1,0 m. Salinity between 35 and 30 PSU was recorded for the bottom waters in the lower 4,0 to 5,0 km of the system. Brackish waters between 20 and 10 PSU were measured at 1,0 km from the mouth at the surface and at 4,0 to 5,0 km from the mouth at the bottom. The average river inflow for the preceding four weeks was between 26 and 28 m^3/s, with minimum and maximum flows for the same period between 7 and 85 m^3/s. The two flood tide surveys were taken at slightly different flow ranges and state of the flood tide. This clearly showed the sensitivity of the stratification in the system at these intermediate flow ranges.

During the 23 August 2012 ebb tide survey (Figure 9), saline water was recorded about 5,5 km from the mouth, but only in areas were the estuary was deeper than 2,0 m mean sea level (MSL). The system was highly stratified at a depth of 1,5 m MSL, with only pockets of saline water (35 and 30 PSU) occurring in the deeper areas between 1,0 to 5,0 km from the mouth. Similarly, brackish water between 30 and 10 PSU was only present as a stratified layer (between 0,5 – 1,0 m deep) in the system between 0,0 and 5,5 km from the mouth. During this survey the surface of the estuary was nearly fresh with salinity between 2 and 7 PSU recorded in the vicinity of the mouth and less than 5 PSU measured at 2,5 km from the mouth. The related average river inflow for the preceding four weeks was 29 m^3/s, with minimum and maximum flows for the same period between 7 and 85 m^3/s.



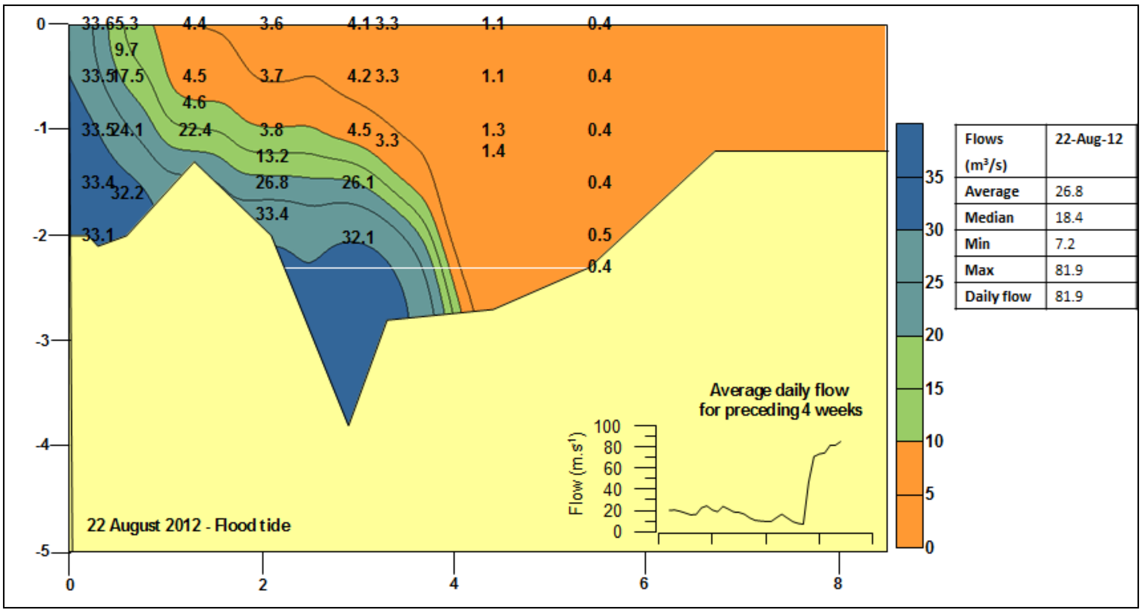


Figure 8. Orange Estuary flood tide salinity penetration, 22 and 23 August 2012

To provide insight in the salinity distribution under higher flow ranges steady state river inflows were numerically modelled to the Orange Estuary (see Appendix A). The results show the following:

- For steady flows of 50 m^3/s the surface waters in the estuary remain fresh except for during spring flood tides. However, higher salinity bottom waters extend approximately 2 km upstream of the mouth under neap flood tide and up to 4 km under spring flood tides.

- The salinity distributions for steady flows of 30 m³/s are similar to those for steady flows of 50 m³/s. Under these conditions higher salinity bottom waters now extend approximately 3,5 km upstream of the mouth under neap flood tide and up to 5 km under spring flood tides.
- For flows of 20 and 10 m³/s the lower 4 km of the estuary typically are highly stratified, however the higher salinity waters do not seem to extend upstream of 6 km from the mouth under these conditions.

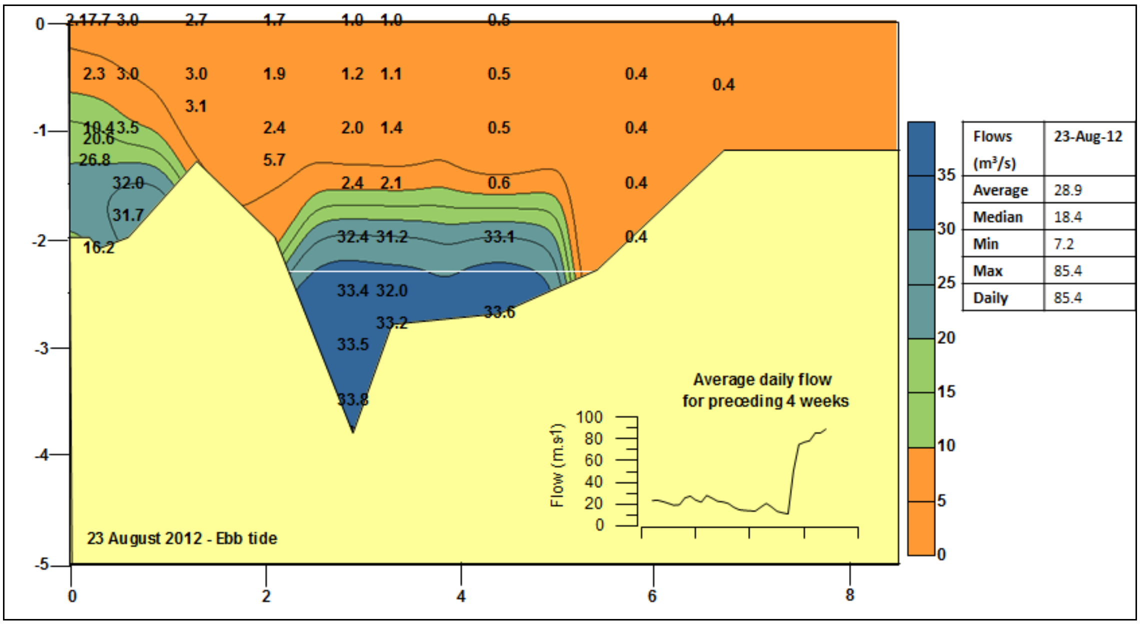


Figure 9. Orange Estuary ebb tide salinity penetration, 23 August 2012

- At flow of 5 m³/s and 3 m³/s the higher salinity waters penetrated upstream of 6 km from the mouth. Under flows of 3 m³/s the higher salinity waters penetrate upstream of 8 km from the mouth during spring high tides.
- The salinity distribution for flows of 2 m³/s are similar to those for flows of 3 m³/s, however flow flows of 1 m³/s the higher salinity water penetrate approximately 9 km upstream and beyond, particularly under spring tides. Under neap tides the higher salinity waters typically do not extend beyond 8 km upstream.
- For very low flow conditions 0,5 m³/s higher salinity waters are observed at 10 km upstream and beyond during spring tides. During neap tides the higher salinity waters extend only approximately 9 km upstream.

Salinity distribution

The following preliminary conclusions are made on salinity distribution patterns for the Orange Estuary:

- At high river flows, i.e. greater than 50 m^3/s, salinities in the estuary will typically be very low throughout with very limited saline intrusion at the mouth at times (January 1997).
- At river flows between 50 and 20 m^3/s, the estuary is expected to be open to the sea with tidal intrusion. Strong vertical stratification occurs in the deeper basin area in the lower reaches, with salinities of greater than 20 PSU in bottom waters and between 0 and 10 PSU in the surface layer. Moving further upstream salinities decrease markedly with 0 PSU occurring approximately 6 km from the mouth (August 2012).
- At flows between 20 and 5 m^3/s some vertical stratification is still present in the deeper basin, with salinities nearer to that of seawater in the lower reaches. Further upstream, as the estuary becomes shallower, salinities decrease gradually to 0 PSU at about 7 – 8 km from the mouth (August 2004).
- The only data reported for the closed phase was that of Harrison (1997) for September 1993, assumed to be just after closure. Based on the September 1993 survey, the system is strongly stratified, particularly in the lower reaches, immediately after closure (September 1993), similar to the situation during the low flow range in the tidal phase (see above). No suitable measurements were available to establish salinity distribution patterns during periods of prolonged mouth closure. However, it is expected that with time, turbulence caused by wind mixing will eventually create a brackish zone throughout the estuary, except perhaps in the deeper basin in the lower reaches where salinities could remain around 20 – 30 PSU for extended periods (i.e. turbulence generated by wind mixing may not be sufficient to erode this denser saline water at such depths).

2.2 Sediment dynamics

2.2.1 February 2012 field survey

Background conditions

A site inspection of the estuary and adjacent beach areas was conducted from 7 to 9 February 2012. The main purpose was to obtain information and field data on estuarine and adjacent coastal hydrodynamics, sediment dynamics and morphology. Spring tides occurred during this period, with the maximum sea tides predicted for 9 February, namely high water level (HWL) at +2 m CD (16h26) and low water level (LWL) at +0,26 m CD (10h14) at Port Nolloth. The average Orange River inflow for the preceding four weeks was 36 m^3/s, with minimum and maximum flows for the same period between 10 and 102 m^3/s respectively. Wave conditions during the site visit were average to slightly below average, with breaking wave heights off the mouth between 1,5 and 3,0 m. No sea storms occurred during this period. Winds ranging from westerly to south-westerly, with lighter wind of 3 to 8 knots in the mornings, and stronger winds of up to 20 knots in the afternoons.

Sediment characteristics

Sediment samples were collected at 17 locations during the site inspection conducted in February 2012. A summary of the sediment characteristics based on a visual and textural examination is given in Table 2.

Grain size analyses were also conducted on the samples in the CSIR laboratories and the results are summarised in Table 3. The median grain sizes (D50) of the 4 samples from the vicinity of the mouth ranged from 0.29 mm to 0.51 mm (fine to coarse sand, Udden-Wentworth scale). The four estuary bank samples had median grain sizes (D50) ranging from 0.1 mm to 0.2 mm (all very fine sand, Udden-Wentworth scale).

Table 2. Orange Estuary sediment characteristics based on a visual and textural examination of February 2012 field samples

Sample location Date	***Colour***	***Main sediment type***	***Median grain size(mm)***	***Cohesiveness***	***Predominant sediment type***
Mouth - inside					
08/02/2012	Mid grey (mixed grains)	Very fine sand	0.1 to 0.4	Low	Very fine sand to coarse sand
Mouth - neck					
08/02/2012	Dark grey (mixed grains)	Fine sand	0.2 to 0.5	Very low to Low	Very fine sand to coarse sand
Mouth - beach					
08/02/2012	Dark sandy (mixed grains)	Fine sand	0.2 to 0.5	Very low	Very fine sand to coarse sand
Mouth - outflow channel beach					
09/02/2012	Mid grey to light brown (mixed grains)	Medium to coarse sand	0.4 to 0.8	Very low	Very fine sand to coarse sand
Estuary bank - launch site intertidal					
07/02/2012	Brown	Mud: Silty clay	<0.063	Medium	Silt to very fine sand
Estuary bank - launch site above HWL					
07/02/2012	Mid brown	Mud (powdery): Silt (and clay?) and some very fine sand	<0.1	Low	Silt to very fine sand
Estuary bank - WLR2					
07/02/2012	Mid brown	Silt to very fine sand (black mud 2 cm below surface)	<0.125	Low	Silt to very fine sand
Estuary bank - WLR1 @ 0.5 m depth					
07/02/2012	Mid brown	Silt to very fine sand	<0.1	Medium	Silt to very fine

Sample location ***Date***	***Colour***	***Main sediment type***	***Median grain size(mm)***	***Cohesiveness***	***Predominant sediment type***
				(to low)	sand
Estuary in channel - WRL2 mid channel					
07/02/2012	Brown to grey (mixed)	Gravel: Silt to 60 mm cobbles	5 to 10	Very low to Low	Gravel
Estuary in channel - WQ6 (grab)					
09/02/2012	Mid brown to grey	Muddy gravel (<0.063 to 10 mm)	wide	Low	Gravel
Estuary in channel - WQ5 (grab)					
09/02/2012	Mid to dark brown (some black)	Mud: Clay	<0.063	Medium to High	Mud: Silt and clay
Estuary in channel - WQ4 (grab)					
09/02/2012	Mid brown and black (some orange patches)	Mud: Clay	<0.063	Medium	Mud: Silt and clay
Estuary in channel - WQ3 (grab)					
09/02/2012	Mid brown and black (some orange patches)	Mud: Silty clay	<0.063	Medium	Mud: Silt and clay
Estuary in channel - WRL1 (grab)					
09/02/2012	Mid brown and black (some orange patches)	Mud: Silt & clay	<0.063	Medium	Mud: Silt and clay
Estuary blind arm					
09/02/2012	Mid brown	Mud: Silty	<0.063	Low to Medium	Silt
Estuary blind arm - top end opposite flood embankment					
09/02/2012	Mid brown (to dark brown)	Silt to fine sand	0.063 to 0.2	Low	Silt

As also reported in Table 3, the mid channel samples ranged from gravel to muds according to the laboratory analyses. (In general, the visual estimates of sediment characteristics were similar to the results reported from the laboratory sample analyses.) The laboratory analyses indicated that the organic content of the samples were all very low (ranging from about 1 to 6%, based on percentage loss of sample weight on ignition which however may not be conclusive in some circumstances).

Based on the field investigation and the sediment sampling, as well as the available literature, some generalised conclusions 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 silts and clays/muds. Examples of such layered deposits can be seen in Figure 9.

Table 3. Grain size analyses of sediment samples collected at Orange Estuary

Sample location	***Percentage soil particle sizes***			***Percentiles***				
	% Gravel	***% Sand***	***% Silt & clay***	***D90***	***D50 Median***	***D10***	***Mean size***	***% Loss on ignition***
Mouth - inside	0.0	100.0	0.0	0.41	0.29	0.23	0.30	0.8
Mouth - neck	0.0	100.0	0.0	0.70	0.39	0.26	0.43	0.9
Mouth - beach	0.2	99.8	0.0	0.62	0.29	0.22	0.35	0.8
Mouth - outflow channel beach	0.4	99.6	0.0	0.89	0.51	0.27	0.53	0.8
Estuary bank - launch site intertidal	0.0	75.8	24.2	0.20	0.10		0.09	1.9
Estuary bank - launch site above HWL	0.0	95.1	4.9	0.25	0.14	0.08	0.15	5.4
Estuary bank - WLR2	9.0	84.1	6.9	1.78	0.20	0.08	0.47	1.4
Estuary bank - WLR1 @ 0.5 m depth	0.0	91.2	8.8	0.19	0.10	0.06	0.11	1.6
Estuary in channel - WRL2 mid channel	70.9	26.8	2.3			0.39		1.0
Estuary in channel - WQ6 (grab)	50.8	35.3	13.9		2.08			2
Estuary in channel - WQ5 (grab)	0.0	43.1	56.9	0.13			0.03	3.2
Estuary in channel - WQ4 (grab)	0.0	41.9	58.1	0.21			0.05	4.0
Estuary in channel - WQ3 (grab)	0.0	34.3	65.7	0.14			0.03	5.9
Estuary in channel - WRL1 (grab)	0.0	73.5	26.5	0.37	0.11		0.12	2.5
Estuary blind arm	6.7	87.7	5.6	1.49				1.6
Estuary blind arm - top end opposite flood embankment	1.0	95.0	4.0	0.83		0.26		1.4

Of the four samples taken from the banks of the estuary at various locations (Table 3), the predominant sediment type varies from silt to very fine sand. These mid brown sediments have cohesion ranging from medium to low. The muddy sediment deposits located above the HWL eventually dry out and become prone to wind action, i.e. aeolian sediment transport, when not covered by vegetation. It seems that in some areas, the wind tends to preferentially winnow out the finer fractions leading to a veneer of very fine to fine sands at the surface, examples of these are indicted in Figure 10. In some areas, for example, at the boat launch site, the intertidal bank consists of sticky muds (relatively high in cohesion), as indicated in Figure 10.

Figure 10. Orange Estuary examples of sediment deposits (source: A Theron, February 2012)

Figure 11 illustrates the difference in bank sediment characteristics above and below the HML. Figure 11A and B show wet and dry sediments below and above the HWL respectively; Figure 11 C shows partially encrusted dry sediments; and the Figure 11 D shows dry fine sand blown into the estuary.

Figure 11. Illustration of the difference in bank sediment characteristics above and below the HML, February 2012 (source: A Theron)

Figure 12. Illustration of muddy bank sediments with high cohesion, February 2012 (source: A Theron)

During high tide in the estuary (perhaps more so during the rising tide), muddy bank sediments are a source of local turbidity (suspended sediments) as seen in Figure 13. This is mainly due to erosion resulting from wind wavelets with generally smaller contributions from aeolian transport. The mini turbidity plumes are then spread further through tidal currents and surface wind action.

Figure 13. Illustration of local turbidity from erosion of muddy bank sediments (source: A Theron)

Less prevalent deposits of sands, gravels, pebbles and cobbles are occasionally found in channel and bank deposits, examples of which are shown in Figure 14. Of the six in-channel bottom (i.e. sub-tidal) grab samples collected, the two collected in the upper estuary (at WLR2 and WQ6 – Table 3) predominantly consisted of gravels, but included a range from muddy sediments to 60 mm cobbles. The other four in-channel bottom (i.e. sub-tidal) grab samples collected from the mid and lower estuary (at WLR1 and WQ5 to WQ3 – Table 3) predominantly consisted of muds containing mixtures of silts and clays (anaerobic conditions appeared to occur in some of these brown and black bottom sediments).

Figure 14. Orange Estuary examples of occasional sands, gravels, pebbles and cobbles sediment deposits (source: A Theron, February 2012)

The two sediment samples collected from the blind arm on the south-eastern side of the estuary near the mouth, consisted mainly of muddy silt to fine sand (Table 3).

Some of the muddy and sandy sediment deposits located at the HWL or above, have become vegetated and consolidated (Figure 15).

Figure 15. Orange Estuary examples of vegetated and consolidated estuary banks (source: A Theron)

However, some of the supra tidal sediment deposits are not covered by vegetation and are prone to wind action (Figure 16). A contributing factor in some areas could be trampling and grazing by livestock. During strong winds, dust, fine sediments and sand is blown into the estuary as is evident from Figure 16 (bottom left and right).

Figure 16. Orange Estuary examples of supra tidal sediments subject to aeolian transport (source: A Theron)

Beach sediments observed on the shoreline adjacent to the mouth displayed significant variation in characteristics (Figure 17), ranging from fine to coarse sand, but also included some granules, gravels, pebbles and cobbles, as well as seemingly heavy mineral traces.

Figure 17. Examples of beach sediments observed on the shoreline adjacent to the mouth (source: A Theron)

A photograph of the beach sand near the mouth (as depicted in Figure 18) gives a rough visual indication of the varied nature of the sand and individual grains.

Figure 18. Photograph of beach sediment near mouth - 08/02/2012 (source: A Theron)

Hydro- and sediment dynamics in the mouth area

The mouth was open with an outflow channel width of several hundred metres wide aligned obliquely towards roughly the southwest (Figure 19 – left). A shallow sand bank located along the seaward side of this channel resulted in wave breaking and energy dissipation on the seaward (c.a. north-western) edge of the channel (Figure 19 – right).

During ebb tide, fine sediments are entrained in the estuarine waters flowing out through the mouth (Figure 20 A), but the suspended sediment concentration appeared to be generally low. Both ebb and flood tide velocities through the mouth were more than sufficient to entrain fine sediments (as suspended load) and to transport even coarse sand as bottom load. On the landward side of the outflow channel a low sand spit of some 200 m long protruded from the southern side of the mouth (Figure 20 B). The head of this spit is continually eroded by the flood tide (Figure 20 C), carrying some of the beach sediment (sand) into the estuary. During high tide the spit was overwashed by wave action (Figure 20 B). The berm adjacent to the spit on the southern side had a crest elevation in the order of 5 m above MSL (Figure 20 D).

Figure 19. Orange Estuary Mouth, February 2012. Left: Estuary mouth outflow channel during strong flood tide; Right: waves breaking on the seaward edge of the channel (source: A Theron).

Figure 20. Orange Estuary Mouth, February 2012 (source: A Theron).

Abiotic shoreline characteristics

The generally linear shoreline adjacent to the mouth has an overall northwest-southeast orientation. The coastline features a sandy foreshore of a relatively steep slope (Figure 21 A and B), leading onto a flatter sandy backbeach with a medium high dune-ridge running parallel to the shore near the mouth. The surf zone appears to have a sandy bottom and exhibits a shore parallel bar and trough profile (intersected by some rip channels). The beach sediments near the mouth range from fine to coarse grained sands, while sparse pebbles and cobbles are observed in some areas (Figure 21 A). The distinctly darker coloured beach sediments also observed on the shoreline adjacent to the mouth (Figure 21 A), are thought to be traces of heavy mineral deposits. This shoreline is completely exposed to incident deep sea waves from virtually all seaward sectors (especially from waves propagating from the dominant south-west). To some extent the surf zone sandbar (multi-barred in some places) helps to dissipate wave energy and reduces wave impact on the shoreline (Figure 21 C). The beach sand of medium grain size, along with the relatively steep intertidal beach face slope, is indicative of a moderate to high wave regime.

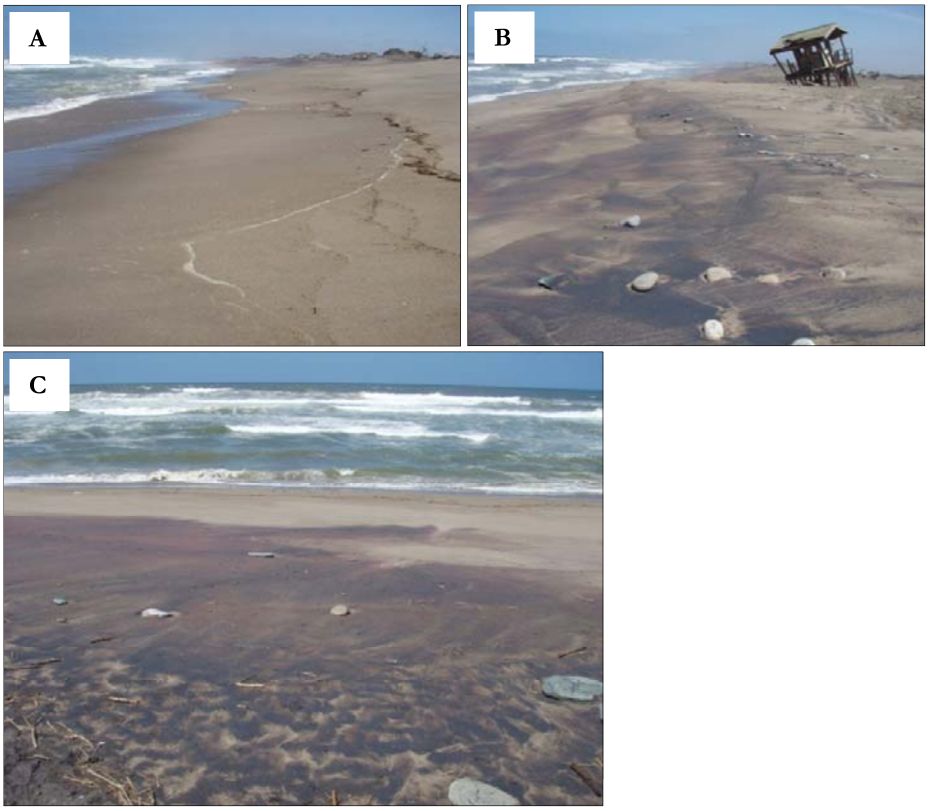


Figure 21. Shoreline adjacent to the Estuary Mouth, February 2012 (source: A Theron). A: Steep beach profile; B: Dark coloured beach sediment deposits; C: Illustration of wave energy dissipation on surf-zone sand bar.

2.2.2 Estuarine sediment dynamics and morphology

The Orange Estuary consists of a braided channel system, with many islands in the upper estuary, which feeds into a relatively smaller and shallow open tidal basin area. The inlet is maintained by fluvial discharge, and additional fluvial sediment passes through the estuary and is deposited in the sea, where it is dispersed. Fluvial sediment extends from the upper estuary to close to the bar (Cooper, 2002).

Overall, large floods are crucial in maintaining the long-term dynamic equilibrium with respect to the sediment regime. During large resetting floods in the river, large volumes of sediment are flushed out from the entire estuary, removing many of the islands between the braided channels, scouring out the basin area and flushing a large part of the sand bar into the ocean. Bremmer et al. (1990) stated that nearly all sediment transported during the 1988 floods was derived from bank erosion and riverbed scouring downstream of the major dams. Thus, although the dams trap most of the catchment sediment, large volumes of sediment still reaches 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 bedload, which soon infills the estuarine channel and reduces the tidal prism. The sand bar across the mouth is rapidly rebuilt by coastal processes after the flood. Smaller river floods tend to move some of the sediment from the upper estuary towards the tidal basin 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 tide) 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 Estuary prodelta, and are dominated by laminated clay-rich sediments (Meadows et al., 2002).

2.2.3 Effects of changes in sediment supply

The available information currently indicates that the depth and bed morphology over most of the estuary are relatively similar to that of the reference condition. Under the present state the braided channels in the upper estuary are deemed to be more stable, but probably slightly narrower and/or shallower, due to reduced intermediate river flows. The increased cohesion of riverine sediments and stabilisation of sand bars by vegetation in the braided channel area, means that relatively higher magnitude floods are necessary to effect significant morphological change. The reduction in large floods from the reference condition to the present state, indicates that the system would originally have been reset more frequently, thus increasing overall variability in morphology, sediment processes and characteristics. The residence period and average extent of marine sediments (carried into the tidal basin during flood tides) would also originally have been less.

The sediment supply has changed significantly over the years. Bremmer et al. (1990) calculated a discharge rate of 119 million tons/year prior to 1921 (Table 4). By the 1980's this was estimated to be less than 17 million tons/year, primarily due to dam developments.

Table 4. Sediment discharge rates of the Orange River (Bremmer et al., 1990)

Period	***Sediment discharge (milion tons per year)***
Pre 1921	119
1929–1934	89
1934–1943	56
1943–1952	52
1952–1960	46
1960–1969	34
1980's	<17

A new sediment discharge determination by Basson (2011) estimated a present value of about 44 x 10^6 tons/year, which is significantly higher than the value based on Bremner's study. Basson does state that sediment load data are limited, especially in the lower Orange and lower Fish Rivers, from which it is concluded that there is large uncertainty (potential inaccuracies) in such estimates. The newer estimate may be more accurate, but the main point remains, in that present Orange River discharge rates are greatly reduced from reference (even the higher Basson value is only in the order of 1/3 of pre 1921 values).

It should be noted that the sand content (which potentially affects beach erosion or accretion) of the discharge is in the region of 20% or less (Bremmer et al., 1990).

However, although the river flow volumes and velocities (and consequent sediment carrying capacity) are reduced, and the major impoundments are trapping more sediment from reference condition to the present state, the sand/mud ratio is still very similar in the river load, and river sediment is still dominant over marine sediment intrusion. The potential load reduction is probably offset to some extent by increased erosion in the mid- and lower-Orange River catchment (because of less vegetation cover). It is also estimated that the overall reduction in intermediate flows cause the average extent of the marine sediment intrusion (of a more non-cohesive and coarser nature than river sediment) slightly further upstream.

2.2.4 Local anthropogenic effects relative to river flow changes

The morphology of the intertidal area has also been impacted through the estuary bank adjacent to the golf course being artificially stabilised. Similarly, the salt marsh area has also been cut off from the main estuary through the stabilisation of the south-eastern estuary bank due to the road and as protection for the oxidation pond. This has also resulted in a reduction of the estuary mouth-location envelope (i.e. reduced migration of the mouth). Further migration to the south has also been prevented by discarded heavy mining machines deposited on the berm where the old causeway road connected with the berm. In the intertidal zone, the morphological impacts of roads and bank protection are much larger than those of the more stable braided channels and mouth migration reduction. However, most morphological change in the sub-tidal zone is due to reduced river flows and reduced smaller floods (possibly 1 in 2 to 1 in 10 year).

2.2.5 Effects of mining operations

The proposed discharge of about 97 million tons of sediment into the nearshore region north of Oranjemund by Namdeb during the wet overburden mining system (WOMS) mining, and continuation of existing dredge operations, will result in about 200 m of shoreline accretion at the Orange Estuary mouth. A previous investigation (CSIR, 2003) regarding the WOMS reached the following conclusions and recommendations:

The maximum shoreline accretion at the Orange Estuary mouth and approximate times of occurrence are provided in Table 5 for each of the three WOMS mining scenarios:

Table 5. The maximum shoreline accretion at the Orange Estuary mouth and approximate times of occurrence for each of the three WOMS mining scenarios

WOMS mining scenario	***Predicted max accretion (m)***	***Approx time after start of mining (yrs)***
1 (most likely case)	160	30
2 (similar, moving north to south)	145	30
3 (additional mining south of G011)	250	35

It was foreseen that beach accretion at the Orange Estuary could increase mouth closure slightly.

If major flood(s) occur after beach accretion, the estuary mouth will be scoured such that the configuration of the estuary is unlikely to change significantly. However, if this does not occur, the wide beach berm (i.e. sandspit) could cause a slight decrease in tidal flow into the estuary. It is deemed that this is likely to have a negligible impact on the estuary.

It is likely that more frequent mouth closures (as has occurred under natural conditions) will benefit the estuary, and particularly the degraded salt-marsh on the south bank through backflooding. However, if future river flows are greatly reduced, the resulting excessively frequent mouth closure could be detrimental (examples of negatives effects include: excessively reduced salt water intrusion into the estuary; excessive reduction in marine fish and benthic invertebrate migration; and decreased tidal variation limiting access to birds feeding on intertidal mudflats).

Predictions of the change in fine sediment concentrations under worst-case scenarios of environmental conditions and mine discharges indicate that the increased concentrations of suspended inorganic matter entering the estuary will be negligible.

2.3 Water quality

2.3.1 Background

In this study the water quality of the Orange Estuary is assessed in terms of the following parameters:

- system variables (salinity (see previous chapter), temperature, pH, dissolved oxygen (DO) and turbidity/Secchi depth/Total suspended solids);
- dissolved inorganic nutrients (nitrogen, phosphate and reactive silicate); and
- toxic substances (limited data on metals).

To describe the quality of river inflow to the estuary, available data (1995 – 2005) from the DWA water quality monitoring stations at the Sir Ernest Oppenheimer Bridge (D8H012Q01) and Vioolsdrift (D8H083Q01) were used. Water quality data from both the Sir Ernest Oppenheimer Bridge (monitoring point close to the head of estuary) and Vioolsdrift, (some 280 km from the estuary) were included in the graphs illustrating variation in water quality of river inflow. The marked differences observed in the results emphasize the importance of monitoring river water quality in close proximity to the head of an estuary. Significant inaccuracies in results can arise from using monitoring points that are too far removed from the estuary. In this instance differences in agricultural land-use immediately above, and between Vioolsdrift and the Sir Ernest Oppenheimer Bridge is the likely cause of these marked differences.

Available data on water and sediment quality in the Orange Estuary are summarized in Table 6. The water quality sampling station is indicated in Figure 22. Data collected during February and August 2012 (this study) are presented in Appendix A.

Table 6. Summary of available water and sediment quality data on the Orange Estuary

Recommended data required	***Availability***	***Reference***
Water quality measurements (pH, DO and turbidity) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at: • end of low flow season; • peak of high flow season.	Once-off Jan 1979, Sep 1993, Feb 2004, Aug 2004, Feb 2005, Feb 2012, Aug 2012.	CSIR (1984) Harrison (1997) Wooldridge and Deyzel (2008) DAFF[1] and CSIR(unpublished data) Collected during this study (2012)
Water quality measurements (inorganic nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at: • end of low flow season; • peak of high flow season.	Once-off Jan 1979, Feb 2012 and Aug 2012.	CSIR (1984) Collected during this study (2012)
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary.	Trace metal in sediment (1979).	Orren (1979); (CSIR 1980)
Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary.	pH, inorganic nutrients (1995 – 2011). Metals (1998 – 2003).	DWA water quality monitoring Namibia Water Corporation Ltd (unpublished data)
Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater.	Derived from literature.	e.g. DWAF (1995)

1 Department Agriculture, Forestry and Fisheries.

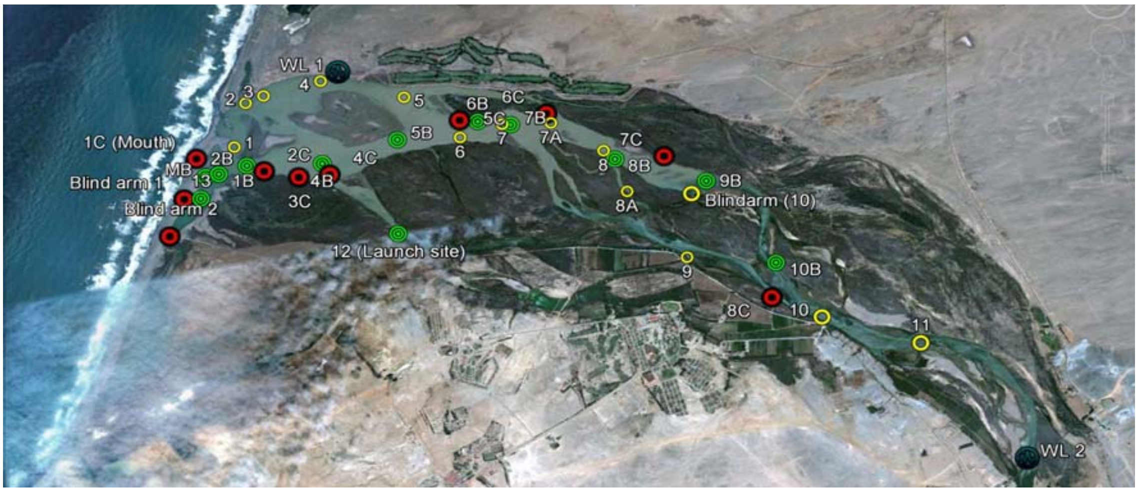


Figure 22. Water quality sampling station in the Orange Estuary

An approach that is widely used to assess water quality conditions in estuaries (specifically nutrient cycling and transformation) is the use of mixing diagrams (or property-salinity plots) (e.g. Ferguson et al., 2004; Eyre, 2000; Eyre and Balls, 1999).

The mixing diagram approach consists of a plot of variable concentrations against salinity along the estuarine gradient. This provides a convenient method for visualising the net effect of processes within estuaries whereby deviation from the conservative mixing line is used to interpret results. For example, downward curvature in the mixing diagram implies removal, while upward curvature implies release. To orientate oneself in terms of the spatial distribution of water quality concentrations along the estuary under a specific flow regime, the property-salinity plots should be compared with corresponding longitudinal salinity profiles.

2.3.2 Temperature

No temperature data are available for river inflow to the estuary. However, it is expected that river temperatures will be largely influenced by atmospheric temperatures, with highest temperatures occurring during summer and lowest during winter. Generally, the natural seawater temperature regime along the west coast of South Africa is largely influenced by wind-induced upwelling (south-easterly and southerly winds) which varies seasonally. Seasonality is strongest in the south where south-easterly winds are rare in winter but common in summer. Temperatures of the upwelled waters range from 9 – 14°C, depending upon the 'strength' of the upwelling process. Surface temperatures can increase after upwelling to 16°C and higher through sun warming.

Figure 23 displays temperature data collected in the Orange Estuary on five occasions – three during February (late summer) and two during August (winter). On all five occasions the mouth was open to the sea and seawater intruded into the estuary. Results show that seasonal variability in seawater temperatures (salinity 35) are significantly less (approximately 5°C) compared with variability in river water (salinity 0) (approximately 10°C). As a result the difference in water temperatures along the salinity gradient in the estuary is significantly higher in summer (approximately 10°C) than in winter (approximately 5°C).

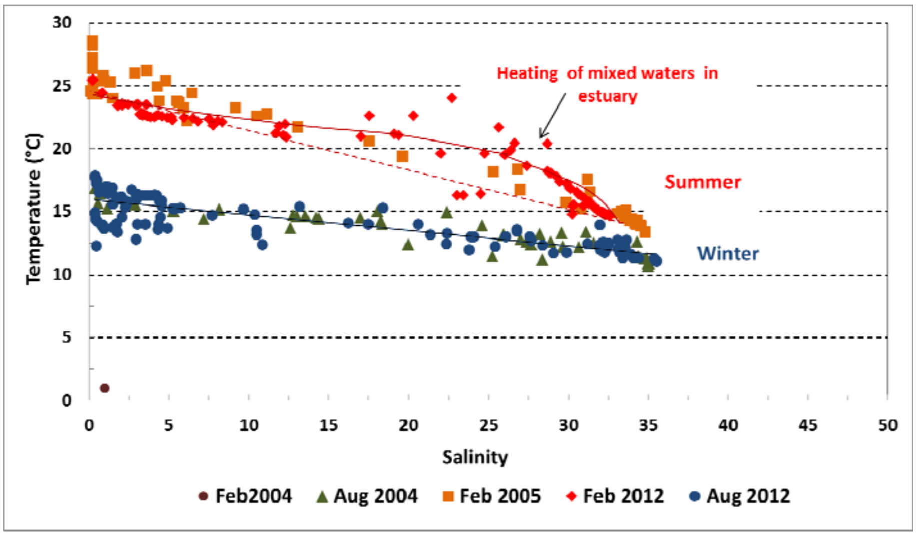


Figure 23. Relationship between salinity and temperature measured in the Orange Estuary in August 2004, February 2005, February 2012 and August 2012

During open mouth conditions, there is a strong correlation between temperature and salinity, both in summer and winter (Figure 23). However, in summer the water temperatures in the estuary are not influenced only by mixing between colder, seawater and warmer river water, but atmospheric temperatures contribute significantly to warming of mixed waters in the estuary (indicated by upward curvature in summer plots). The direct effect of atmospheric temperatures on the estuary in winter, when they are much lower, is less significant (indicated by a linear relationship in winter plots). Salinity distribution patterns in the estuary reveal strong longitudinal and vertical stratification during periods of tidal intrusion. Similarly, temperature variability reveal strong stratification where saline waters are warmer compared to fresher waters.

During high flow periods when the estuary is freshwater dominated, temperatures are expected to largely reflect that of the inflowing river water. During closed mouth conditions – when intrusion of cold seawater is cut off and river inflows are low – atmospheric temperatures is expected to be the strongest driver of the temperature regime in the estuary (specifically surface temperatures).

2.3.3 pH

Median monthly pH levels measured in river inflow to the Orange Estuary (1995 – 2011, indicative of the present state), as well as monthly median river flow, over the same period, are presented in Figure 24. Median pH levels at the Sir Ernest Oppenheimer Bridge fall within a narrow range between 8,2 and 8,5 with a tendency for levels to be associated with periods of high flow (e.g. March). Maximum pH levels measured during this period was 8,8.

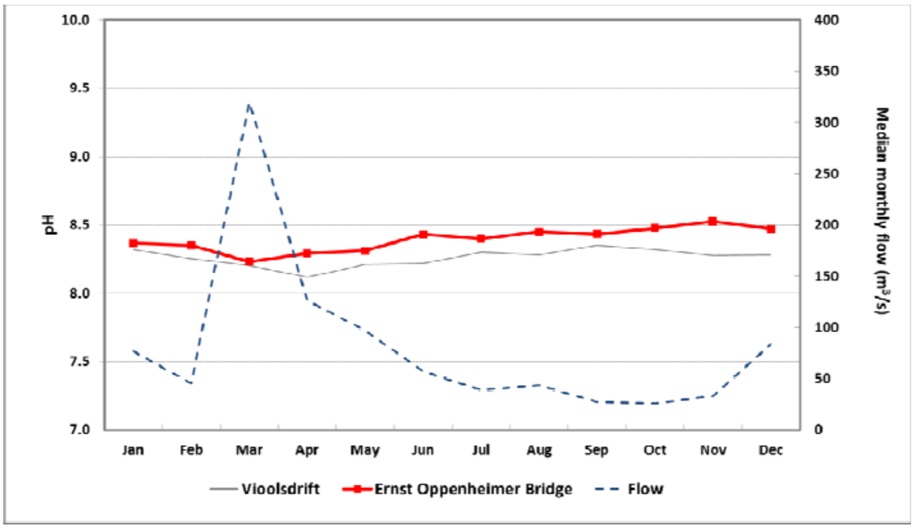


Figure 24. Monthly median pH levels (1995 – 2011) measured at Vioolsdrift (grey) and Sir Ernest Oppenheimer Bridge (red), as well as median monthly river flow measured at Vioolsdrift (Source: DWA)

The pH levels in river inflow under Reference Condition were expected to be lower, ranging between 6,5 and 7. This is considered representative of undisturbed freshwater systems in this area (information supplied by Southern Waters as part of the 2004 EFR study).

The pH of seawater in the region typically ranges between 7,9 and 8,2 (DWAF, 1995). Lower pH values are usually associated with cold, newly upwelled waters (Gonzalez-D´avila et al., 2011).

Figure 25 displays pH data collected in Orange Estuary on four occasions when the mouth was open to the sea and seawater intruded into the estuary. Although these pH results did not show any seasonal trends, a strong linear relationship with salinity is evident, with lower pH levels (7,5 – 8) associated with saline waters and higher pH levels (8,5 – 8,9) with fresher waters, reflecting characteristics of the sea and river source waters. However, under the Reference Condition the trend would have been the opposite, where fresher waters would have had lower pH levels (6,5 – 7) compared to saline waters (7,9 – 8,2).

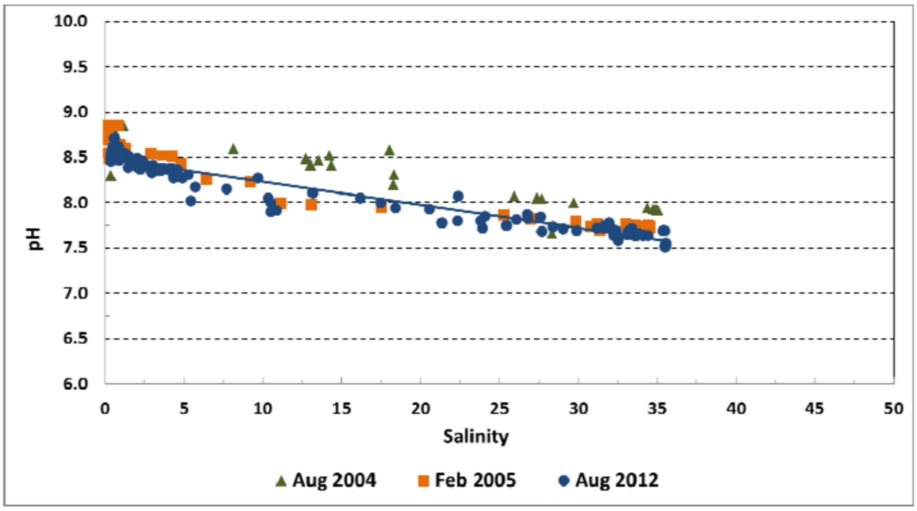


Figure 25. Relationship between salinity and pH measured in the Orange Estuary in August 2004, February 2005, and August 2012

During periods of strong freshwater inflow when the estuary was freshwater dominated pH levels are expected to have been influenced by river inflow, as recorded in January 1979 when no marked trends were evident in pH and levels averaged 8,5 (CSIR, 1984). During closed periods it is expected for pH levels to remain between 8 and 8.9, depending on the conditions and extent of sea and river water mixing at closure. In September 1993, just after mouth closure, the estuary was strongly stratified, particular in the deeper basin area, as a result of significant marine influence just prior to closure. At the time there was no marked difference between pH levels of the fresher surface layers and the saline bottom water, with average pH levels around 8 (Harrison, 1997).

2.3.4 Dissolved oxygen

No dissolved oxygen measurements are available for river inflow or seawater entering the Orange Estuary. While it is expected for river inflow to be generally oxygenated (>6 mg/ℓ), low oxygen events have been reported. For example in April 2003 a large algal bloom originating further upstream in the Orange catchment made its way to the estuary. During this event dissolved oxygen concentrations in river inflow were down to 0,06 mg/ℓ (Ms B Conradie, DWA, Northern Cape Regional office, pers. comm.). Coastal surface waters along the west coast are expected to be generally well-oxygenated. Low oxygen waters are known to occur along the southern Namibian coast, but typically limited to bottom waters (<20 m) (Grobler and Noli-Peard, 1997).

Figure 26 displays the relationship between dissolved oxygen and salinity and dissolved oxygen and temperature measured in the Orange Estuary during August 2012 when the mouth was open to the sea and seawater intruded.

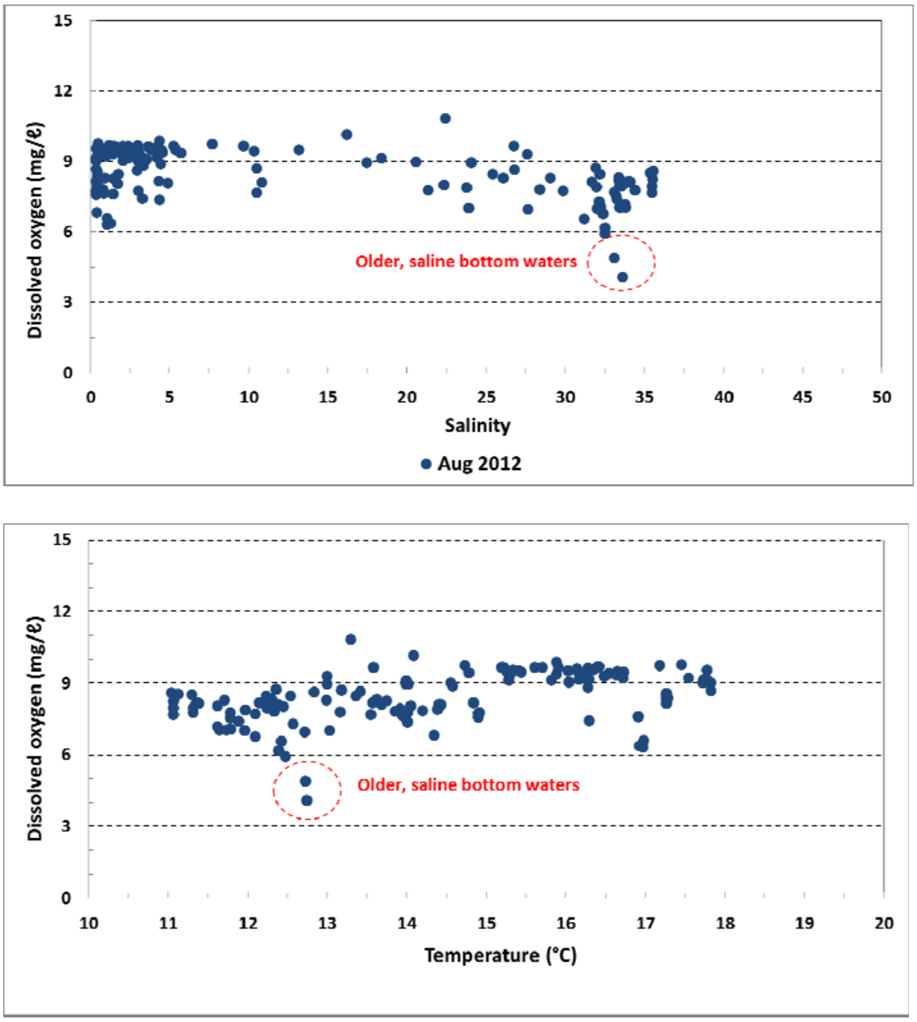


Figure 26. Relationship between dissolved oxygen and salinity (top) and temperature (bottom) measured in the Orange Estuary in August 2012

Under saturated or near-saturated conditions (as is the case in the Orange Estuary), dissolved oxygen concentrations are higher in fresher and/or colder waters compared with saline and/or warmer waters. However, in this case, saline waters are also coldest which implies that the effect of salinity on dissolved oxygen is counteracted by the effect of temperature, therefore explaining relatively constant, well-oxygenated conditions (>6mg/ℓ). The two lower oxygen levels (4 to 5 mg/ℓ) were measured in the bottom water at one station. Strong vertical stratification and weaker tidal flushing of this deeper pool in the upper estuary explained these slightly lower concentrations. Wooldridge and Deyzel (2008) also measured well-saturated dissolved oxygen waters (>95% saturation) during the open tidal phase in the estuary during August 2004. During periods of strong freshwater inflow when the estuary is freshwater dominated the system is expected to also be well-oxygenated, as recorded in January 1979 when dissolved oxygen concentrations averaged 8 mg/ℓ (CSIR, 1984). During the closed phase oxygen concentrations in the system may vary. During September 1993, just after mouth closure, the estuary was still well-oxygenated (average concentration of 9 mg/ℓ), despite strong stratification in the deeper basin area (Harrison, 1997). Although no measurements could be obtained for a prolonged stage of mouth closure, it is possible that strong stratification could prevent replenishment of the bottom waters in the deeper basin, resulting in a decrease in dissolved oxygen concentrations in this area. The severity of such a decrease will depend on the duration of closures, as well as the organic content of the bottom waters and sediments at the time.

2.3.5 Turbidity

Water from the Orange River is naturally turbid, especially during high flow periods. Measurements collected during a survey conducted as part of the Lower Orange River Management study, show Secchi depth below Kakamas of between 25 and 28 cm (information supplied by Southern Waters as part of the 2003 EFR study). Namwater collected data at Sendelingsdrift (Rosh Pinah), about 70 km from the mouth, during the period 2001 and 2003 (Figure 27) (Mr Andries Kok, Namwater, Keetmanshoop, pers. comm.). Results show that turbidity levels in river inflow vary greatly. Levels are mostly between 10 – 100 NTU, but can increase markedly to greater than 200 NTU (presumably during periods of high flow).

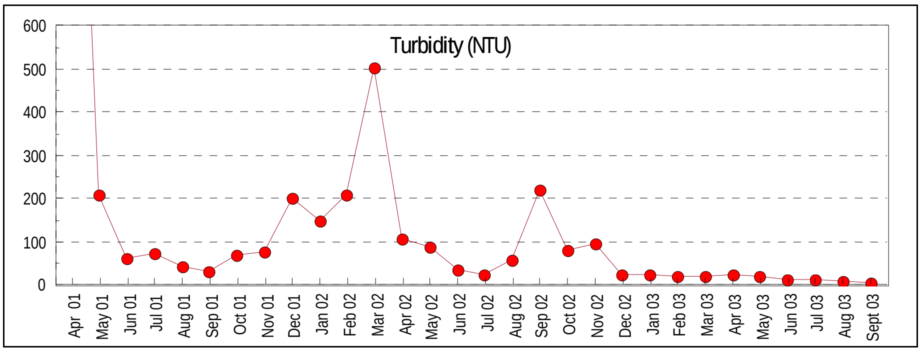


Figure 27. Turbidity measurements collected at Sendelingsdrift (Rosh Pinah), about 70 km from the mouth, during the period 2001 and 2003 (Source: Mr Andries Kok, Namwater, Keetmanshoop)

Turbidity in seawater is site specific and no data could be obtained for surface waters along the west. However, it is expected for turbidity levels to be relatively low compared with that in river inflow (<20 NTU).

Turbidity data collected in the Orange Estuary during August 2004, February 2005 and August 2012 is presented in Figure 28. On all occasions the mouth was open with seawater intruding into the estuary during high tide. The data suggest that turbidity concentrations entering the estuary during summer (February 2005) is significantly higher as compared to winter (August surveys). While, at first glance, this may seem to correspond with '*higher turbidity measured during summer (higher river flow)*', the median monthly flows preceding the August 2004, February 2005 and August 2012 surveys were 7 m^3/s, 23 m^3/s and 18 m^3/s, respectively, which did not reflect the expected pattern. These results suggest that turbidity levels in river flows associated with the open, tidal phase can vary greatly (10 to 100 NTU).

This will result in high variability in the fresh part of the upper estuary (salinity <5) during the open, tidal phase. However, due to significant flocculation of colloidal matter from river water on entering the estuary - as a result of mixing with more saline water – average turbidity levels in the brackish, and more saline middle and lower estuary is expected to be lower (<20 NTU) during this phase.

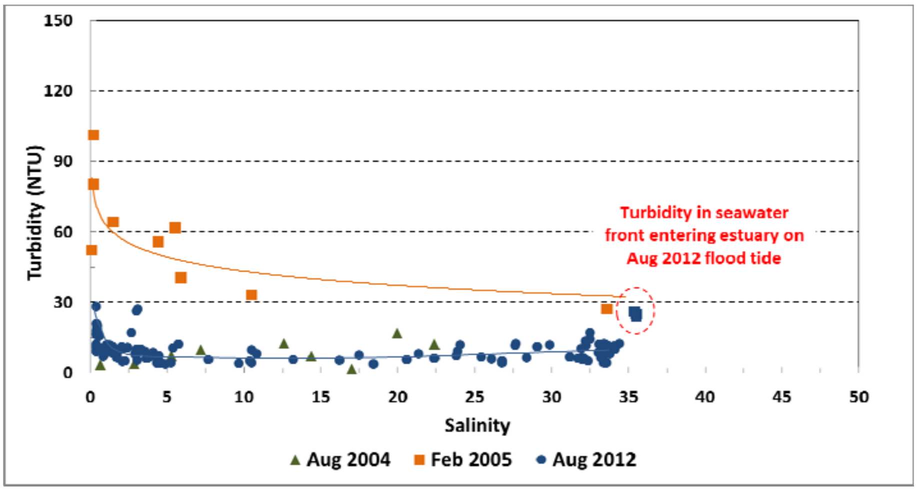


Figure 28. Relationship between salinity and turbidity measured in the Orange Estuary in August 2004, February 2005[1] and August 2012[2]

No data were available on turbidity levels during the freshwater dominated phase. However, considering the natural characteristics of the Orange River, it is expected that levels in river inflow, and thus throughout the estuary, will be high – greater than 200 NTU. Turbidity levels during the closed phase are expected to vary depending on duration of closure. Measurements taken during September 1993 (Harrison, 1997) when the mouth had just closed, values ranged between 12 and 45 NTU, showing a tendency to be higher in the fresher surface layers (river origin) compared with the saline bottom water (seawater origin). As a result of flocculation of colloidal material from river water on entering the estuary – as a result of mixing with more saline water – a larger part of the estuary is expected to become gradually more brackish during the closed phase, thus turbidity levels are expected to be low (<20 NTU). The relationship between turbidity and suspended solids and turbity and Secchi depth – as observed during the August 2012 survey – are presented in Figure 29.

1 Only surface salinity data from Wooldridge and Deyzel (2008) was used in these plots, as bottom water data sets suggest possible disturbance of sediments layers during such measurements

2 Elevated turbidity levels measured in saline waters during the August 2012 survey were taken at the seawater front just inside the mouth of the estuary at the onset of the flood tide. Such fronts are often recognised as zones of accumulation of organic and other suspended matter.

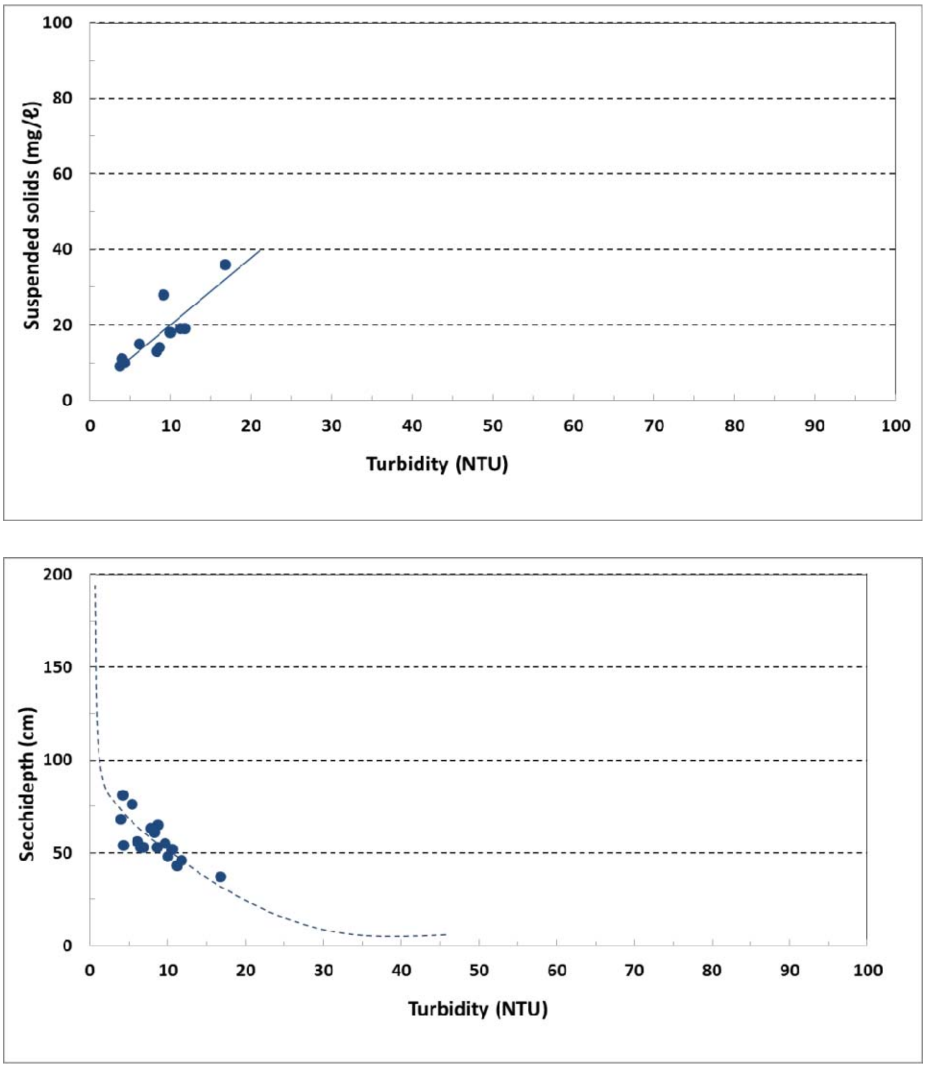


Figure 29. Relationship between turbidity and suspended solids (top), and turbidity and Secchi depths (bottom) measured in the Orange Estuary during August 2012 (open, tidal phase)

Results show a positive, linear relationship between turbidity and suspended solids (in the range of 0 – 20 NTU), although this specific relationship may not hold, for example during periods of high flows when turbidity is much higher. The slope of the correlation between turbidity and suspended solids could vary because the relationship is sensitive to the shape and composition of the suspended matter (Brando et al., 2006). Turbidity shows inverse linear relationship with Secchi depth (in the range 0 – 20 NTU). However, the relationship between turbidity and Secchi depth is usually a continuous inverse relationship (Harrington et al., 1992), as suggested by the dotted line in Figure 29 (bottom).

2.3.6 Nutrients

Dissolved inorganic nitrogen

Median monthly values for dissolved inorganic nitrogen (DIN) concentrations measured in river inflow to the Orange Estuary (1995 – 2011, indicative of the present state), as well as monthly median river flow, over the same period, are presented in Figure 30. Median DIN concentrations at the Sir Ernest Oppenheimer Bridge (mainly comprising nitrate - N) correlate well with median monthly flow, where highest concentrations are measured during months of high river inflow. DIN concentrations were around 100 µg/ℓ, peaking at 400 µg/ℓ during high flow periods. De Villiers and Thiart (2007) estimated DIN concentrations in river flow from the lower Orange catchment under Reference Condition to be <50 µg/ℓ. Higher concentration under the present state are mostly associated with runoff from agricultural land-use in the catchment.

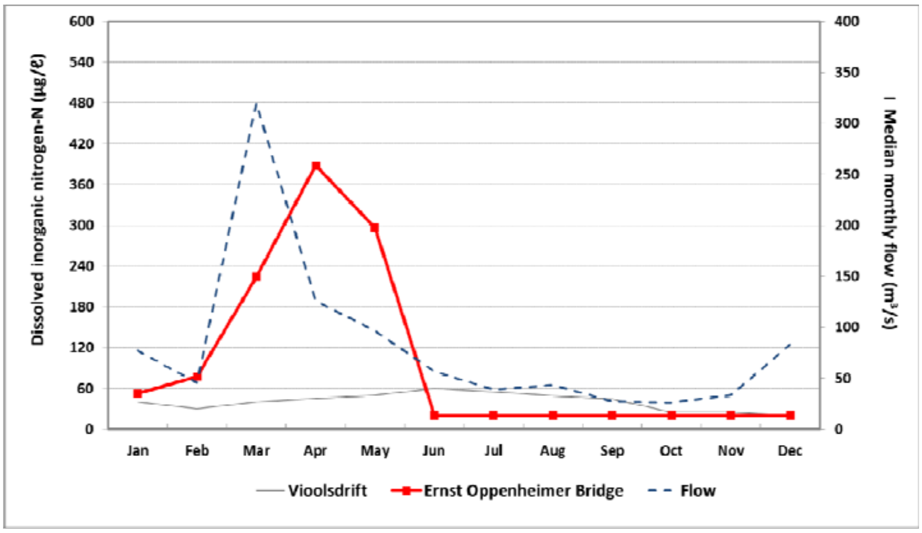


Figure 30. Monthly median DIN concentrations (1995 – 2011) measured at Vioolsdrift (grey) and Sir Ernest Oppenheimer Bridge (red), as well as median monthly river flow measured at Vioolsdrift (source: DWA)

DIN concentrations (particularly nitrate - N) in seawater along the west coast of South Africa are often influenced by upwelling when concentrations can peak at 200–400 µg/ℓ (Andrews and Hutchings, 1980; Chapman and Shannon, 1985; Bailey and Chapman, 1991; DWAF, 1995).

The relationship between DIN (mainly nitrate - N) and salinity measured in the Orange Estuary during February 2012 and August 2012 are presented in Figure 31. On both occasions the mouth was open to the sea with tidal intrusion. During the February 2012 survey concentrations in the estuary were fairly uniform, ranging between 100 – 200 µg/ℓ (similar concentrations were measured in the blind arm to the south just inside the mouth). During the August 2012 survey, DIN concentrations in saline waters (salinity ~30) were high (~300 µg/ℓ) while concentration in river inflow remained low (salinity 0) around 100 µg/ℓ. The higher concentrations in saline waters were attributable to freshly upwelled waters (temperature 10°C) entering the estuary during this period (Figure 23).

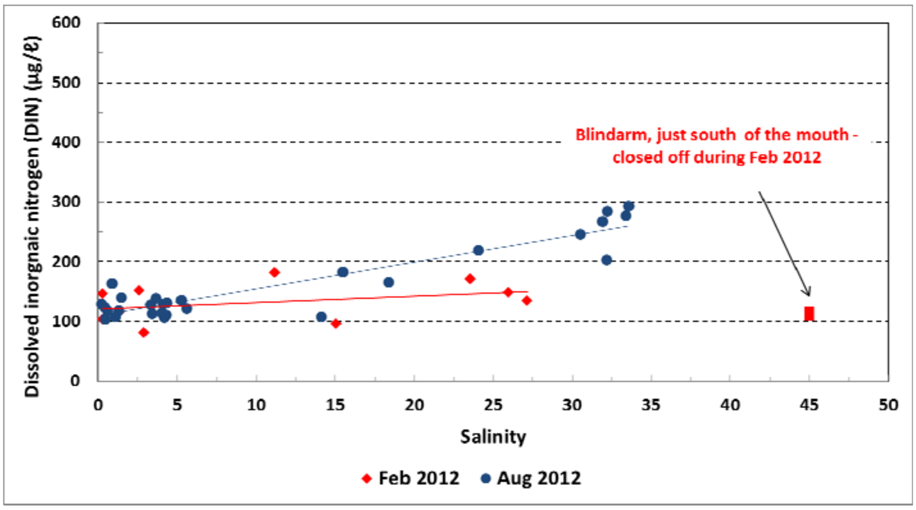


Figure 31. Relationship between salinity and DIN concentrations measured in the Orange Estuary in February 2012 and August 2012

The positive linear relationship between DIN and salinity – especially during August 2012 (r^2 =0.9) – indicate that mixing between sea- and river water is the strongest driver of DIN distribution in the estuary, indicative of good flushing. No data are available from the freshwater dominated phase, but DIN distribution patterns in river inflow (Figure 30) indicate that DIN concentrations in the estuary can rise (200 – 400 µg/ℓ) during high flow periods under the present state. However, according to De Villiers and Thiart (2007) DIN concentration during high flow periods under the reference would have remained low (50 µg/ℓ). Concentrations during the closed state will vary, depending on factors such as degree of upwelling and the extent of mixing between seawater and riverwater at the time of closure. During prolonged periods of closure DIN – as the limiting nutrient in marine systems – may become depleted in the absence of significant in situ remineralisation of nutrients.

Dissolved inorganic phosphate

Median monthly dissolved inorganic phosphate (DIP) and total phosphorus (TP) concentrations measured in river inflow to the Orange Estuary (1995 – 2011, indicative of the present state), as well as monthly median river flow, over the same period, are presented in Figure 32. Both DIP and TP show correlation with median monthly flow, where highest concentrations are measured during months of high river inflow, but TP is much more pronounced. Results also reveal that a significant proportion of P enters the estuary is in the particulate (or organic) form.

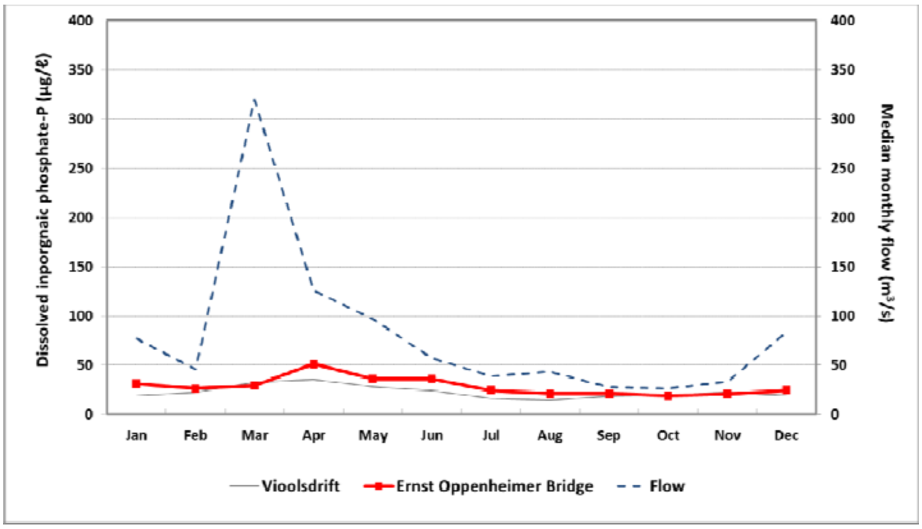


Figure 32. Monthly median DIP concentrations (1995 – 2011) measured at Vioolsdrift (grey) and Sir Ernest Oppenheimer Bridge (red), as well as median monthly river flow measured at Vioolsdrift (source: DWA)

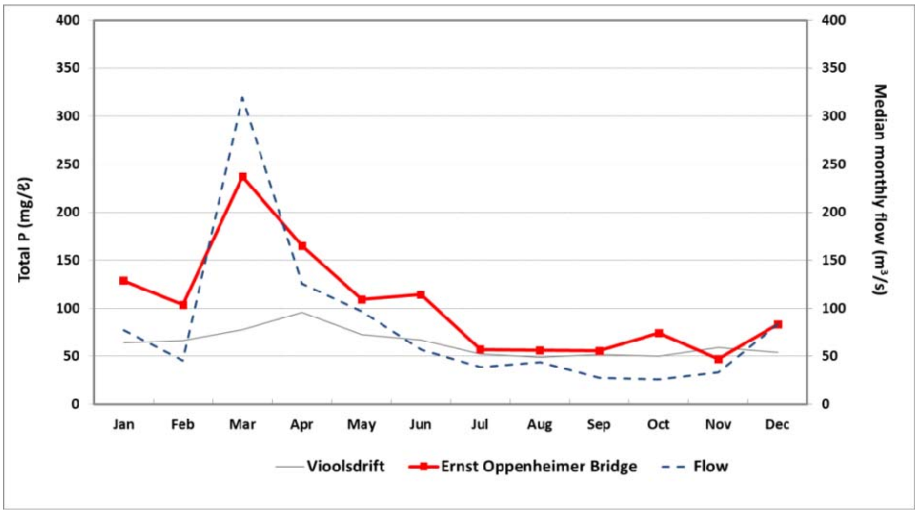


Figure 33. Monthly median TP concentrations (1995 – 2011) measured at Vioolsdrift (grey) and the Sir Ernest Oppenheimer Bridge (red), as well as median monthly river flow measured at Vioolsdrift (source: DWA)

DIP concentrations ranged between 20 – 30 µg/ℓ, peaking at 40 – 50 µg/ℓ during high flows. De Villiers and Thiart (2007) estimated DIP concentrations in river flow in the lower Orange catchment under reference condition to be <10 µg/ℓ. Higher concentrations under the present state are mostly associated with runoff from agricultural land-use in the catchment.

Similar to DIN concentrations, DIP concentrations in seawater along the west coast of South Africa are influenced by upwelling and can increase to 40–50 µg/ℓ (Andrews and Hutchings, 1980; Chapman and Shannon, 1985; Bailey and Chapman, 1991; DWAF, 1995). The relationship between DIP and salinity measured in the Orange Estuary during February 2012 and August 2012 are presented in Figure 34. On both occasions the mouth was open to the sea allowing seawater to intrude. DIP concentrations in seawater (salinity 35) were higher (~40 µg/ℓ) during both surveys, compared with concentrations in river inflow (10 µg/ℓ). These higher DIP concentrations in saline waters were attributed to the influence of upwelling (higher DIP concentrations in the blind arm to the south just inside the mouth, also suggested strong marine influence).

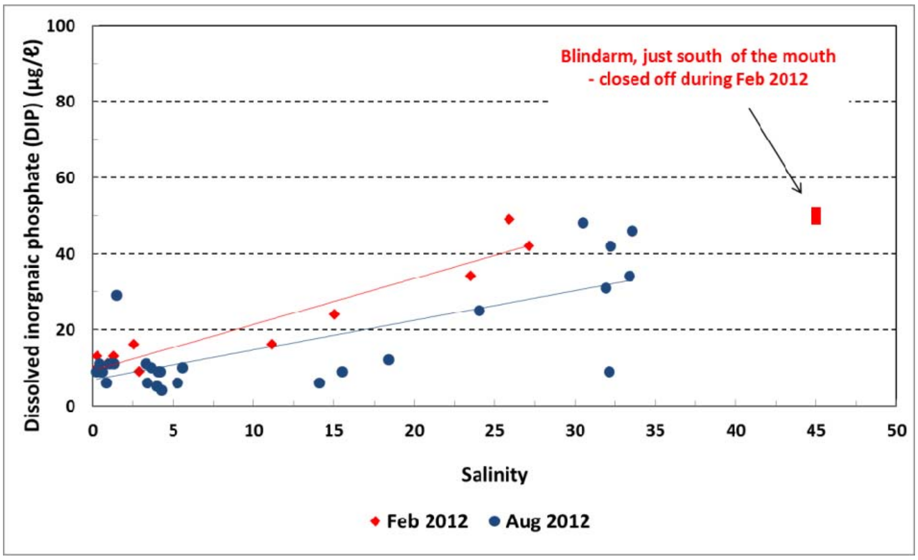


Figure 34. Relationship between salinity and DIP concentrations measured in the Orange Estuary in February 2012 and August 2012

The positive linear relationship between DIP and salinity ($r^2>0.5$) indicate conservative mixing as the strongest driver of DIP distribution in the estuary, indicative of good flushing. No data are available for the freshwater dominated phase, but DIP distribution patterns in river inflow (Figure 32) indicate that DIP concentrations in the estuary could rise (50 µg/ℓ) during high flow periods under the present state. However, according to De Villiers and Thiart (2007) DIP concentration during high flow periods under the reference would have remained low (10 µg/ℓ). Concentrations during the closed state will vary, depending on factors such as the degree of upwelling and the extent of mixing between sea- and river water at the time of closure, although concentration is expected to be low during prolonged period of closure in the absence of significant in situ remineralisation of nutrients.

Dissolved reactive silicate

Median monthly dissolved reactive silicate (DRS) concentrations measured in river inflow to the Orange Estuary (1995 – 2011, indicative of the present state), as well as monthly median river flow, over the same period, are presented in Figure 35. Median DRS concentrations at the Sir Ernest Oppenheimer Bridge correlate well with median monthly flow, where highest concentrations (7,500 µg/ℓ) are associated with high flow periods and lower concentrations (2,500 µg/ℓ) with low flow periods. The reference condition was most likely relatively similar as DRS can be naturally higher in river water, compared to seawater, due to catchment geological characteristics (Eagle and Bartlett, 1984).

Typical DRS concentrations for newly upwelled water range between 140 – 1,400 µg/ℓ (Chapman and Shannon, 1985; Bailey and Chapman, 1991; DWAF, 1995).

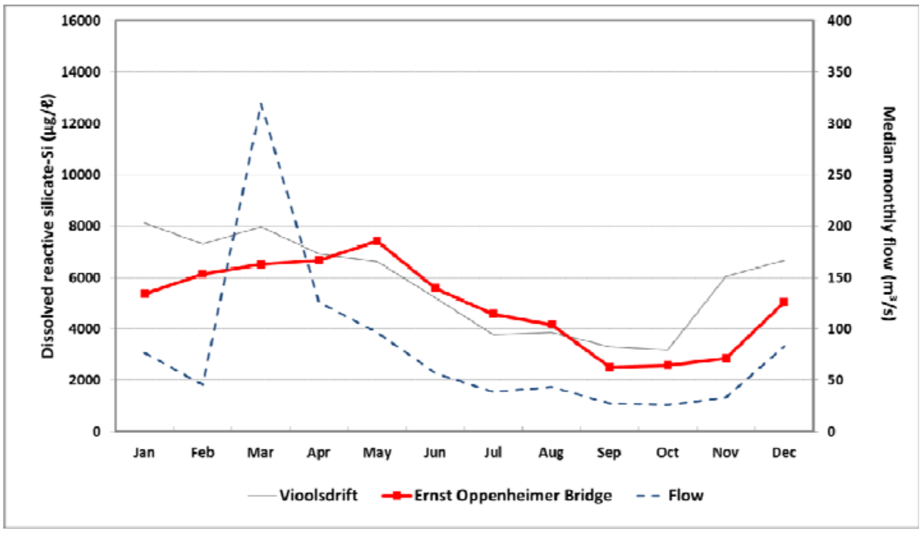


Figure 35. Monthly median DRS concentrations (1995–2011) measured at Vioolsdrift (grey) and Sir Ernest Oppenheimer Bridge (red), as well as median monthly river flow measured at Vioolsdrift (source: DWA)

The relationship between DRS and salinity measured in the Orange Estuary during February 2012 and August 2012 are presented in Figure 36. On both occasions the mouth was open to the sea with tidal intrusion. As expected, results from the February 2012 survey, show highest DRS in river water (salinity 0) and lowest in seawater (salinity 35), although the DRS in river water were exceptionally high. DRS concentrations of 11,000 µg/ℓ have been measured at the Sir Ernest Oppenheimer Bridge (1995 – 2011) but only on occasion. The positive linear relationship with salinity (r^2 = 0.8) indicate conservative mixing as the strongest driver of DRS distribution patterns in the estuary, indicative of good flushing. DRS concentrations in the blind arm to the south just inside the mouth were slightly elevated (possibly influenced by evaporation as reflected in hyper-salinities).

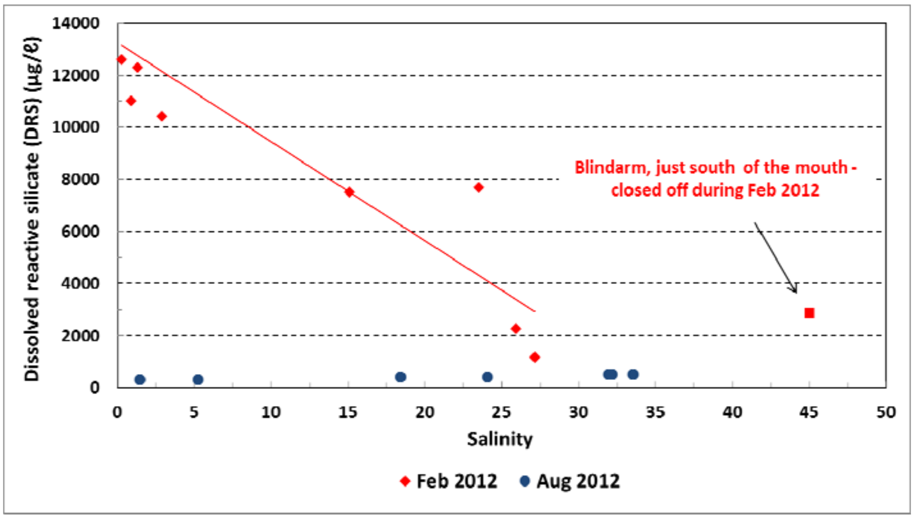


Figure 36. Relationship between salinity and DRS concentrations measured in the Orange Estuary in February 2012 and August 2012

The very low concentrations measured in river water (salinity 0) during the August 2012 survey was unexpected and could not be explained. DRS concentrations of <200 µg/ℓ have been recorded at the Sir Ernest Oppenheimer Bridge (1995 – 2011) but only on two occasions and are therefore very atypical.

No data are available for the freshwater dominated phase, but distribution patterns in river inflow (Figure 35) indicate that DRS concentrations in the estuary can rise (6 000 – 8 000 µg/ℓ) during high flow periods. Concentrations during the closed state will vary, depending on factors such as degree of upwelling and the extent of mixing between sea- and river water at the time of closure.

Toxic substances

Data on toxic substances in the Orange Estuary are very limited (Van Niekerk et al., 2003). The only measurements taken in the estuary are sediment metal data collected in January 1997 (Orren et al., 1979; CSIR, 1980) (Table 7). Also presented in Table 7 are the recommended quality guidelines for the protection of marine biota as proposed for the BCLME region (BCLME, 2006). For once-off sampling of toxic substances (e.g. metals) in highly dynamic systems such as estuaries, it is considered more appropriate to sample environmental components (for example sediments), which tend to integrate or accumulate change over time.

Sediments in the estuary mainly comprised fine sand and muds with an anaerobic layer extending to within 1 cm from the surface in places. In this case, it is difficult to distinguish whether accumulation was a result of anthropogenic influences or of natural origin. It is possible for conditions to arise where total metal concentrations in sediments are high, but completely linked to the natural structure of clay minerals, in which case the trace metals will not be bio-available. Geochemical ratios of aluminium versus trace metal concentration are typically used to establish this although it was not done in this instance. However, comparing total metal concentrations with sediment quality guidelines for the protection of marine ecosystems in the Benguela Current Large Marine Ecosystem (BCLME) region (including South Africa's west coast), these fall within the recommended limits (BCLME, 2006).

Table 7. Metal concentrations in the Orange River at Rosh Pinah (70 km from the estuary mouth) (1998 – 2003) and in sediments of the estuary (1979)

	Water (µg/ℓ)			***Sediment (µg/g dry mass)***			***BCLME guidelines***	
	n	***Mean***	***Range***	***n***	***Mean***	***Range***	***Water***	***Sediment***
Cd	25	<10	5.5–0.68	44	0.03	0.01 – 0.06	5.5	0.68
Cu	25	33	10–80	44	10.8	7.8 – 17.2	1.3	18.7
Ni	–	–	–	44	<1.5	<1.5 – 3.5	70	15.9
Pb	25	<20	4.4–30.2	44	5.4	2.4 – 8.7	4.4	30.2
Zn	25	32	10–80	44	23.1	14.7 – 51.9	15	124

Available metal concentration in water is limited to river samples collected at Rosh Pinah (about 70 km from the mouth) on about 25 occasions during 1998 to 2003 (Ms M Conradie, Namibia Water Corporation Ltd., pers. comm.). Average concentrations measured for different trace metals are shown in Table 7. The comparison of average metal concentrations to generic quality guidelines for the BCLME region, revealed that certain metals exceeded the target values. This suggests that there may be metal contamination in river inflow (although this station is well above the estuary).

Although no data are available on sediment concentrations of other toxic substances (e.g. persistent organic pollutants) it is possible that extensive urban development and agricultural practices in the catchment could result in some contamination. However, floods often act as 'resetting' mechanisms in this regard, when large quantities of sediment (and associated toxic substances) are scoured from the estuary (Van Niekerk et al., 2003).

2.4 Typical abiotic conditions and zonation

2.4.1 Orange Estuary response to typical flow ranges

Based on historical data and projected future flow modifications, five typical abiotic conditions have been identified for the Orange Estuary (Table 8). Note that *State 1b: Closed and hyper saline* is a predicted condition as extended periods (>6 month) of zero inflow have not been observed under the present inflow regime.

Table 8. Typical abiotic conditions linked to measured and projected river inflow

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

2.4.2 Zonation

Based on its bathymetry and flushing regime the Orange Estuary can be divided into two main components (Figure 37):

- the lower estuary (approximately 6 km in length), with a deep basin of 3 – 4 m. This region is also characterized by shifting braided channels and islands, which provide localized areas (pockets) of high retention;
- the upper reaches (from about 6 – 11 km), with an average depth of less than 2 m. While braided channels and islands also occur in this region, flushing is more effective and retention less;
- in view of the strong stratification that occurs at about 1 m depth under elevated flow ranges, both the lower and upper reaches are subdivided into surface and bottom waters (Figure 38).

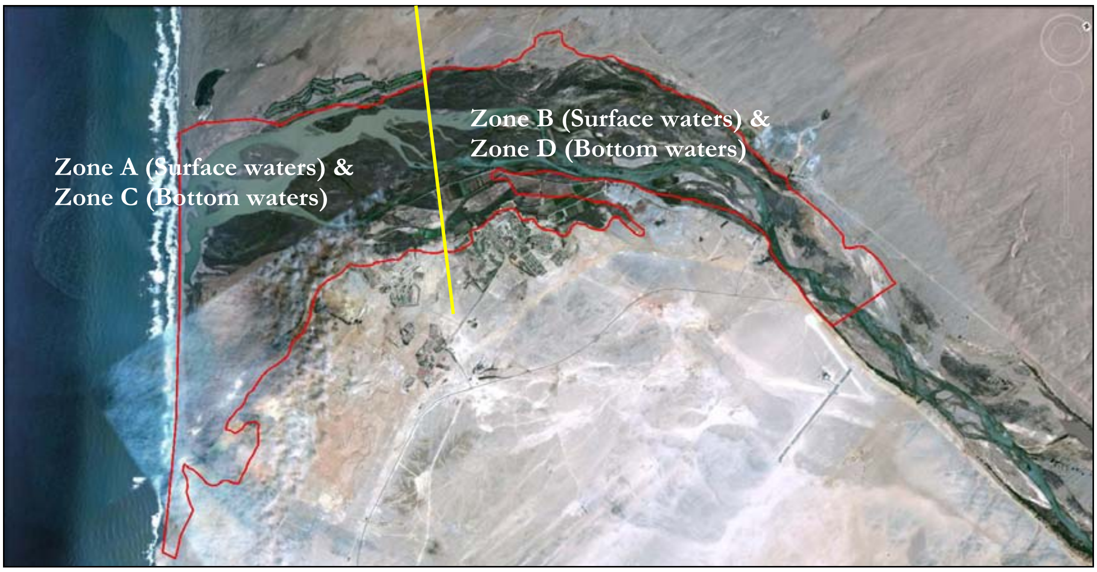


Figure 37. Satellite image showing the lower and upper reaches of the Orange Estuary

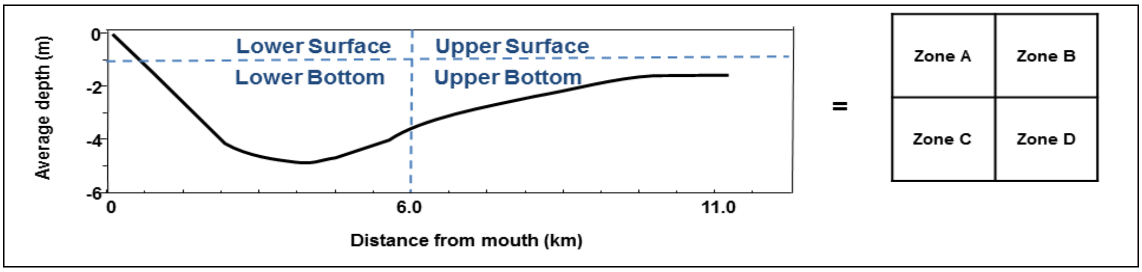


Figure 38. A schematic illustration of the Orange Estuary zonation

Based on an interpretation of the available data discussed in the previous chapters, typical physical and water quality characteristics for each of the five abiotic states are summarised in Table 9.

Table 9. Summary of typical physical 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
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.				
DO (mg/ℓ)	>6 >6 4 4	>6 >6 4 4	>6 >6 > 4	>6 >6 >6 >6	>6 >6 >6 >6
Turbidity (NTU)	10 10	10 20	10 30	30 30	100 100

Parameter	***State 1: Hyper Saline***		***State 2: Closed***		***State 3: Marine***		***State 4: Brackish***		***State 5: Fresh***	
	10	10	10	20	1	30	10	30	100	100
DIN (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 (μg/ℓ)	10	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 (μg/ℓ)	1000	1000	500	3000	100	6000	4000	6000	6000	6000
	1000	1000	200	2000	200	6000	1000	6000	6000	6000

* 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 – 11 km) estuary (moving upstream from the mouth left to right) and into surface (water depth <1 m) and bottom (water depth >1 m) waters

3. Estuarine microalgae

3.1 Introduction

Microalgae, as primary producers, form the base of the food chain in estuaries. The group includes those living in the water column (phytoplankton) and those living on exposed intertidal or submerged surfaces (benthic microalgae). Phytoplankton biomass indicates the river-estuary interface zone, a brackish zone in the estuary characterised by high biomass and diversity. As freshwater inflow is reduced the extent of the river-estuary interface zone changes and the flow requirements of the estuary are set based on the acceptable change.

Phytoplankton biomass indicates the nutrient status of an estuary. For example, the Mhlanga Estuary receives sewage input and phytoplankton chlorophyll a, an index of biomass, exceeded 200 µg/ℓ, which is typical of a eutrophic system. Species composition also indicates the nutrient and hydrodynamic status of an estuary. Dinoflagellates are typically abundant when the estuary is nutrient-rich and stratified. They occur in the middle reaches of an estuary where salinity is >5 ppt whereas cyanophytes (blue-green algae) are common in nutrient-rich water where salinity is <5 ppt.

Benthic diatoms are known to respond to salinity and most references describe diatoms as freshwater, brackish or marine species (Bate et al., 2004). In addition, diatoms have proven to be useful indicators of trophic status, particularly in freshwater ecosystem studies (Taylor et al., 2007). As such, knowledge of diatom ecology is a vital component of estuarine management it is therefore imperative that they, and phytoplankton, are included in Resource Directed Measures (RDM) studies.

There is very little information available on the microalgae in the Orange Estuary. The CSIR (Harrison, unpublished data) completed a once-off survey of the estuary on 17 January 1994. The estuary was turbid (Secchi depth = 5 cm), pH ranged from 7,7 to 7,8, temperature 22 to 23°C, salinity was 1 ppt throughout, nitrate 890 to 1730 µg/ℓ, and orthophosphate 50 to 80 µg/ℓ. The estuary was clearly flowing strongly and any phytoplankton in the water column must have been imported in the riverwater with little production due to the short residence time.

Phytoplankton chlorophyll *a* ranged from 2,4 to 4,2 µg/ℓ , averaging 3,0 µg/ℓ, which is low (<3,.5 µg/ℓ) based on the classification scheme of Snow (2007). Historically, it is expected that the high river flow and frequency of floods would have kept the microalgal biomass low, the median benthic chlorophyll *a* content being <11 mg/m^2 (Snow, 2007).

3.2 Materials and methods

3.2.1 Study site

This site description includes a summary of abiotic variables, sourced from Van Niekerk et al. (2012) that are most likely to influence microalgae.

The Orange Estuary is classified as a permanently open river mouth, i.e. open for more than 90% of the time. The estuary extends from the mouth, through a braided channel system to the Sir Ernest Oppenheimer Bridge, 11 km upstream (Figure 39). River flow has been severely reduced (40% of the MAR) and regulated but the system is still regarded to be river dominated. With marine intrusion limited to the lower reaches of the estuary under normal flow conditions. The surface water area of the estuary is estimated to be between 2 x 10^6 m^2 and 6 x 10^6 m^2, and can reach 12 x 10^6 m^2 if the surrounding flood plain is inundated with water.

The mouth of the estuary does close infrequently, the most recent closures recorded in 1994 and 1995. This is most likely to occur for extended periods at flows <10 m^3/s. Tidal variation of up to ~1 m occurs at the mouth of the estuary and decreases to ~2 cm at the Sir Ernest Oppenheimer Bridge. There is little difference in tidal variation in the lower 6 km of estuary. Salinity intrusion typically extends 6 km from the mouth where channel depth exceeds 3 m. The channel becomes shallower from 5 to 7 km creating a barrier to further intrusion under normal flows (20 – 50 m^3/s). Strong vertical salinity stratification typically occurs in the deeper basin in the lower and middle reaches of the estuary.

Sediment in the estuary is relatively coarse compared to other estuaries, ranging from very fine to coarse sand at the mouth, clay to silt in the middle reaches, and silt in the riverine upper reaches. The sediment supply has changed significantly over the years primarily because of dam developments. The sediment load has decreased from 119 M tons/a pre-1921 to <40 M tons/a in the 1980's.

Water temperature is most affected by atmospheric temperatures. During winter the river water is usually colder than the intruding seawater, creating a strong stratified water column. The opposite is true for summer where warm river water forms a stratified layer over the cooler intruding seawater. The intrusion of upwelled water from the adjacent coast can introduce seawater with temperatures of 9 to 14°C.

The pH in the river water was expected to be 6.5 to 7.0 during reference conditions. More recent measurements have found the pH in the estuary to range from 7.5 in seawater up to 8.9 in riverwater.

Dissolved oxygen measurements have found the water in the estuary to be well oxygenated (>6 mg/ℓ), with only infrequent measurements of 4 and 5 mg/ℓ in localised, deep water (2 m). It is important to note that the measurements were taken during daylight hours in August 2012 in a phytoplankton bloom. A large bloom in the river introduced near-anoxic water into the estuary in April 2003. It is likely that hypoxic, or even anoxic, conditions could occur at night time when the large biomass of microalgae is respiring and there is no oxygen contribution through photosynthesis.

Dissolved inorganic nitrogen (DIN), dominated by nitrate-N, were expected to be <50 μg/ℓ in river water during reference conditions. Concentrations have increased to ~100 μg/ℓ under normal flow conditions, and peaking at ~400 μg/ℓ under high flows. Elevated nutrients are mostly associated with agricultural return flows. Concentrations in the estuary during 2012 ranged from ~100 μg/ℓ in the fresh upper reaches to ~ 300 μg/ℓ in the more saline lower reaches.

Dissolved inorganic phosphorus (DIP) concentrations were expected to be <10 μg/ℓ. Recent measurements in the river have found concentrations ranging from ~20 μg/ℓ to ~50 μg/ℓ. Concentrations in the estuary during 2012 ranged from ~10 μg/ℓ in the fresh upper reaches to ~50 μg/ℓ in the more saline lower reaches. The nutrient-salinity plots show a distinct concave shape indicating the estuary as a net sink for nutrients, probably lost through the process of flocculation or uptake by primary producers.

Dissolved reactive silicate (DRS) was typically high in the Orange River water, being introduced from the large catchment. Median concentrations ranged from 2,500 μg/ℓ during low flows to 7,500 μg/ℓ during high flow periods.

A total of 10 sampling sites were included for phytoplankton measurements in August 2012 (Figure 39) and six sampling sites for benthic microalgae. Phytoplankton was collected from the mouth to the site where there was no evidence of saline intrusion (5,5 km from the mouth). Benthic microalgae were collected at sites where there was a clear intertidal zone and were accessible by boat, from the mouth to 7,2 km.

3.2.2 Phytoplankton chlorophyll a

Water samples (500 ml) were gravity-filtered through Whatman GF/C filters then stored in the dark of a cooler box until they could be frozen. The chlorophyll *a* was extracted by placing the frozen filters into 10 ml of 95% ethanol (Merck 4111). After extraction for 24 hours, spectrophotometric determinations of chlorophyll *a* were performed according to Nusch (1980). Absorbance was measured before and after acidification of extracts with 10% HCl.

3.2.3 Phytoplankton identification

Water samples for phytoplankton enumeration were collected at the surface, 0,5 m, 1,0 m and then at 1.0 m intervals to the bottom. The water samples were fixed with 1,5 ml of 1% (v/v) glutaraldehyde solution. Glutaraldehyde was preferred to a 10% neutral formalin solution as formalin can cause flagellates to lose their flagella making identification difficult (Lund et al., 1958, Boney, 1989). Samples were then placed in 60 ml settling chambers and allowed to settle for 24 hrs then counted following the Utermöhl method of cell enumeration as modified by Snow et al. (2000). Functional and dominant groups were categorised into flagellates, dinoflagellates, chlorophytes (greens), cyanophytes (blue-greens), diatoms and euglenoids. It is important to note that all flagellates were included as phytoplankton in this study. Many flagellates do not contain chloroplasts and are more correctly classified as protozoans.

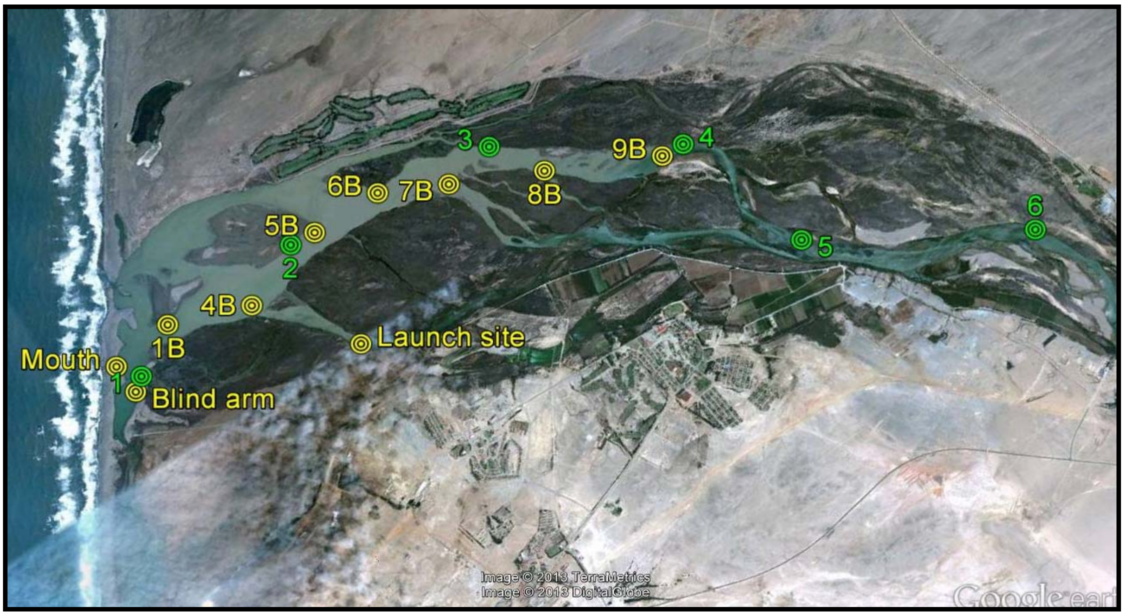


Figure 39. Google Earth image of the Orange Estuary showing sampling sites for phytoplankton (yellow markers) and benthic microalgae (green markers)

3.2.4 Benthic chlorophyll a

Four replicate intertidal benthic samples were collected from premarked locations (20 mm internal diameter circle) at low tide from each site by scraping a known area of surface sediment (<2 mm depth) just above the estuarine water level. Four subtidal samples were collected from each site using a 20 mm internal diameter corer attached to an extension pole and the surface sediment was scraped from the core. Both intertidal and subtidal samples were stored in the dark of a cooler box until they could be frozen. The chlorophyll *a* was extracted by placing 30 ml of 95% ethanol (Merck 4111) onto the samples. After extraction for 24 hours, spectrophotometric determinations of chlorophyll *a* were performed according to Nusch (1980). Absorbance was measured before and after acidification of extracts with 0.1 N HCl.

3.2.5 Benthic diatom collection and identification

The epipelon was sampled based on the method described by in Bate et al. (2004). Samples were taken using a length of PVC piping (~15 mm I.D.) that was drawn across the sediment and allowed to fill with a mixture of surface sediment and water. This process was repeated up to five times in different positions in order to get a sample that was representative of the different micro-habitats. The mixture was stored in a plastic sample container (250 ml). In a field laboratory, some of the settled material was placed in a Petri dish and a sheet of lens tissue paper (covering ca. 100% of the sediment surface) was placed on top of the wet sediment. On the same day (ca. 6 hours later) the lens tissue was carefully removed with as little sediment as possible. In this way only living cells that had attached to the lens tissue were sampled. The lens tissue from each sample was placed in glass bottles and transported to the laboratory. There is no time limit at this stage to process the diatoms further. To each glass bottle containing the lens tissues, 2 ml of saturated $KMnO_4$ and 2 ml of 10 M HCl was added. This mixture was heated on a hot plate at ca. 80°C until the solution cleared (~20 – 40 mins) and became a transparent straw colour. All acid cleaned samples were washed with distilled water using five consecutive spins (2,000 rpm for 10 mins). Permanent light microscopy slides were made with 1 – 2 drops of diatom 'digest', placed onto an acid-washed cover slip (previously stored in ethanol) and allowed to dry in air. Cover slips treated in this manner allow the drop of sample to spread more evenly. Once completely dry, a small amount of Naphrax® mounting medium (Northern Biological Supplies, U.K.) was dotted onto a glass microscopy slide and the cover slip placed over it. Air trapped under the slide and the Naphrax were dispersed by heating the slide on a hot plate (~60°C). The Naphrax was allowed to dry for 2 – 3 days.

Diatom frustules were examined under a Zeiss Axioplan light microscope with differential interference contract optics. Using a television camera (JVC KY-F3), images of the dominant taxa were visualised using the AnalySIS image analysis programme (©1999, Soft Imaging System GmbH). Diatom valves were counted in each sample using 1000x magnification until the obvious dominant was established. At least one of every taxon was made into a digital image. All the images were then printed and used in the counting procedure. This achieves two important aspects, (1) a digital image of each taxon and (2) a count of the total number of taxa. The nomenclature of Archibald (1983), Bate et al. (2004), Riznyk (1973) and Taylor et al. (2007) were used.

3.3 Results

3.3.1 Phytoplankton chlorophyll a

Phytoplankton chlorophyll a was lowest at the mouth of the estuary and highest 1 km upstream, ranging from 1,5 μg/ℓ in the blind arm to 27,6 ± 7.1 μg/ℓ (Figure 40). Phytoplankton chlorophyll a is usually highest near the surface but this was not the case in the Orange Estuary where concentrations typical of blooms were measured at depth in the 'old water'. The highest concentrations were measured in the bottom water (2 m) at sites 1,0; 1,4 and 2.3 km from the mouth (45,1 μg/ℓ, 20,6 μg/ℓ and 36,82 μg/ℓ respectively). Average chlorophyll a in the estuary was relatively 15,7 ± 1,9 μg/ℓ with localised bloom concentrations (>20 μg/ℓ) in the mid to lower reaches.

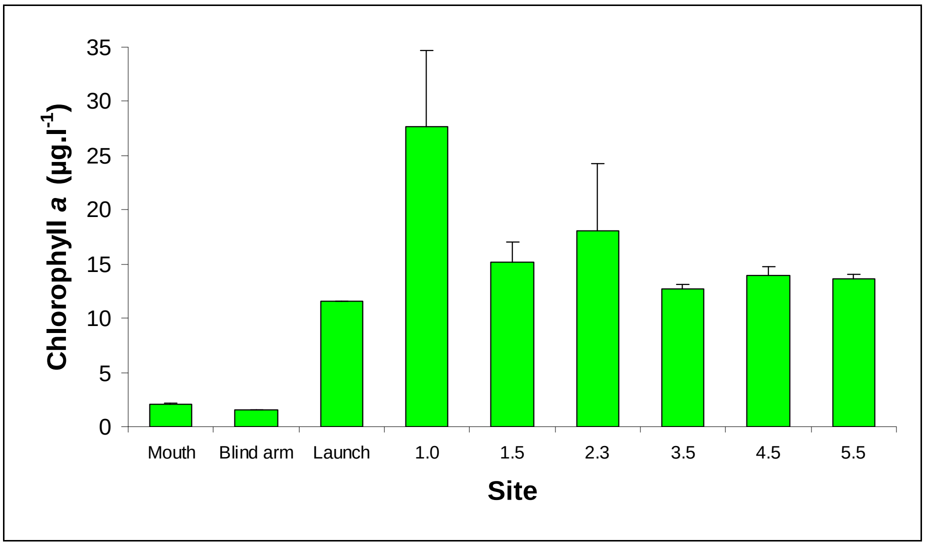


Figure 40. Average phytoplankton chlorophyll a along the length of the Orange Estuary, August 2012

3.3.2 Phytoplankton community structure

The total phytoplankton cells were lowest near the mouth of the estuary (0.2 km; 2,045 cells/ml) and increased with distance to 31,440 ± 2,510 cells/ml, 3,5 km from the mouth (Figure 41). Cell density exceeding 10,000 cells/ml is typical of a phytoplankton bloom, supporting the chlorophyll a results. The flagellates and dinoflagellates were highest in the middle reaches of the estuary reaching maxima of 12,485 ± 3,038 cells/ml (1,4 km) and 104 ± 46 cells/ml (2,3 km) respectively. The highest flagellate densities were collected from the deep (2 m) 'old water' at sites 1.0, 1,4 and 2,3 km from the mouth, making this the most likely group to have contributed to the elevated chlorophyll a at these sites.

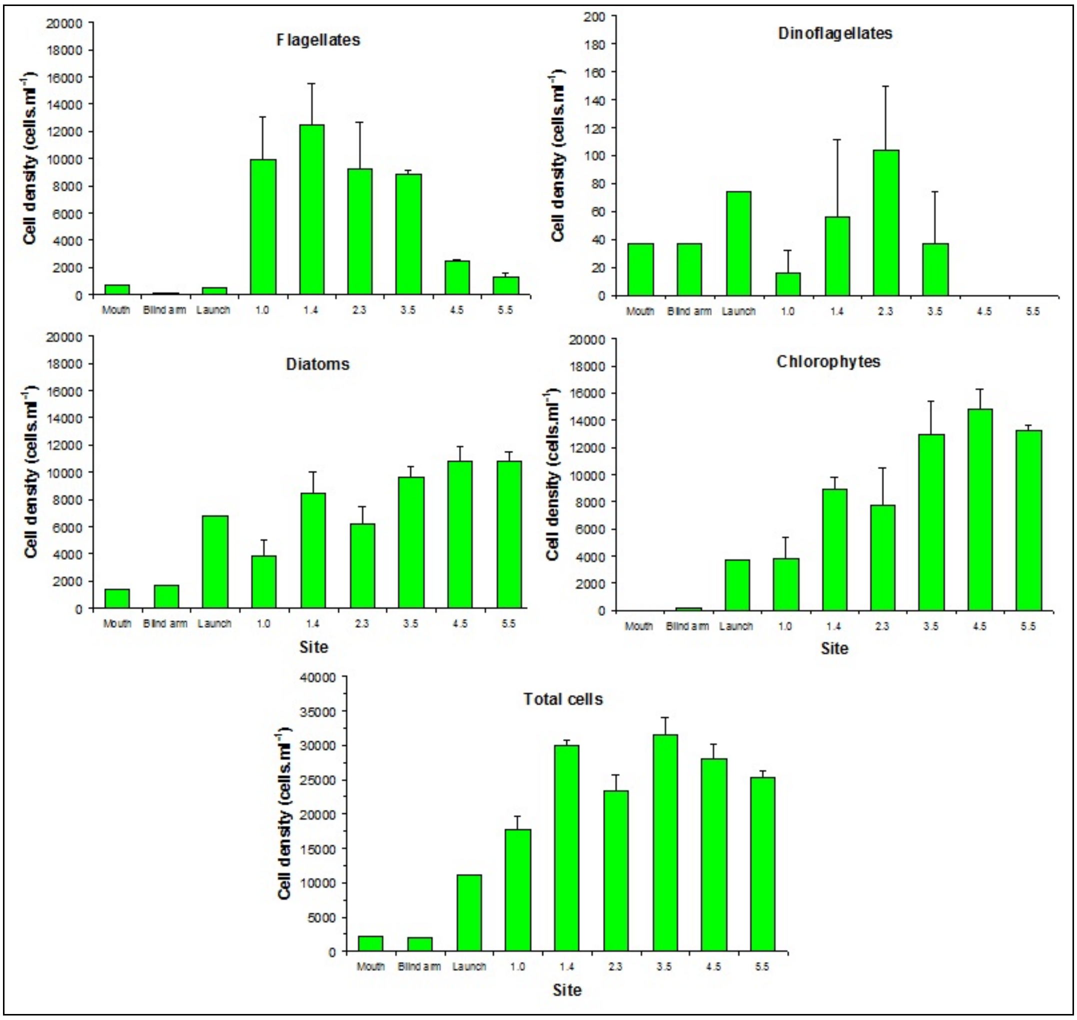


Figure 41. Phytoplankton cell counts along the length of the Orange Estuary, August 2013

The diatoms and chlorophytes increased in density with distance from the mouth, indicating that the majority of cells were transported into the estuary in the river water. Average diatom density ranged from 1,412 cells/ml at the mouth to 10,813 ± 1,036 cells/ml in the upper reaches (4,5 km). There were no chlorophytes cells recorded at the mouth of the estuary and 14,789 ± 1,488 cells/ml were measured at 4,5 km.

3.3.3 Benthic chlorophyll a

Benthic chlorophyll a in the intertidal zone ranged from 1,23 ± 0,15 mg/m^2 (± SE) near the estuary mouth to 126,93 ± 22,38 mg/m^2 2,0 km from the mouth (Figure 42). Subtidal chlorophyll a ranged from 13,84 ± 0,55 mg/m^2 (5,7 km) to 108,48 ± 12,96 mg/m^2 4,0 km from the mouth. The median content for the estuary was 48,47 mg/m^2, which is very high (>42 mg/m^2) based on the classification scheme of Snow (2007). The average content was 56,36 ± 6,93 mg/m^2.

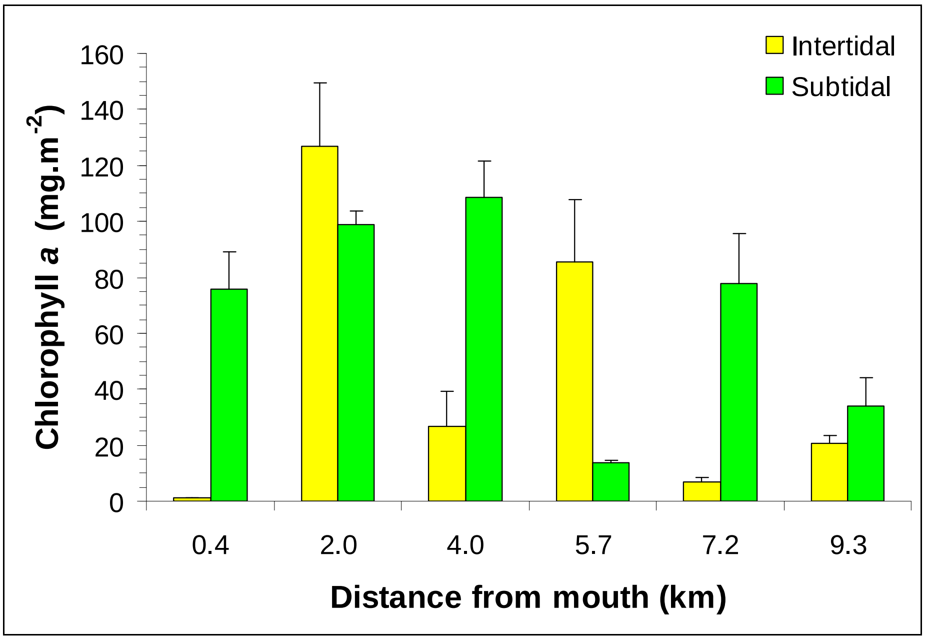


Figure 42. Intertidal and subtidal benthic chlorophyll a along the longitudinal axis of the Orange Estuary, August 2012

3.3.4 Benthic diatom community structure

The benthic diatoms in the Orange Estuary in August 2012 were dominated by *Diploneis puella*, *Amphora ovalis* var. *affinis*, *Nitzschia clausii*, *Fragilaria tenera* and *Navicula gregaria*. Of these species, Taylor et al. (2007) described *N. clausii* as a species tolerant of strongly polluted waters, *F. tenera* is typically found in meso- to eutrophic waters, and *N. gregaria* as being very tolerant of strongly polluted environments. Based on Taylor et al.'s (2007) descriptions, the vast majority of species he describes that were identified at the estuary are tolerant of electrolyte-rich or brackish conditions, are tolerant of strongly or critically polluted water, and in two cases are tolerant of elevated temperature or turbidity. The general community composition in the estuary indicates that the estuary was brackish or electrolyte-rich for a period of time leading up to sampling and, more importantly, the environment was eutrophic or strongly polluted.

3.3.5 Discussion

The microalgal biomass, based on a once-off survey by Centre of Scientific and Industrial Research (CSIR) (Harrison, 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 – 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.

3.3.6 Responses to reduced flow

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/m^2), and phytoplankton biomass would have been low too (<3,5 μg/ℓ), being dominated by diatoms with few chlorophytes. As river flow decreased to present (normal flow of 20 – 50 m^3/s), the concentration of nutrients in the river water has increased supporting elevated biomass of phytoplankton (>20 μg/ℓ) and benthic microalgae (>42 mg/m^2). If flow were to be reduced further, REI would become more established with a higher density of flagellates and dinoflagellates in the middle reaches, with the freshwater and its associated diatom and chlorophyte community being restricted to low salinity in the extreme upper reaches. More frequent periods of hypoxia, or even anoxia, as a result of established blooms in the estuary will favour the presence of cyanobacteria. If the mouth were to close for extended periods, the water column would go through cycles of being dominated by flagellate blooms or fast growing filamentous algae (e.g. *Cladophora* sp. or *Ulva intestinalis*) similar to that found in the Great Brak Estuary. Conditions would favour a high biomass of benthic microalgae, particularly in the middle reaches, in areas protected from the resuspension of sediments through wind mixing and where silts, clays and organic materials are deposited.

Table 10. Summary of typical physical, water quality and microalgal 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***	
Mouth condition	Closed		Closed		Open		Open		Open	
Salinity (ppt)	45	35	25	10	20	0	5	0	0	0
	45	35	30	15	30	5	25	0	5	0
DIN (µg/ℓ)	50	50	Reference		Reference		Reference		Reference	
	50	5	150	100	200	50	50	50	50	50
			150	100	200	50	200	50	50	50
			Present/Future		Present/Future		Present/Future		Present/Future	
			150	50	200	100	100	100	3	300
			150	150	200	100	200	100	300	300
DIP (µg/ℓ)	10	10	Reference		Reference		Reference		Reference	
	10	10	30	20	40	10	10	10	10	10
			30	20	40	10	40	10	10	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 (µg/ℓ)	1000	1000	500	3000	1000	6000	4000	6000	6000	6000
	1000	1000	200	2000	200	6000	1000	6000	6000	6000
Phytoplankton chl-a (µg/ℓ)	27	29	25	19	23	15	17	15	15	15
	27	29	29	21	27	17	25	15	17	15

4. Estuarine macrophytes

4.1 Introduction

The Orange Estuary is characterised by a variety of habitats in the form of islands and braided channels. These create sheltered shallow water areas where birds such as herons, ducks, egrets and waders can feed and roost. In particular the extensive reed beds provide habitat for warblers and other roosting or reedbed-dwelling passerines. Fringing reeds also provide perches for the variety of kingfishers. The macrophytes also stabilize the riverbanks thus protecting the mouth area.

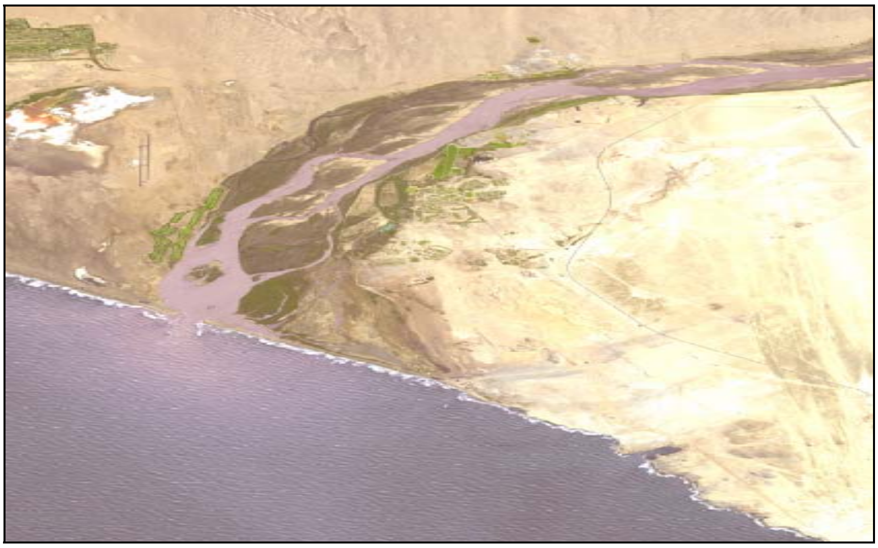


Figure 43. Satellite image of the Orange Estuary showing braided channels and associated vegetation (2010)

The Orange Estuary has unique estuarine macrophyte species diversity. Steffen et al. (2010) described an ecomorphotype of *Sarcocornia pillansii* (Moss) A.J.Scott that shows unique morphology in this estuary. The Orange River ecomorphotype is characterised by corky, swelling internodes. Other estuarine macrophytes that were previously recorded in the estuary were *Bassia diffusa* (Thunb.) Kuntze, *Bolboschoenus maritimus* (L.) Palla, *Cotula coronopifolia* L*., Juncus kraussii* Hochst., *Mesembryanthemum* L., *Phragmites australis* Cav.) Steud., *Salicornia meyeriana* Moss, *Sarcocornia natalensis* (Bunge ex. Ung-Sternb.) A.J.Scott, Sarcocornia *tegetaria* S. Steffen, Mucina & G. Kadereit, Sporobolus *virginicus* (L.) Kunth and *Triglochin striata* Ruiz & Pav. The total estuarine habitat area was calculated by Bornman (2002) as 974,52 ha. The total wetland habitat is estimated at 2,700 ha. The major habitat types were channel, sand/mud banks, reeds & sedges, submerged macrophytes, supratidal salt marsh and intertidal salt marsh.

The Orange Estuary vegetation had been highly modified since 1929 because of the following events:

- In 1929 attempts were made to keep the mouth open that would have prevented backflooding of the marsh area.
- In the late 1960's tidal penetration into the western extreme of the salt marsh was blocked by a rubble berm in an attempt to control the mosquito problem.
- In 1974 the first dykes or levees were constructed to increase agricultural area. The dykes cut off two flood channels that used to extend southwards into the salt marsh via the Dunvlei channel system, part of which is now used as a sewage oxidation pond for Alexander Bay.
- From the mid 1970s the operation of the Gariep (1971), Vanderkloof (1977) and other dams reduced small floods. The combination of these floods with high spring tides is thought to have played an important role in flooding the marsh area (Taljaard et al., 2003).
- Mining operations first commenced in 1929, the process uses seawater and wastewater collects in a slimes dam that is positioned adjacent to the salt marsh. Seepages from the slimes dam would have inundated the salt marsh for extended periods causing die back and in 1984 the final collapse of the system started and progressed rapidly. The trigger event around which the collapse is considered to have hinged was the introduction of North Sieve process water and slimes dam dust into the marsh along its south-western perimeter (Raal, 1996).

In 1995 Alexkor together with the CSIR initiated a rehabilitation programme. Several sections of the causeway at the mouth were removed to allow for regular tidal flushing of the lower reaches of the degraded salt marsh area. Aerial photographs from 2002 indicated some success of this programme; however it was suggested that a vegetation survey would be necessary to confirm this.

4.2 Previous studies on macrophytes of the Orange Estuary

The earliest studies on the vegetation of the lower reaches of the Orange Estuary are described by O'Callaghan (1984), Burns (1989) and Morant and O'Callaghan (1990). Anon (2002) also used this data in subsequent reports. The results from the report described the estuarine plant communities that are distributed along the southern bank of the estuary, corresponding to the 2 to 2,5 km limit of saltwater penetration. The delta-type river mouth has a wide range of habitats that consists of a series of braided channels interspersed with sandbanks, channel bars and small islands, with a tidal basin and a salt marsh on the southern bank. Several pans occurred on either bank, extensive mudbanks occurred at the mouth and large areas of interfluvial marsh occurred upstream of the mudflats.

Several small, artificial wetlands occurred on either side of the river including the Alexander Bay oxidation ponds, lucerne fields pan on the South African side and the yacht club pan on the

Namibian side. The submerged macrophyte *Stuckenia pectinata* was associated with common reed *Phragmites australis* (CSIR, 1991). This plant grows best at salinity less than 10 ppt. The submerged macrophyte *Ruppia cirrhosa* was also reported but its abundance was said to be limited because of low salinity and high turbidity of the water (CSIR, 1991; Raal, 1996).

The vegetation on the islands within the lower reaches of the river is ephemeral due to periodic flooding. The pioneers such as *Sporobolus virginicus* (brakgras) and *Bolboschoenus maritimus* dominate these communities and are normally in a sub-climax state. The peripheral marshes are dominated by *Sporobolus virginicus*, but various herbs, sedges and grasses such as *Cotula coronopifolia*, *Juncus kraussii*, *Apium graveolens* and *Cyperus laevigatus* also occur. All these species would thrive under brackish conditions (<15 ppt).

Aerial photographs from 2002 indicated that two large vegetated areas occur on the south bank of the main river channel. These areas are probably composed of a mosaic of brackish species as described above. The following species formed a mosaic of salt marsh vegetation: *Cotula coronopifolia*, *Triglochin* spp., *Ficinia laevigatus*, *Sporobolus virginicus* and *Sarcocornia pillansii*. *Sarcocornia tegetaria* formed a salt marsh on the right bank of the river near the mouth (Morant and O'Callaghan, 1990).

This species usually occurs in the intertidal zone of permanently open estuaries. *Sarcocornia pillansii* was dominant in the salinized lower floodplains. On the south bank of the river a large area of desertified salt marsh exists. In 1986 approximately 90% of this saltmarsh had died. Salt marsh communities that were still present at elevated zones were dominated by *Sarcocornia pillansii*. This species usually occurs in the supratidal salt marsh zone of South African estuaries. The sequence of events that led to the current situation is shown below (Figure 44).

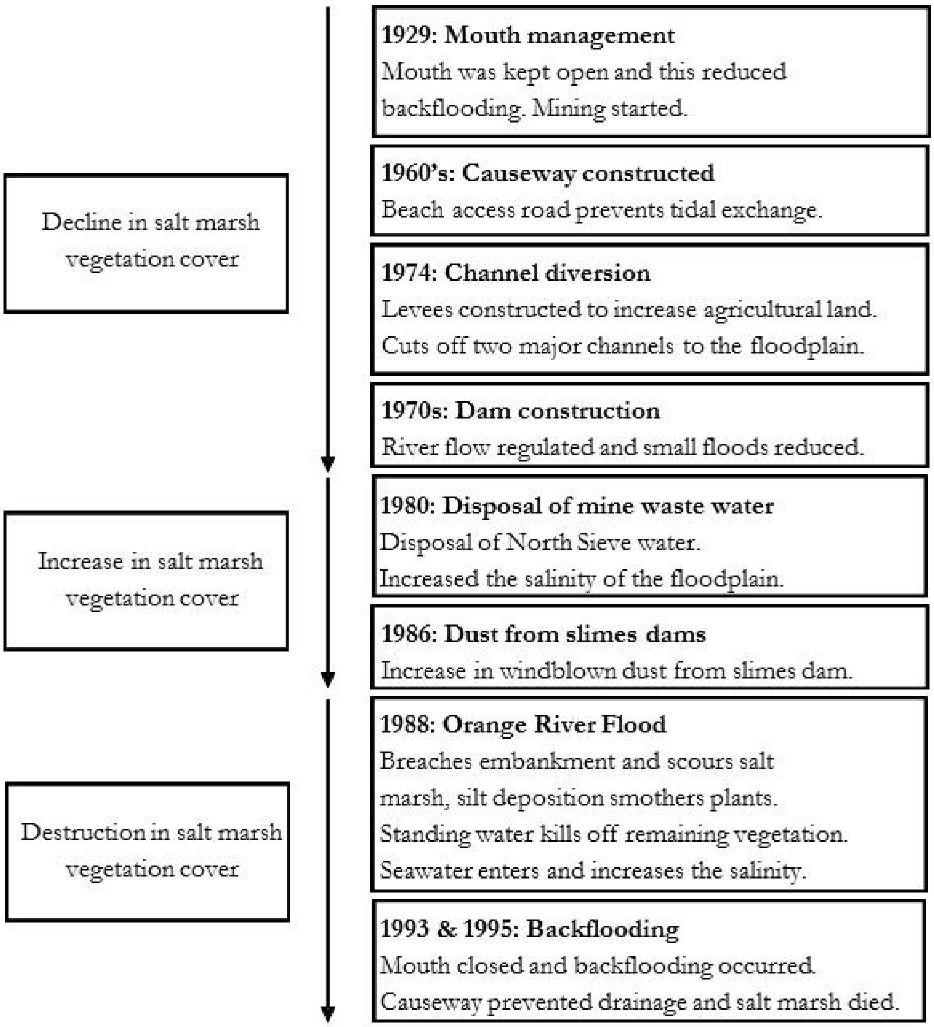


Figure 44. History of the degradation of the salt marsh at the Orange Estuary (Bornman et al., 2002; Shaw, 2007)

Table 11. Available information on the macrophytes of the Orange Estuary

Detail	***Reference***
Aerial photographs of the estuary (ideally 1:5,000 scale) reflecting the present state, as well as the reference condition (earliest year available). A GIS map of the estuary must be produced indicating the present and reference condition distribution of the different plant community types.	2012 GIS map from Spot 5 imagery (2010) and ground truthing in August 2012.
Number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit. The extent of anthropogenic impacts (e.g. trampling, mining) must be noted.	Data available, updated from 2012 field survey.

Detail	*Reference*
Permanent transects (fixed monitoring stations that can be used to measure change in vegetation in response to changes in salinity and inundation patterns) must be set up along an elevation gradient: Measurements of percentage plant cover of each plant species in duplicate quadrats (1 m^2). Measurements of sediment salinity, water content, depth to water table and water table salinity.	Recent data not available although South African Environmental Observation Network (SAEON) did sample transects in January 2012. Data set from 2006 used in this study.
Information on the vegetation distribution and response to environmental variables.	Raal (1996), Bornman (2002), Van Niekerk et al. (2003), Bornman et al. (2004), Shaw (2007) and Shaw et al. (2008).
Hydrology, Hydrodynamics, Water quality, Sediment dynamics, Microalgae, Invertebrates, Fish, Birds.	Taljaard et al. (2003).

4.2.1 Rehabilitation of the Orange Estuary salt marsh

Rehabilitation at the Estuary was first initiated in 1997 through the removal of a section of causeway near the mouth by the mining company, which allowed water to permanently return to a small section of the salt marsh. The intertidal salt marsh species, *Cotula coronopifolia,* re-colonised the new area subjected to tidal flows. *Sarcocornia pillansii* responded to the increased tidal flushing through increased cover abundance, growth and seed production in the supratidal zone surrounding the newly re-created intertidal area. Although water was also able to flow into the remainder of the wetland through the breach during times of flooding and backflooding, the outflow was restricted to the same small breach resulting in long periods of standing water in the desertified marsh. This meant that instead of the water flowing easily through the system and flushing out the salts leached from the sediment, it receded slowly re-depositing most of the salt as the water evaporated and the problem of hypersalinity persisted (Shaw, 2007). The first phase of the Working for Wetlands project began at the Orange Estuary in June 2005 and the objective was to breach the causeway at strategic places to allow drainage of the marsh after a backflooding event. The effectiveness of these breaches was demonstrated in 2006 when the wetland was subjected to two instances of flooding. The breaches facilitated drainage of the marsh. The marsh was completely covered by water and although the breaches were successful, two more sites on the causeway were identified as requiring further breaching (Working for Wetlands, 2006). The current state of the Orange Estuary (Table 12) was influenced by the occurrence of the following sequence of events.

Table 12. Recent changes in the Orange Estuary and the response of macrophytes

Year	*Event*	*Response of macrophytes*
1997	Rehabilitation at the Estuary and removal of a section of causeway near the mouth.	Increase in abundance of *Sarcocornia pillansii.*
2005	Working for Wetlands project began removal of causeway.	No immediate response.

Year	***Event***	***Response of macrophytes***
2006	Flooding and rainfall led to a decrease in sediment electrical conductivity.	Germination and establishment of salt marsh species, *S. pillansii* and *Cotula coronopifolia*.
2010	Floods.	Deposition of sediment and filling of tidal changes resulted in the loss of intertidal area.

Bornman et al. (2004) studied the response of macrophytes to changes in the environmental conditions of the desertified salt marsh in the Orange Estuary. They found that depth to the water table and the salinity of the groundwater was the most important factor influencing the distribution of floodplain salt marsh plants. The soil of the desertified floodplain was hypersaline all year round with the combined summer and winter mean sediment electrical conductivity at 53,1 mS/cm. The surface soil salinity was also higher in the desertified marsh than in the vegetated areas during both summer and winter. The large desertified areas on the marsh were also characterised by high groundwater salinity. Typically, under conditions of high sediment electrical conductivity and high groundwater salinity the species *Sarcocornia pillansii* would be the dominant species of supratidal and floodplain salt marshes around South Africa (Bornman, 2002). However, in this study the conditions were mostly above the tolerance range of *S. pillansii*. The influence of season, presumably the rainfall, on the soil EC was limited to the vegetated areas. The species characteristic of more brackish areas (*Sporobolus virginicus*, *Drosanthemum* sp. and *Salsola* sp.) occurred where the groundwater was too deep to influence the surface soil salinity.

Bornman et al. (2004) suggested that in order for rehabilitation of the desertified marsh to succeed the groundwater salinity needs to be reduced through linking the marsh back with the main river channel. This meant that the remaining sections of the causeway or the whole causeway should be removed, thereby introducing less saline water through backflooding and establishing favourable geohydrological conditions.

Shaw (2007) and Shaw et al. (2008) studied the desertified salt marsh of the Orange Estuary just after the start of the rehabilitation. The focus of these studies was sediment and seed bank characteristics in order to recommend options for rehabilitation of the degraded salt marsh. Their results were similar to Bornman et al. (2004) where sediment electrical conductivity of the sediment was above the tolerance range of the dominant species *Sarcocornia pillansii* (>80 mS/cm). The study showed that rainfall and flooding were important in lowering sediment electrical conductivity, which would promote the growth of adult vegetation. They also found that due to flooding in 2006 there was a decrease in sediment electrical conductivity across all sites. This indicates the importance of freshwater pulses (e.g. rain and floods) for the germination and establishment of the two dominant salt marsh species, *S. pillansii* and *Cotula coronopifolia*.

They also compared the influence of different microhabitats (driftlines, open sites and under vegetation) on sediment characteristics and consequently seed germination success. Vegetated habitats were conducive for the germination and establishment of seedlings. Sediment compaction and shear was higher for the open areas compared to under the vegetation. A hard crust formed in the open areas reducing the ability of the seed to germinate.

Conditions required for rehabilitation of the area included frequent river flooding or backflooding to flush the salts from the surface soils. The initial frequency of the flooding events should be in two concurrent years in order to allow for dilution of salts and to promote seed germination and establishment. A third year of high flow could ensure the survival of the seedlings. As the desertified marsh is progressively colonised the microhabitat provided by the adults will ensure the survival of the seedlings. Interference with the hydrodynamics of the mouth and river flow only need to continue until the entire marsh has been recolonized to the natural cover abundance of *S. pillansii*. Thereafter large floods as occurred in 2006 should be sufficient in maintaining the salt marsh community.

Bornman and Adams (2010) studied the importance of large floods in the Orange Estuary. The study tested the hypothesis that the large flood (of 2006) and rainfall events would be sufficient to significantly reduce the salinity of the soil and groundwater thereby creating favourable conditions for the re-establishment of floodplain species. Their results showed no significant difference in sediment electrical conductivity in the sediment and groundwater over the four sampling periods and that depth to groundwater in the desertified marsh mostly retained a similar pattern after the flood. The flood and high rainfall had a limited impact on the soil and groundwater characteristics.

They consequently suggested human intervention is needed to ensure the rehabilitation of the Orange Estuary.

4.3 The ecological flow requirement of the Orange Estuary

The EFR determination on a rapid level for the Orange Estuary was based on the methodology for estuaries as set out by South Africa's Department of Water Affairs and was completed in 2003. The macrophyte and microalgae component study was conducted by Adams (2003). The Orange Estuary was considered to be an estuary of 'high importance'. In addition, it is also a Ramsar site (i.e. protected area in particular for water birds). According to the guidelines the recommended ecological category should therefore be a category A – if not possible then the best attainable state (BAS). With major dam developments in the catchment that have reduced river inflow to the estuary by more than 50% (considered to be irreversible), it is unlikely that the estuary could be returned to a category A. The best attainable status for the estuary is therefore considered to be an ecological category C, with a strong recommendation that mitigating actions to reverse modifications caused by the non-flow-related activities and developments in the estuary be investigated by the responsible authorities.

As part as the specialist study Adams (2003) identified the following factors that determine the growth and distribution of the macrophytes of the Orange Estuary:

Flow, where high river inflows/floods (1:1 – 1:10 year floods) and high spring tides are the major mechanism for inundating the salt marshes and washing out accumulated salts. However there has been a marked reduction in floods from the reference to the present condition and thus this mechanism of inundating the salt marsh does not occur. Reduced flooding will result in reed encroachment.

The salinity of the groundwater must be maintained at acceptable levels (<70 ppt) through the influence of the estuary on groundwater to ensure the establishment, seeding, germination of the supratidal species *S. pillansii*. 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.

An open mouth is important for the recovering salt marsh on the south bank. When a section of the causeway was removed in the vicinity of the mouth, the salt marsh showed signs of recovery that was dependent on regular tidal inundation.

4.4 Study approach (2012)

4.4.1 Field work

A field trip to the Orange Estuary was undertaken from the 21 – 24 of August 2012. This survey focussed on the vegetation associated with the main river channel as previous studies had investigated the desertified salt marsh area. SAEON had undertaken a field investigation of the desertified marsh area in January 2012 but the data were not available for inclusion in this report. During the field visit species were identified in areas that were most likely to change i.e. the water area including intertidal banks and the desertified salt marsh. Voucher specimens of each species were collected along the entire length of the estuary. Note was taken of the geographical location, estuary habitat and adjacent threats. The species collected in this study was added to the existing Estuarine Botanical database.

4.4.2 Mapping for assessment of habitat area and changes over time

Mapping of macrophyte habitats focussed on the water area including intertidal banks and the desertified salt marsh. The estuarine functional zone (estuarine ecosystem area) and open water areas was digitized using Spot 5 imagery (2010) and Google Earth (Arc-View GIS 10; ESRI). The 5 m topographical contour (CSIR) was used as the boundary to delineate the estuarine functional zone. Ground truthing was done to identify the boundaries for intertidal, supratidal and floodplain salt marsh in August 2012. The end of salinity penetration was the Sir Ernest Oppenheimer Bridge 11 km upstream.

4.5 Results

4.5.1 Species richness

The total number of species in the Orange Estuary increased from 12 noted in 2003 to 31 in 2012 (Table 13, Figures 47 – 49). This is not a real increase but could rather be related to the more thorough recent taxonomic investigation. The intertidal salt marsh had the greatest species richness (13). This diversity was concentrated in the lower reaches on the west bank of the channel. Three macroalgal species occurred in the west channel near the mouth where flow conditions were low. A few individuals of *Bolboschoenus maritimus* was found along the estuary, where they showed signs of stress.

The rest of the reeds and sedges such as *Phragmites australis* were found along the estuary, with disappearance of this species closer to the mouth. Supratidal species such as *Sarcocornia pillansii* and *Psilocaulon dinteri* were also restricted to the lower reaches. *Suaeda fruticosa* was the dominant species in the middle to upper reaches of the salt marsh. This species was also dominant on the desertified salt marsh. Further along the estuary wetland-terrestrial species were dominant. This included weedy and exotic species such as *Datura stramonium* and *Gomphocarpus* sp. Grass species such as *Sporobolus africanus* were also abundant. Only one submerged macrophyte species was found, *Stuckenia pectinata* and this occurred in the upper reaches in channels with reduced flow.

4.5.2 Habitat area and diversity

The earliest aerial photographs are available for 1937. The total area mapped from 2010 imagery and 2012 ground truthing showed that the total estuarine area (mapped within the 5 m orthographic contour) is 2,709 ha (Table 14, Figure 45). Based on abiotic components such as flow, salinity and sediment conditions the following changes in vegetation occurred. The total area of sand and mudbanks (from 101 ha to 144 ha) and reeds and sedges increased from the reference to the present state. Macroalgae also increased in abundance. There was large decrease in the area of supratidal marsh, which became desertified (511 ha in 2012). Figure 45 shows the area where there has been an increase in vegetation on the desertified salt marsh north of the causeway in 2010.

Table 13. List of macrophyte species recorded in 2012 and associated habitat

Species	**Habitat**
Apium graveolens L.	Intertidal salt marsh
Beta vulgarus subsp. *maritima* (L.) Arcang.	Intertidal salt marsh
Cotula coronopifolia L.	Intertidal salt marsh
Juncus kraussii Hochst.	Intertidal salt marsh
Plantago lanceolata L.	Intertidal salt marsh
Samolus porosus (L.f.) Thunb.	Intertidal salt marsh
Sarcocornia decumbens (Toelken) A.J. Scott	Intertidal salt marsh
Sarcocornia natalensis (Bunge ex. Ung-Sternb.) A.J.Scott	Intertidal salt marsh
Sarcocornia tegetaria S. Steffen, Mucina & G. Kadereit	Intertidal salt marsh
Spergularia media (L.) C.Presl ex Griseb	Intertidal salt marsh
Tetragonia decumbens Mill.	Intertidal salt marsh
Triglochin bulbosa L.	Intertidal salt marsh
Polysiphonia incompta Harvey	Macroalgae
Ulva capensis J.E. Areschoug	Macroalgae
Ulva intestinalis L.	Macroalgae

Species	***Habitat***
Bolboschoenus maritimus (L.) Palla	Reeds and Sedges
Ficinia lateralis (Vahl) Kunth	Reeds and Sedges
Phragmites australis (Cav.) Steud.	Reeds and Sedges
Schoenoplectus scirpoides (Schrad.) Browning	Reeds and Sedges
Stuckenia pectinata (L.) Boerner	Submerged macrophtytes
Atriplex vestita (Thunb.) Aellen	Supratidal salt marsh
Atriplex semibaccata R.Br.	Supratidal salt marsh
Cynodon dactylon (L.) Pers.	Supratidal salt marsh
Lagurus ovatus L.	Supratidal salt marsh
Psilocaulon dinteri Schwantes	Supratidal salt marsh
Salsola aphylla Spreng.	Supratidal salt marsh
Sarcocornia pillansii (Moss) A.J.Scott	Supratidal salt marsh
Sporobolus virginicus (L.) Kunth.	Supratidal salt marsh
Suaeda fruticosa (L.) Forssk.	Supratidal salt marsh
Aspalathus sp	Terrestrial Fringe
Datura stramonium L.	Terrestrial Fringe
Gomphocarpus fruticosus (L.) Aiton f.	Terrestrial Fringe
Sporobolus africanus (Poir.) Robyns & Tournay	Terrestrial Fringe

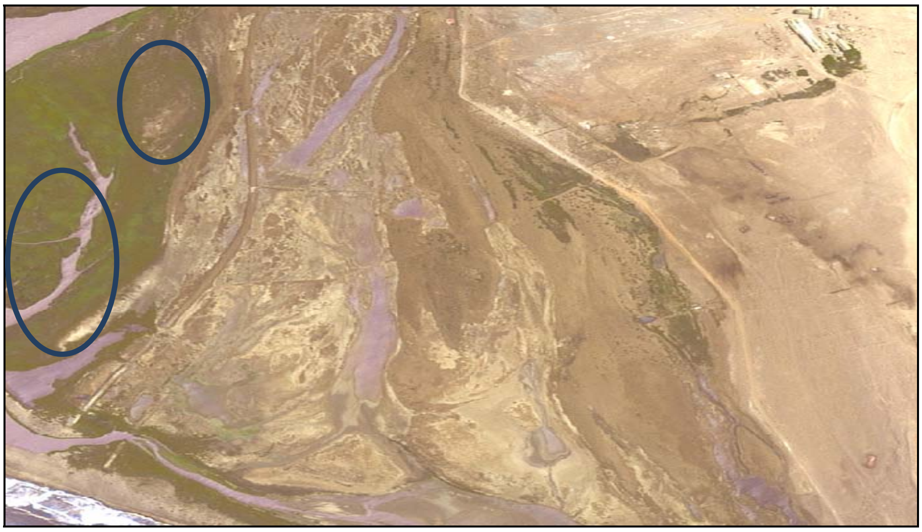


Figure 45. Increase in vegetated area of the floodplain as indicated with blue circles (satellite image from 2010)

Table 14. Changes in vegetation cover of the Orange Estuary

Habitat type	***Reference (ha)***	***Area (ha) 2012***
Channel	630	609
Sand/mud banks	101	144
Reeds and sedges	300	316
Submerged macrophytes	0	<1
Supratidal salt marsh	1.144	602
Macroalgae	0.5	1
Intertidal salt marsh	134	144
Desertified salt marsh	0	511
Terrestrial vegetation	399.5	383
Total	**2.709**	**2.709**

4.6 Discussion

The following section describes changes in the vegetation of the Orange Estuary. Information on the present status, a comparison to past conditions, and what environmental factors have caused these changes is presented for each habitat type.

4.6.1 Supratidal salt marsh

Under reference conditions (1929) the Orange Estuary had a large salt marsh area of approximately 1,158 ha. 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. A series of events (Figure 46) has ultimately resulted in the present status of the salt marsh. The current desertified salt marsh area on the south bank would have functioned like a brackish wetland with some halophytic salt marsh species. In 1986 approximately 90% of this salt marsh had died. Salt marsh communities that were still present at elevated zones were dominated by *Sarcocornia pillansii.*

Aerial photographs for September 2002 indicated some success of the salt marsh rehabilitation programme. It is during this period that backflooding of the desertified salt marsh area occurred. This event would have flushed out accumulated salts and lowered groundwater salinity. Shaw et al. (2008) found many seeds (3,616 per m^2) and seedlings (1,296 per m^2) in drift lines in 2006. The increase in the supratidal salt marsh can thus be a result of rapid colonization of the bare areas when conditions are favourable.

Recent aerial photographs (2010) and ground truthing in 2012 also showed an increase in vegetation cover in the desertified salt marsh of less than 1 ha (Figure 46). On the side of the causeway that is closer to the main river channel there was an increase in cover of *S. pillansii.* There were also patches all along the rehabilitated site of *Suaeda fruticosa* (Figure 47). The invasive alien species *Acacia cyclops* was found in the desertified salt marsh. The supratidal salt marsh therefore needs both tidal and river inflow to reduce the salinity of the sediment and groundwater. This could occur through flooding, natural or increased release from dams, or salt marsh drenching. In the future if there is a decrease in river inflow and increased in mouth closure there will be significant changes to the groundwater characteristics. The depth to the groundwater may exceed the depth to which species such as *S. pillansii* can extend their roots thereby increasing the area of the desertified salt marsh. If river inflow remains low the mouth area and supratidal salt marsh will become barren.

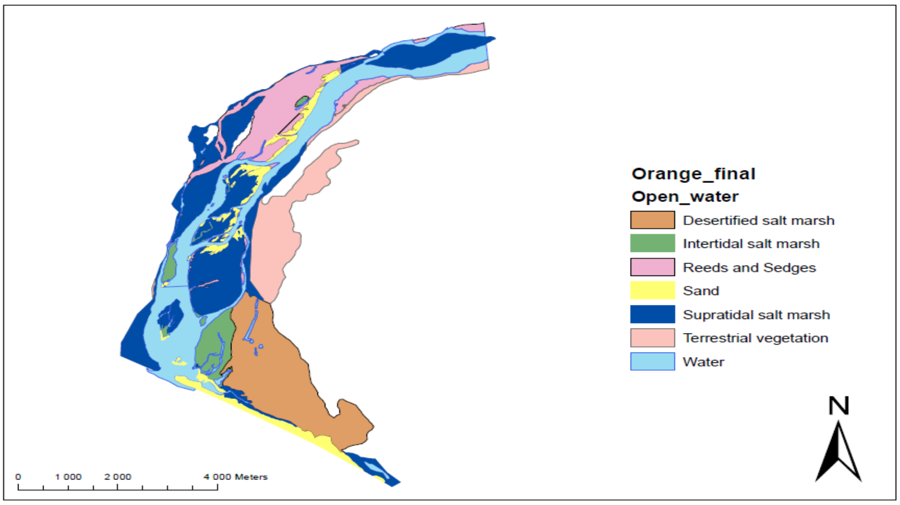


Figure 46. Vegetation map of the Orange Estuary (2012)

Figure 47 depicts the supratidal salt arsh of the Orange Estuary. *Sarcocornia pillansii* salt marsh in the lower reaches is visible in Figure 47 A with remaining bare patches in the desertified salt marsh visible in Figure 47 B. Figure 47 C depicts bre cover before rehabilitation and Figure 47 D shows patches of *Suaeda fruticosa.*

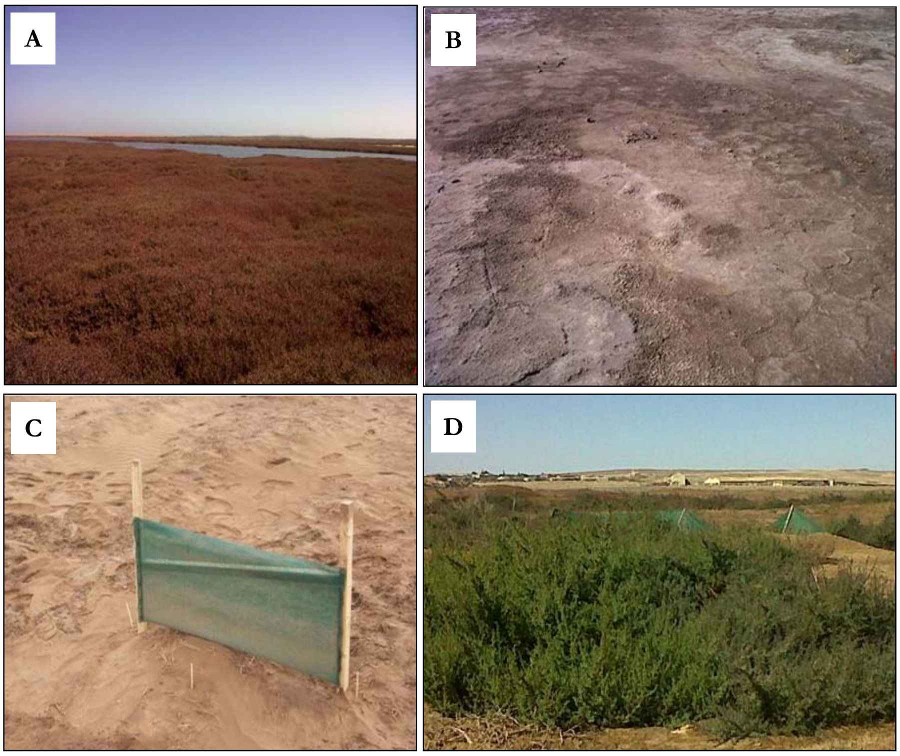


Figure 47. The supratidal salt marsh of the Orange Estuary in 2012

4.6.2 Sand and mud banks

The area around the mouth of the Orange Estuary is very dynamic. In past aerial photographs there were no sand islands around the mouth area. Strong marine inflow during storms would have deposited sand along the mouth area. Large floods would have flushed sediment out of the channel thereby increasing the overall water area. In 2012 there was increase in sand close to the mouth (Figure 48). 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 also led to closure of small streams that used to feed tidal water to intertidal salt marshes. Approximately 144 ha of sand flat area occurred in 2012. Lack of large floods probably resulted in an increase in sand and mud banks. Future water management scenarios where there is low river inflow and closed mouth conditions will result in colonization of these exposed sand and mud banks by emergent macrophytes. An increase in flooding would scour the sand and mud banks resulting in less area for colonising of emergent macrophytes.

Figure 48 shows various sand banks of the Orange Estuary. In Figure 48 A an island close to the mouth is shown while Figure 48 B shows infilling of small creeks. Sand in the middle reaches of the estuary is visible in Figure 48 C while Figure 48 D depicts intertidal sandy habitats available for birds.

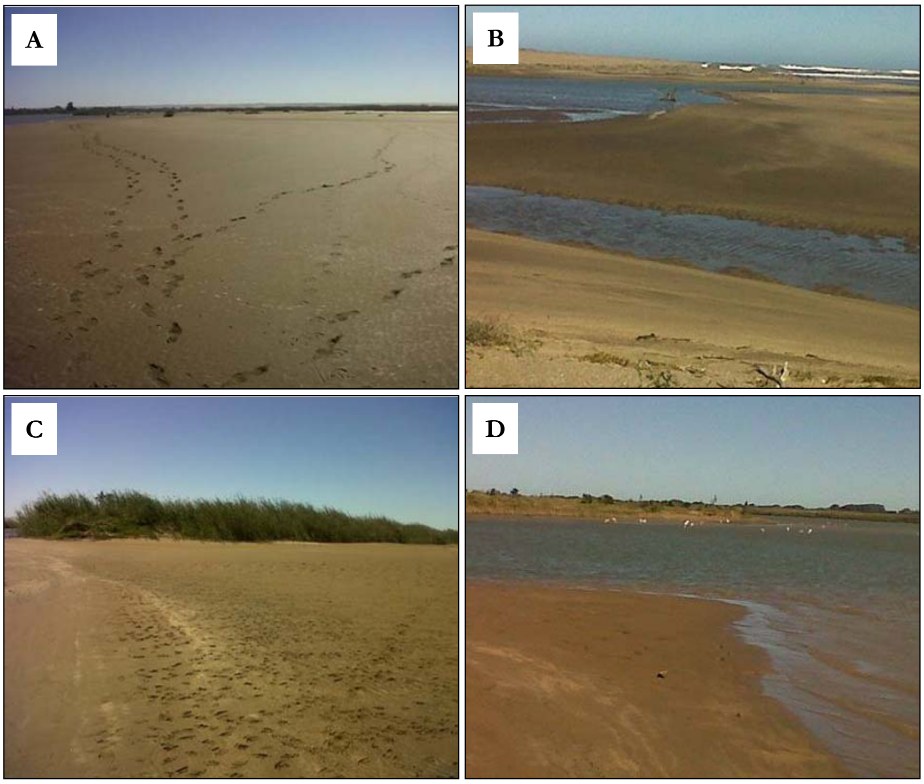


Figure 48. The sand banks of the Orange Estuary in 2012

4.6.3 Intertidal salt marsh

The Orange Estuary has been described to have large areas of intertidal salt marsh. The 2002 aerial photographs indicated that two large vegetated areas occur on the south bank of the main river channel. These areas were composed of a mosaic of brackish species. Morant and O'Callaghan (1990) found the following species to form a mosaic of salt marsh vegetation: *Cotula coronopifolia*, *Triglochin* spp., *Cyperus laevigatus*, *Sporobolus virginicus* and *Sarcocornia pillansii*. *Sarcocornia tegetaria* formed a salt marsh on the right bank of the river near the mouth. This species usually occurs in the intertidal zone of permanently open estuaries. Shaw et al. (2008) also noted that *C. coronopifolia is* the dominant intertidal species. However, it appears that there was a decrease in the area of this species also related to sand infilling or salinity intrusion as *C. coronopifolia* is found in brackish conditions.

Aerial photographs from 2010 combined with ground truthing in 2012 showed that the area of intertidal salt marsh still exists (Figure 49). Here the same species are still found however it appears that it receives little tidal flushing. This is due to a large area of sand that occurs in the intertidal zone. Site visits to the west bank of the estuary revealed a diversity of *Sarcocornia* species occurring where there is tidal action. A patch of *Bolboschoenus maritimus* also occurred closer to the water's edge but individuals showed signs of what was probably salt stress. Under conditions where there is an increase in closed mouth conditions compared to the reference state there would be a die-back of intertidal salt marsh as they are sensitive to prolonged mouth closure, high water level and permanent inundation.

Figure 49. Intertidal salt marsh of the Orange Estuary in 2012

4.6.4 Macroalgae

No resident macroalgae have previously been recorded in the system. In 2012 along the west bank high abundance of green algae *Ulva capensis, Ulva intestinalis* and red algae *Polysiphonia* sp. were found (Figure 50). Macroalgal species in the genus *Ulva* are often found in areas of nutrient enrichment and low salinity (Sousa-Dias and Melo, 2008). Under closed mouth conditions with low flow 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. 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.

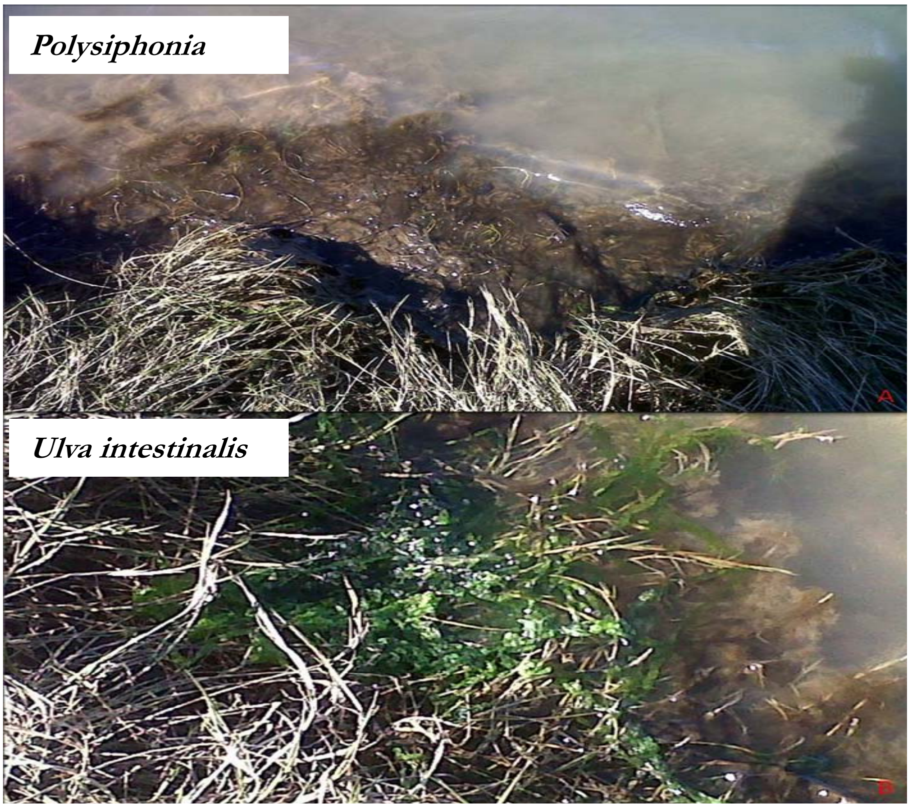


Figure 50. Macroalgae in the Orange Estuary

4.6.5 Submerged macrophytes

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. Greater water retention would provide better opportunities for nutrient uptake by macrophytes. Rooted submerged macrophytes are not a dominant feature of the estuary probably because of the high flows and low water retention times. Under conditions of low flow some submerged macrophytes 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. 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 of submerged macrophytes.

4.6.6 Reeds and sedges

Dense stands of *Phragmites australis* occurred along the length of braided streams where they provide habitat for warblers and other roosting or reed bed-dwelling passerines. Fringing reeds also provide perches for the variety of kingfishers (Anon, 2002). This species is known to thrive in brackish conditions when salinity is less than 15 ppt. It is not found on banks close to the mouth. This could be due to an increase in salinity intrusion. One other species that also occurred along the river in association with *P. australis* is *Schoenoplectus scripoides*. In 2012 the reeds and sedges covered 316 ha compared to reference conditions where the area was 300 ha. Low river inflow conditions, sedimentation, and nutrients would result in the increase in reeds and sedges. Under conditions of low flow or mouth closure and increase in salinity intrusion the death of reeds and sedges is expected. 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. Increased freshwater flushing to the system and an increase in the deposition of fine sediments could lead to the expansion of reeds and sedges.

4.6.7 Non-flow-related anthropogenic influences that are presently directly affecting biotic characteristics in the estuary

Agricultural developments at Alexander Bay, the levees protecting these developments and the oxidation pond system near the village of Alexander Bay cut off freshwater flow into the lower floodplain and salt marsh area which occurred via the Dunvlei river and flood channel system. The beach access road and embankment near the river mouth restricted tidal exchange and flooding of the desertified marsh area. Both freshwater and tidal inputs were cut off to the marsh area and as a result of this it started to die. Marsh decline was accelerated by dust and seepages from saline slimes dams that inundated the salt marsh for extended periods of time (CSIR, 1991). Thus there was a sequence of development events that were responsible for the loss of the salt marsh. Agricultural activities along the river and in the catchment resulted in erosion and an increase in silt load to the estuary which would smother submerged macrophytes and cause die-back.

Figure 51. Reeds and sedges, Phragmites australis and Schoenoplectus scirpoides in the Orange Estuary

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 1998 flood, (Morant and O'Callaghan, 1990) reported that the bare sand on the islands and banks were colonized 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 *Sporobolus 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 invasive alien plants such as *Acacia cyclops*. Other weedy species found in the upper reaches of the estuary in 2012 were *Cynodon dactylon*, *Stenotaphrum secundatum*, en *Pennisetum clandestinum* and *Gomphocarpus fruticosus*. The latter is an indigenous weedy species.

5. Estuarine invertebrates

5.1 Introduction

Relatively little published information exists on the invertebrate fauna of the Orange Estuary Mouth. Brown (1959) described the estuarine fauna of the lower Orange Estuary near the mouth as 'extremely poor' and ascribed this to extreme changes in salinity between summer and winter. The information was based on a five-day visit to the area in July of 1956 by the Zoology Department at the University of Cape Town. At that time, the team concentrated on the macrofauna present in intertidal areas along the south bank. The northern bank was not accessible to the party because of diamond mining operations in the area. No quantitative data are available on the zooplankton, although Grindley (1981) noted the presence of the estuarine copepod *Pseudodiaptomus hessei* in isolated pockets of estuarine water at low tide.

Both Brown (1959) and Day (1981) concluded that the Orange River does not have a 'real estuary' and classed the system as a river mouth. This description was also used by Whitfield (2000) in his general classification of South African estuaries.

5.2 Fieldwork

Three research trips to the Orange Estuary (in August 2004 and February 2005 under previous studies conducted by BCLME and this study September 2012) were undertaken. The duration of these visits extended over – 10 days. Nine invertebrate sampling sites were located along the estuary (Table 15, Figure 52). The nine invertebrate sampling sites are indicated (1 – 9) in Figure 52. Note: the position of the mouth had shifted to the southern bank of the estuary at the time of sampling in 2012. The embayment on the southern shore and adjacent to Station 1 had also disappeared Collection of samples was done from the deck of a 4,5 m twin-hull fibreglass boat equipped with a 40 hp outboard motor**.** The following physico-chemical parameters were recorded at each of the biological sampling sites and on each occasion: Salinity, Water Temperature, Oxygen content, pH, turbidity and water depth. Readings were taken at the surface and thereafter at 0,5 m depth intervals. A sediment sample was also collected at all sites for laboratory analysis of particle size and organic content.

Three major groups of invertebrates were sampled – the macrozooplankton, hyperbenthos, and the hyperbenthos.

5.2.1 Macrozooplankton

Samples were all collected after dark using two slightly modified WP2 plankton nets (57 cm diameter and 200 μm mesh), fitted with calibrated Kahlsico flowmeters. Two replicates were collected per station. Each net was attached to a 1 m boom extending laterally on either side of the bow of a flat-bottomed boat (4,5 m length). Midwater net -tows continued for 2 to 3 minutes (at a speed of 1 to 2 knots) at all stations. Animals retained by nets were stored in 10% formaldehyde solution in 500 ml plastic bottles.

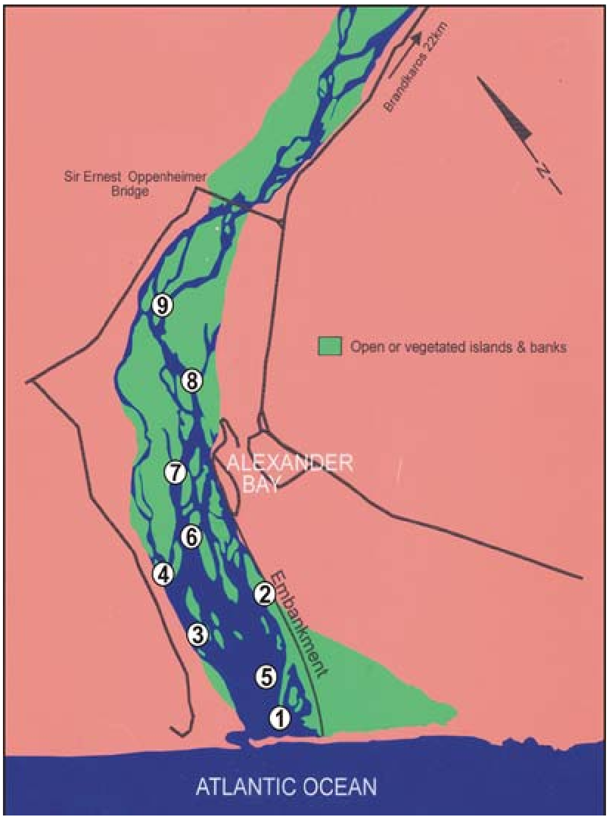


Figure 52. Map showing the sampling location of the Orange Estuary

Table 15. Location and general characteristics of nine stations sampled along the lower section of the Orange Estuary

Station	***Longitude***	***Latitude***	***Comments***
1	S28º 38.127'	E16º 27.673'	Along south-eastern shore
2	S28º 37.635'	E16º 27.405'	Behind sandbank, opposite mouth
3	S28º 37.230'	E16º 26.956'	North-western shore
4	S28º 36.476'	E16º 27.161'	North-eastern shore, very shallow
5	S28º 37.583'	E16º 26.983'	Just below launch area, blind arm
6	S28º 36.794'	E16º 27.380'	Southern channel
7	S28º 36.308'	E16º 27.350'	Main channel, relatively deep
8	S28º 35.670'	E16º 27.871'	Main channel
9	S28º 35.080'	E16º 28.132'	Main channel

5.2.2 *Hyperbenthos*

Hyperbenthic animals were sampled at the same nine stations using a sled mounted on broad skids. Two replicates were collected at each site. The rectangular opening to the sled measured 75 x 70 cm, to which is attached a 500 µm mesh net. A calibrated flowmeter mounted in the entrance quantified water volume passing through the net. Animals collected were then stored in 500 ml plastic bottles and preserved in 10% formaldehyde solution.

5.2.3 *Subtidal benthic invertebrates*

Subtidal benthic invertebrates were collected using Van Veen type grabs (at the nine sites) and the contents sieved through a 500 µm mesh screen bag. The grab during the first two visits has a 210 cm^2 bite that penetrates the sediment down to about 10 – 15 cm depth. In September 2012, a larger grab (510 cm^2 bite) of the same design was used. Nine (smaller grab) or six (larger grab) replicates were taken at each site during daylight hours. Replicates were collected over an area of about 10 m^2 in the channel at each site. Animals retained by the sieve were stored in 500 ml plastic bottles and preserved with 10% formaldehyde solution.

5.3 Laboratory analysis

5.3.1 *Sediment samples*

Sediment samples were oven-dried at 60°C over two days. Samples were then gently crushed using a mortar and pestle in order to separate particles that had co-agulated during the drying process. A known amount of sediment was then sieved through a sieve column (1,000 µm, 500 µm, 250 µm and 63 µm) using a sediment shaker for 10 minutes. Sediment retained by each sieve was then weighed and expressed as a percentage of the total mass of the entire sample passed through the sieves.

Organic content of the sediment was obtained after combusting a known mass of sample (approx 100 g) at 550°C for 12 hrs and weighed again after cooling. Organic content was then expressed as a percentage determined from the difference in mass before and after combustion.

5.3.2 *Mesozooplankton and hyperbenthos*

Although entire samples were enumerated whenever possible, sub-sampling was required when large number of individuals were present in individual samples. In the latter case, animals were transferred into a measuring beaker and tap water added to make up a known volume. The sample was then gently mixed by hand, after which a series of sub-samples was taken. To quantify the smaller specimens (e.g. copepods), a 10 ml polytop vial was used; whereas for the larger specimens (e.g. mysids, isopods and amphipods) a 28 to 49 ml vial was used. Individuals enumerated were identified to species level where possible and their final abundance expressed as the average number of individuals per cubic meter of water ($ind.m^{-3}$) collected at each site.

5.3.3 Zoobenthos

Entire samples for each replicate were analysed and the species identified and enumerated. The combined area sampled at each site (9 x 210 cm^2) or (6 x 510 cm^2) was then expressed as a fraction of 1 m^2 and the density of animals determined (ind/m^2). All data were analysed using multivariate statistics from the statistical package, PRIMER V.6 (Plymouth Routines in Multivariate Ecological Research). If multivariate techniques were not appropriate, MS Excel or Statistica for Windows were used.

5.4 Results and discussion

5.4.1 Physico-chemical

Physico-chemical measurements recorded in August 2004, February 2005 and September 2012 in the Orange Estuary are shown in tables 16–18. Sampling sites are indicated in Figure 52. Strong stratification was evident for both salinity and temperature for all sampling sessions. Maxim salinity stratification in winter occurred in the uppermost reaches (>25, Figure 53 A) and in the lower estuary in summer (>30, Figure 53 B) when freshwater inflow is greatest. Vertical temperature stratification followed the same pattern, with maximum difference in winter in the upper estuary (>2°C, Figure 54 A). In summer (Figure 54 B), the difference was greatest at Station 3 (9.9°C).

Table 16. Physico-chemical measurements recorded in August 2004 in the Orange Estuary at nine sites. Integrated values are the mean for all readings taken in the water column at each site

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Salinity (integrated)	21.2	19.6	33.1	23.5	26.7	18.7	16.1	11.8	10.8
Salinity (surface)	17.0	14.4	20.0	12.6	22.4	7.2	5.3	2.9	0.7
Salinity (bottom)	27.0	28.9	39.3	34.3	31.1	28.2	31.6	29.6	24.6
Temperature (integrated °C)	13.8	13.5	11.8	13.2	14.2	13.8	14.0	14.8	15.2
Temperature (surface °C)	14.5	14.4	12.4	13.7	15.0	14.4	15.1	15.6	16.5
Temperature (bottom °C)	12.8	12.6	11.4	12.6	13.4	13.2	12.5	13.3	13.9
Oxygen (% saturation integrated)	124.4	99.9	102.8	98.7	119.9	108.1	110.1	115.2	103.3
Oxygen (% saturation surface)	111.3	99.1	101.1	97.2	118.0	107.8	111.8	117.9	113.5
Oxygen (% saturation bottom)	143.5	101.8	103.8	100.1	121.8	109.2	109.4	110.3	82.7
Depth (m)	1.0	1.0	1.4	0.4	0.8	1.0	1.2	1.0	2.3
pH (integrated)	8.1	8.1	8.0	8.1	8.1	8.2	8.2	8.4	8.3
NTU (integrated)	21.2	27.1	44.2	22.3	16.8	27.9	26.7	22.5	40.0
NTU (surface)	1.6	7.1	16.9	12.5	12.1	9.8	7.2	3.7	3.6
NTU (bottom)	40.9	45.6	70.6	32.0	21.4	45.2	47.1	42.9	72.1

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Sediment – % mud (<0.065 mm)	83.1	45.3	91.6	13.9	40.9	9.5	31.7	51.9	21.3
Sediment – % sand (0.125 – 0.25 mm)	7.1	15.9	1.0	13.5	6.8	26.7	14.5	11.3	13.0
Sediment – % sand (0.355 – 0.5 mm)	3.1	23.2	0.5	50.5	13.8	41.9	17.8	11.2	49.4
Sediment organic matter (%)	7.0	4.0	5.4	2.5	5.1	1.5	2.6	2.6	2.5

Table 17. Physico-chemical measurements recorded in August 2004 in the Orange Estuary at nine sites. Integrated values are the mean for all readings taken in the water column at each site

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Salinity (integrated)	21.9	15.6	25.0	5.6	14.8	3.1	0.3	0.2	0.2
Salinity (surface)	10.5	0.1	5.9	5.5	4.4	1.5	0.2	0.2	0.2
Salinity (bottom)	33.6	31.2	34.8	5.6	19.6	6.1	0.5	0.2	0.2
Temperature (integrated °C)	19.1	21.1	17.1	23.8	20.8	23.4	24.3	24.4	24.4
Temperature (surface °C)	22.6	24.6	23.3	23.8	23.8	24.0	24.3	24.5	24.5
Temperature (bottom °C)	15.1	17.6	13.4	23.7	19.4	22.2	24.3	24.3	24.3
Depth (m)	2.0	0.5	1.6	0.8	2.0	1.2	1.0	1.9	1.9
pH (integrated)	8.2	8.2	8.0	8.5	8.3	8.6	8.8	8.8	8.8
NTU (integrated)	30.9	63.6	35.0	66.2	65.7	71.6	92.5	94.4	94.4
NTU (surface)	33.1	52.3	40.6	61.9	55.7	64.2	101.2	80.4	80.4
NTU (bottom)	27.2	74.8	43.0	70.5	75.6	92.0	93.8	127.4	127.4
Chlorophyll a (mg/ℓ integrated)	8.4	24.1	12.1	8.5	10.6	20.0	10.6	15.0	15.0
Chlorophyll a (mg/ℓ maximum)	16.3	48.1	30.3	8.5	13.9	34.2	14.3	33.8	33.8
Sediment - % mud (<0.065 mm)	22.2	80.8	80.1	47.5	46.0	37.0	46.1	18.0	14.1
Sediment - % sand (0.125 – 0.25 mm)	36.4	6.4	2.9	37.2	19.1	31.8	6.9	27.6	38.1
Sediment - % sand (0.355 – 0.5 mm)	18.3	1.0	4.7	1.0	1.2	3.9	1.3	50.2	23.9
Sediment organic matter (%)	2.0	2.5	2.0	1.7	1.4	0.8	0.6	0.3	0.2

Table 18. Physico-chemical measurements recorded in September 2012 in the Orange Estuary at nine sites. Integrated values are the mean for all readings taken in the water column at each site

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Salinity (integrated)	33.4	17.8	15.9	15.9	14.1	14.2	3.3	1.2	0.4
Salinity (surface)	33.1	5.3	4.4	4.4	3.7	4.1	3.3	1.1	0.4
Salinity (bottom)	33.6	32.2	31.9	31.9	33.4	32.2	3.3	1.4	0.4
Temperature (integrated °C)	12.2	14.0	14.3	14.3	15.0	14.6	16.3	17.0	17.3

Station	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Temperature (surface °C)	12.2	15.2	15.9	15.9	16.3	16.4	16.3	17.0	17.3
Temperature (bottom °C)	12.1	12.5	12.4	12.4	12.1	12.6	16.3	16.9	17.3
Oxygen (integrated mg/ℓ)	8.1	9.2	9.6	9.6	9.2	8.7	8.5	6.7	8.4
Oxygen (surface mg/ℓ)	7.7	9.7	9.9	9.9	9.6	9.6	7.4	6.6	8.1
Oxygen (bottom mg/ℓ)	7.7	8.5	8.7	8.7	8.2	7.3	9.2	7.6	8.5
Oxygen (% saturation integrated)	93.0	97.8	103.8	103.8	97.8	92.6	88.0	69.5	87.2
Oxygen (% saturation surface)	92.0	100.0	102.0	102.0	100.0	99.0	77.0	69.0	85.0
Oxygen (% saturation bottom)	89.0	97.0	100.0	100.0	92.0	84.0	95.0	78.0	87.0
Depth (m)	2.0	1.6	1.9	1.9	1.8	2.0	1.1	1.2	2.3
pH (integrated)	7.7	8.0	8.1	8.1	8.1	8.1	8.4	8.5	8.5
NTU (integrated)	12.0	8.4	6.9	6.9	6.0	7.0	10.0	11.8	19.1
NTU (surface)	11.0	4.0	4.0	4.0	6.0	9.0	10.0	12.0	17.0
NTU (bottom)	12.0	14.0	10.0	10.0	5.0	6.0	10.0	11.0	20.0
Chlorophyll a (mg/ℓ integrated)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chlorophyll a (mg/ℓ maximum)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sediment - % mud (<0.063 mm)	13.9	1.8	2.9	50.4	24.4	34.4	9.8	18.4	5.1
Sediment - % fine sand (0.63 – 0.25 mm)	82.1	86.4	5.2	41.4	40.0	51.3	37.1	80.0	23.7
Sediment - % medium sand (0.250 – 0.5 mm)	2.2	2.4	36.5	1.9	26.3	0.4	26.7	0.1	55.0
Sediment - % coarse sediment (0.5 – 1 mm)	1.1	1.8	43.6	0.8	12.4	0.2	17.2	0.1	32.2
Sediment - % coarse sediment (> 1. mm)	0.2	1.2	34.6	0.0	10.1	0.0	29.1	0.0	18.8
Sediment organic matter (%)	4.7	1.6	1.8	7.2	4.9	10.0	2.3	5.1	2.4

Strong horizontal salinity and temperature gradients were also evident. Winter surface and bottom salinity values ranged between 17 and 27 at the mouth and 0,7 and 24,6 at Station 9 respectively (Figure 53 A). In spring and summer (Figures 53 B and 53 C), the upper estuary was fresh throughout the water column. Stratification increased downstream, increasing to 10,5 (surface) and 33,6 (near-bottom) at the mouth in Feb 2005, while in Sept 2012, the water column was well mixed at the mouth (Figure 53 C).

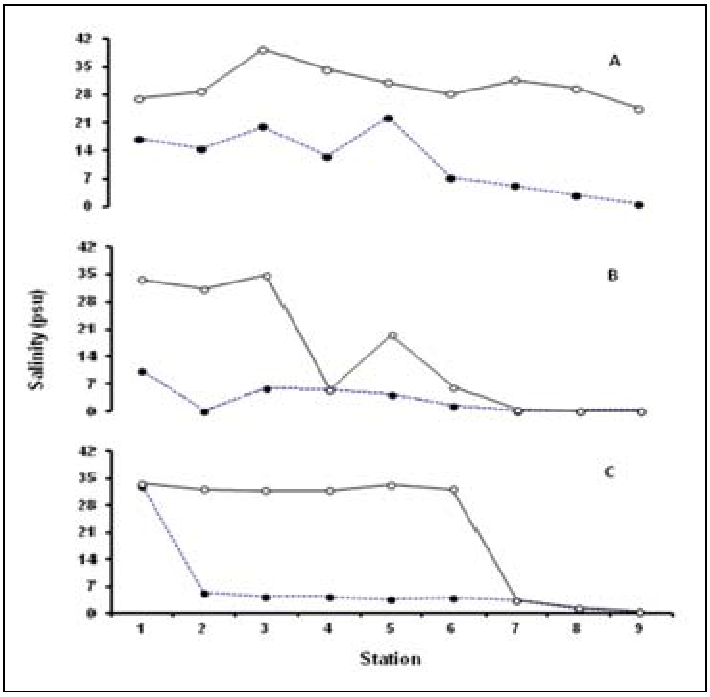


Figure 53. Surface (dashed lines) and bottom salinity (solid lines) values in August 2004 (A), February 2005 (B) and September 2012 (C)

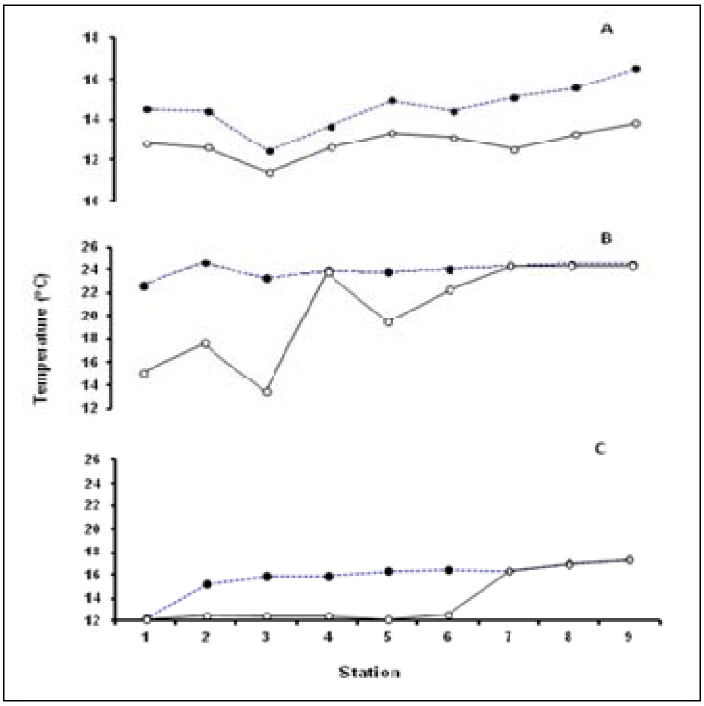


Figure 54. Surface (dashed lines) and bottom temperature (solid lines) values in August 2004 (A), February 2005 (B) and September 2012 (C)

Near-bottom water temperatures were cooler in the lower estuary, particularly in deeper areas where mixing with seawater was minimal. In summer, the water column in the upper estuary was well mixed (Figures 54 B and 54 C). Maximum difference between the upper and lower estuary also occurred in summer when the temperature difference was over 9 °C.

Turbidity levels were particularly high in summer (Figure 55 B), increasing in both surface and bottom waters in an upstream direction. Vertical differences were particularly apparent in August (Figure 55 A) ranging between 1,6 and 16,9 (NTU). Bottom values ranged between 21,4 and 72,1. Corresponding values in February ranged between 33,1 and 101,2 near the surface and 27,2 and 127,4 at the bottom.

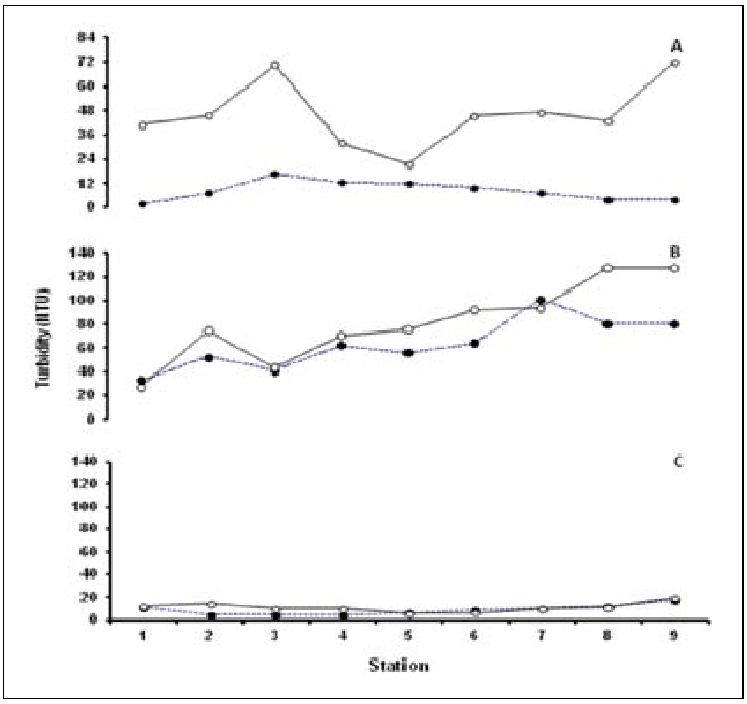


Figure 55. Surface (dashed lines) and bottom turbidity (solid lines) values in August 2004 (A), February 2005 (B) and September 2012 (C)

The percentage mud (<65 µm particle size) in the sediment was generally highest in the lower estuary (Figure 56) on the first two sampling occasions, particularly in sheltered areas (e.g. Station 1 in August 2004 when the mouth was located closer to the northern bank). Percentage organic matter followed the pattern described for the fine sediments (Figure 56, secondary Y-axis). In September 2012, the percentage mud was proportionally less compared to the other two sampling trips (Figure 56), with highest values in the middle estuary (Stations 4–6). On the latter occasion, Stations 3, 7 and 9 had a high proportion of coarse material (Particle sizes > 500 µm, Table 18). The percentage organic matter was also relatively high at all sampling sites, with maximum values in the middle estuary (Stations 4 – 6), following the pattern described for fine particles (<65 µm particle size).

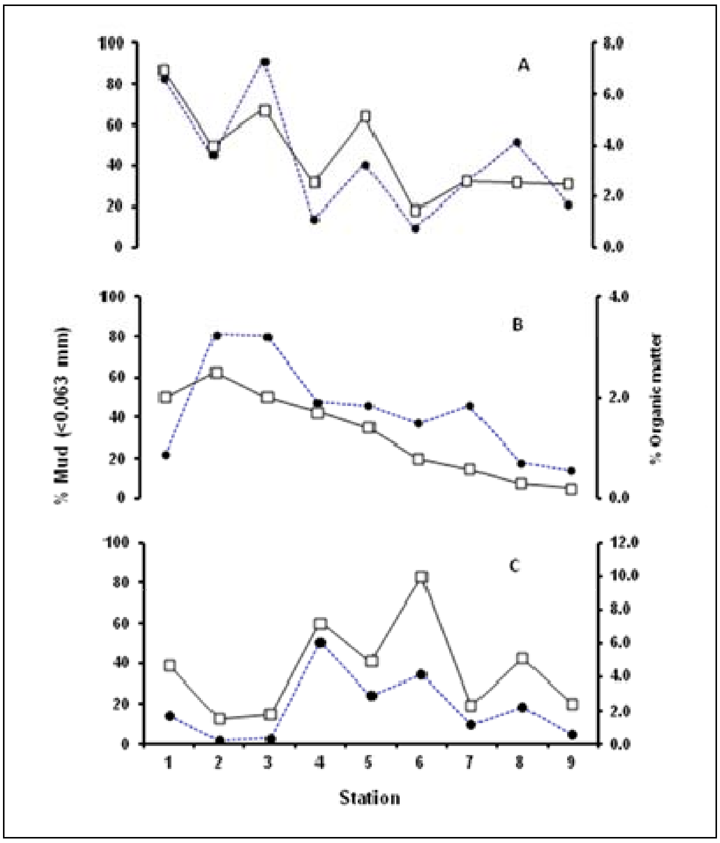


Figure 56. Percentage mud (Primary Y axis and dashed line) and percentage organic matter (Secondary Y axis and solid line) in August 2004 (A), February 2005 (B) and September 2012 (C)

5.4.2 Zooplankton

Species richness was variable between the three sampling sessions (Tables 19–21), linked primarily to the state of the tide and upstream penetration of marine water at the time of sampling. When estuary salinity values were relatively high (Figure 53 A, August 2004), species richness attained 25 mainly due to the presence of neritic copepod species (e.g. Centropagids, Clausocalinids, Clytemnestrids) in the plankton. In February 2005 and September 2012, salinity values were relatively low throughout the estuary, remaining fresh throughout the water column at upstream sampling sites. Species richness was lower compared to August 2004 (16 and 15 respectively) and only few neritic species were present near the mouth. Typical euryhaline copepods such as *Pseudodiaptomus hessei* were present in very low numbers in August 2004, but the species was not present in plankton samples on the other two sampling occasions.

Table 19. Zooplankton abundance (ind. m³) in August 2004

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Cnidaria									
Hydroid medusae	0	0	0	1	6	8	0	11	0
Ctenophora									
Ctenophore sp.	0	0	0	0	0	0	0	0	0
Polychaeta									
Ceratonereis keiskama juvs	0	0	0	0	0	0	0	0	0
*Desdemona ornat*a juvs	0	0	0	0	0	0	0	0	0
Polychaete larvae	0	4	9	4	4	41	45	17	28
Copepoda									
Aegisthidae	0	0	0	1	0	0	0	0	0
Calanidae	2	41	2	3	3	33	0	0	0
Centropagidae	1	0	0	0	0	0	0	0	0
Clausocalanidae	2	19	0	2	5	38	0	0	0
Clytemnestridae	1	0	3	1	2	0	0	0	0
Corycaeidae	2	0	0	0	0	0	0	0	0
Cyclopoid sp.	129	629	116	389	86	818	520	240	144
Daphnia sp.	0	0	0	0	0	0	0	0	0
Ectocyclops sp.	0	0	0	0	0	0	30	51	51
Eucalanidae	1	0	0	0	0	2	0	0	0
Halicyclops sp.	0	0	0	0	0	0	0	0	0
Oithona spp.	0	0	0	0	0	0	0	0	0
Paracalanidae	0	8	0	0	3	9	0	0	0
Megacalanidae	0	0	1	0	0	1	0	0	0
Oncaeidae	3	4	0	4	0	0	0	0	0
Pseudodiaptomus hessei	0	0	0	5	0	2	2	2	2
Saphiriella sp.	1	0	0	1	0	0	0	0	0
Ostracoda									
Ostracod sp.	0	29	16	8	6	25	25	11	0
Mysidacea									
Gastrosaccus brevifissura	0	0	0	0	0	0	0	0	0
Mesopodopsis wooldridgei	0	0	0	7	0	3	9	9	0
Isopoda									
Corallana africana	0	0	0	0	0	0	0	0	0
Eurydice longicornis	1	1	0	0	0	0	0	0	0
Uromunna sheltoni	0	0	0	0	0	0	0	0	0
Amphipoda									

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Lysianassa ceratina	1	0	0	0	0	0	0	0	0
Decapoda									
Decapod larvae	0	0	0	0	0	0	0	0	0
Chaetognatha									
Sagitta sp.	4	0	0	3	0	0	0	0	0
Insectivora									
Chironomid larvae	0	0	0	0	0	0	23	0	0
Insect larvae	0	0	0	0	0	0	0	0	0
Pisces									
Fish eggs	782	1729	860	0	332	401	0	0	0
Fish larvae	7	10	0	8	9	8	0	0	0
Gobiid larvae	0	0	0	2	0	0	0	0	0

Table 20. Zooplankton abundance (ind. m³) in February 2005

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Cnidaria									
Hydroid medusae	0	0	0	1	6	8	0	11	0
Ctenophora									
Ctenophore sp.	0	0	0	0	0	0	0	0	0
Polychaeta									
Ceratonereis keiskama juvs	0	0	0	0	0	0	0	0	0
Desdemona ornata juvs	0	0	0	0	0	0	0	0	0
Polychaete larvae	0	8	0	0	9	0	3	4	0
Copepoda									
Aegisthidae	0	0	0	0	0	0	0	0	0
Calanidae	263	74	34	34	30	0	0	0	0
Centropagidae	0	0	0	0	0	0	0	0	0
Clausocalanidae	0	0	0	0	0	0	0	0	0
Clytemnestridae	0	0	0	0	0	0	0	0	0
Corycaeidae	0	0	0	0	0	0	0	0	0
Cyclopoid sp.	1442	530	45	25	152	0	0	0	0
Daphnia sp.	0	0	0	0	0	16	10	4	37
Ectocyclops sp.	0	0	0	0	0	25	20	55	36
Eucalanidae	0	0	0	0	0	0	0	0	0
Paracalanidae	121	0	0	0	0	0	0	0	0
Halicyclops sp.	0	0	0	0	9	0	0	0	0
Megacalanidae	0	0	0	0	0	0	0	0	0

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Oithona spp.	0	0	0	2	0	0	0	0	0
Oncaeidae	0	0	0	0	0	0	0	0	0
Pseudodiaptomus hessei	0	0	0	0	0	0	0	0	0
Saphiriella sp.	47	6	0	0	0	0	0	0	0
Ostracoda									
Ostracod sp.	81	5	0	0	9	0	0	0	0
Mysidacea									
Gastrosaccus brevifissura	0	0	0	0	0	0	0	0	0
Mesopodopsis wooldridgei	0	2	0	1	0	0	0	0	0
Isopoda									
Corallana africana	0	0	0	0	0	0	0	0	0
Eurydice longicornis	0	0	0	0	0	0	0	0	0
Uromunna sheltoni	0	0	0	0	0	8	0	5	0
Amphipoda									
Lysianassa ceratina	0	0	0	0	0	0	0	0	0
Decapoda									
Decapod larvae	0	0	0	0	0	0	0	0	0
Chaetognatha									
Sagitta sp.	0	0	0	0	0	0	0	0	0
Insectivora									
Chironomid larvae	0	0	0	0	0	2	9	7	0
Insect larvae	0	0	0	0	0	2	2	11	8
Pisces									
Fish eggs	0	5	0	0	0	0	0	0	0
Fish larvae	0	0	0	2	0	0	0	0	0
Gobiid larvae	0	0	0	0	0	0	0	0	0

Table 21. Zooplankton abundance (ind. m³) in September 2012

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Cnidaria									
Hydroid medusae	0	0	0	0	0	0	0	0	0
Ctenophora									
Ctenophore sp.	3	4	0	0	0	0	0	0	0
Polychaeta									
Ceratonereis keiskama juvs	0	0	4	5	52	15	6	6	7
Desdemona ornata juvs	0	0	0	0	0	2	1	0	0
Polychaete larvae	0	10	0	0	9	4	0	0	0

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Copepoda									
Aegisthidae	0	0	0	0	0	0	0	0	0
Calanidae	89	192	19	2	0	5	4	8	5
Centropagidae	0	0	0	0	0	0	0	0	0
Clausocalanidae	0	0	0	0	0	0	0	0	0
Clytemnestridae	0	0	0	0	0	0	0	0	0
Corycaeidae	0	0	0	0	0	0	0	0	0
Cyclopoid sp.	0	0	0	0	0	0	0	0	0
Daphnia sp.	0	0	0	0	0	0	0	0	0
Ectocyclops sp.	0	0	0	0	0	0	0	0	0
Eucalanidae	0	0	0	0	0	0	0	0	0
Halicyclops sp.	0	0	0	0	0	0	0	0	0
Oithona sp.	0	0	0	0	0	0	0	0	0
Paracalanidae	0	0	0	0	0	0	0	0	0
Megacalanidae	0	0	0	0	0	0	0	0	0
Oncaeidae	0	0	0	0	0	0	0	0	0
Pseudodiaptomus hessei	0	0	0	0	0	0	0	0	0
Saphiriella sp.	0	0	0	0	0	0	0	0	0
Ostracoda									
Ostracod sp.	0	10	0	0	0	0	0	0	0
Mysidacea									
Gastrosaccus brevifissura	1	1	0	0	3	0	0	0	0
Mesopodopsis wooldridgei	0	1	7	2	4	0	0	0	0
Isopoda									
Corallana africana	1	0	0	0	0	0	0	0	0
Eurydice longicornis	0	0	0	0	0	0	0	0	0
Uromunna sheltoni	0	0	0	0	0	0	0	0	0
Amphipoda									
Lysianassa ceratina	0	0	4	0	0	1	1	0	0
Decapoda									
Decapod larvae	0	1	0	0	0	0	0	0	0
Chaetognatha									
Sagitta sp.	0	1	0	0	0	0	0	0	0
Insectivora									
Chironomid larvae	0	0	0	0	0	0	0	0	0
Insect larvae	0	0	0	0	38	0	0	6	5
Pisces									

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Fish eggs	0	2	0	0	0	0	0	0	0
Fish larvae	0	1	0	0	0	0	0	0	0
Gobiid larvae	0	0	0	0	0	0	0	0	0

At a high taxonomic level, copepods were usually the numerically dominant group (Figure 57), although fish eggs were the most important component in August 2004. If copepods and fish eggs are removed from Figure 57, the relative importance of other planktonic groups becomes more apparent.

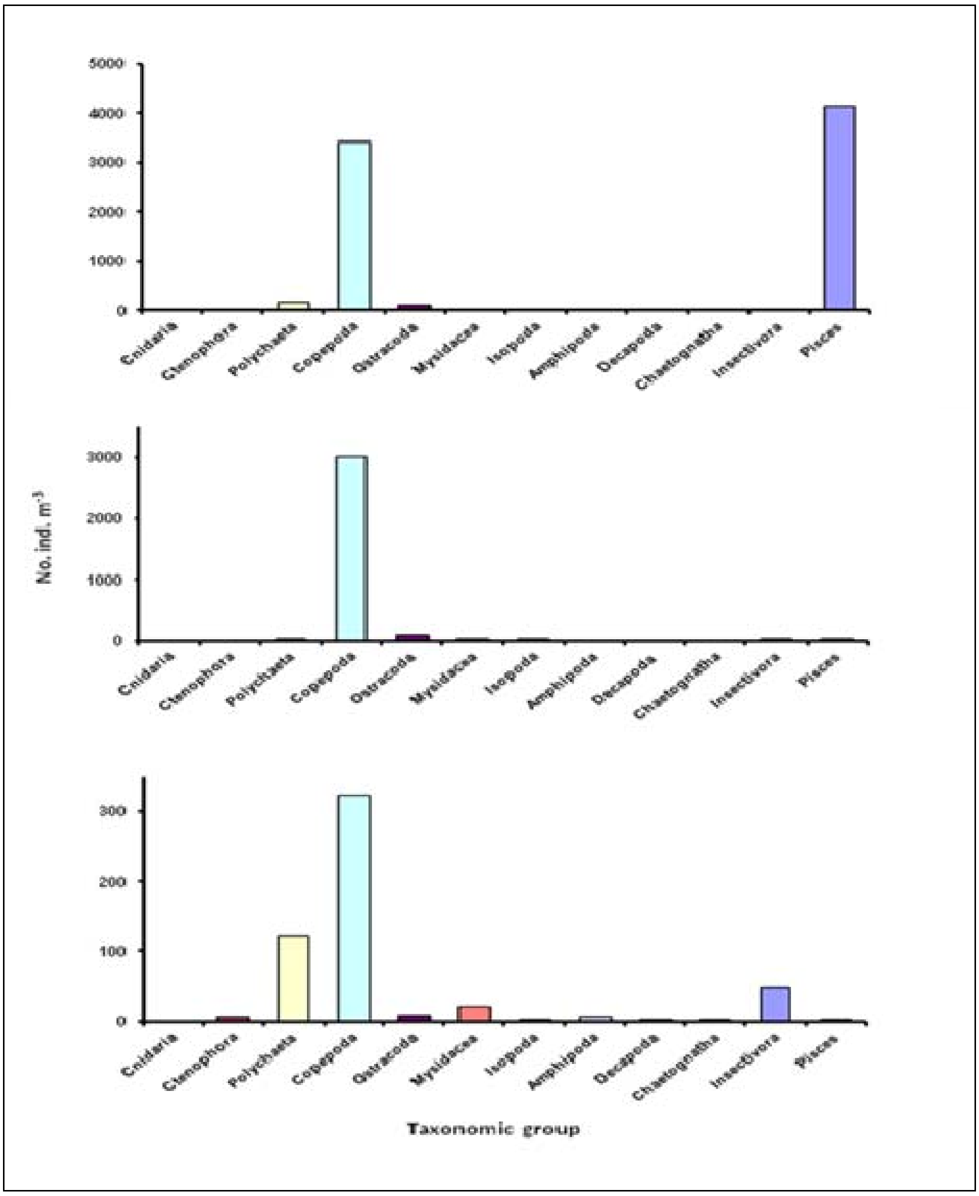


Figure 57. Copepods and fish eggs were usually the most important numerical group in the zooplankton. Note the difference in scale on the Y-axis

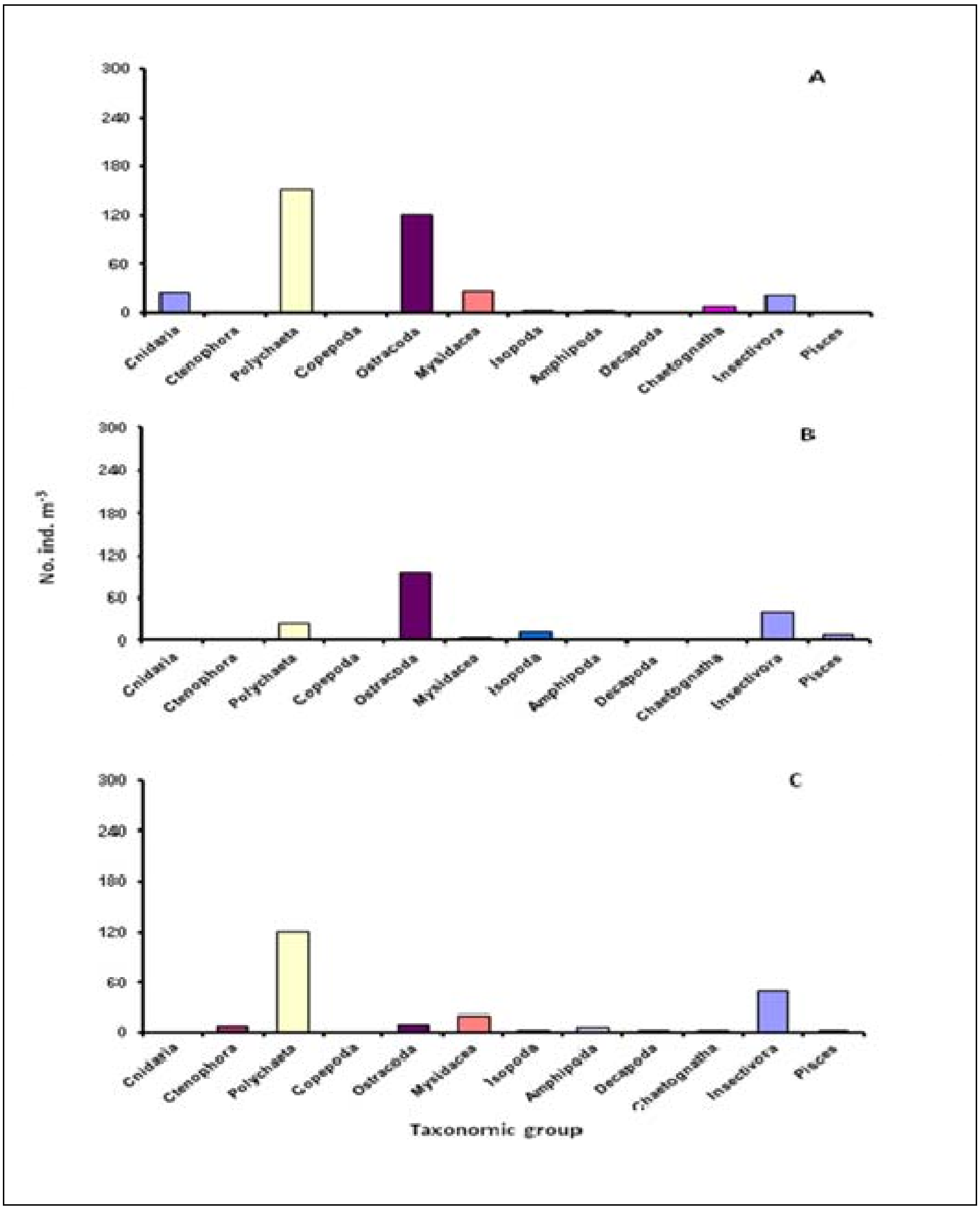


Figure 58. When copepods and fish eggs are removed from Figure 58, the contribution of other taxonomic groups to relative abundance in the zooplankton becomes apparent

An unidentified cyclopoid was the most abundant copepod during the first two surveys (Tables 19 and 21). Peracarid crustaceans such as mysid shrimps, isopods and amphipods also made little contribution to zooplankton abundance.

Group linkages shown by Bray Curtis similarity clustering based on composition and abundance of the zooplankton using group average mode on fourth-root transformed data indicated two major clusters at a similarity level of 37,8% (Figure 59). Data represent August 2004 winter sampling trip. The red hatched lines link those sites that do not vary significantly from each other in multivariate structure (p>0,5%). Stations 1–6 grouped separately from Stations 7 – 9, with a significant split between the groups (p<0,5; SIMPROF test). Within the two groups, no significant substructures were identified between sites (p>0,5). However, the data indicate that although not significant, Sites 3 and 4 along the northern shore developed weak structuring from the mouth site and Stations 2, 5, and 6 in the main channel.

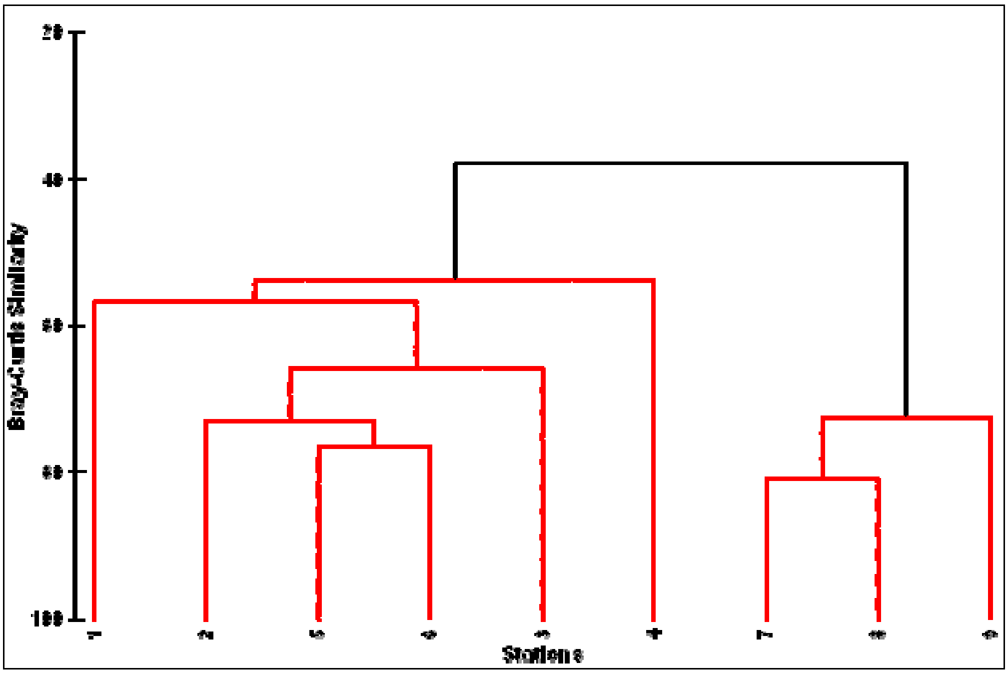


Figure 59. Bray-Curtis similarity dendrogram based on zooplankton composition and abundance at nine sampling sites in the Orange Estuary

A similar pattern was identified in the February 2005 zooplankton data set. Group linkages shown by Bray Curtis Similarity clustering based on composition and abundance of the zooplankton using group average mode on fourth-root transformed data indicated two major clusters at a similarity level of 2.5% (Figure 60). Data represent February 2005 summer sampling trip. The red hatched lines indicate those sites that do not vary significantly from each other in multivariate structure (p>0;5%). Stations 1 – 5 grouped separately from Stations 6 – 9, with a significant split between the groups (p<0,5; SIMPROF test). Within the two groups, no significant substructures were identified between sites (p>0,5). Again, Sites 3 and 4 along the northern shore developed weak structuring from other sites in the lower estuary.

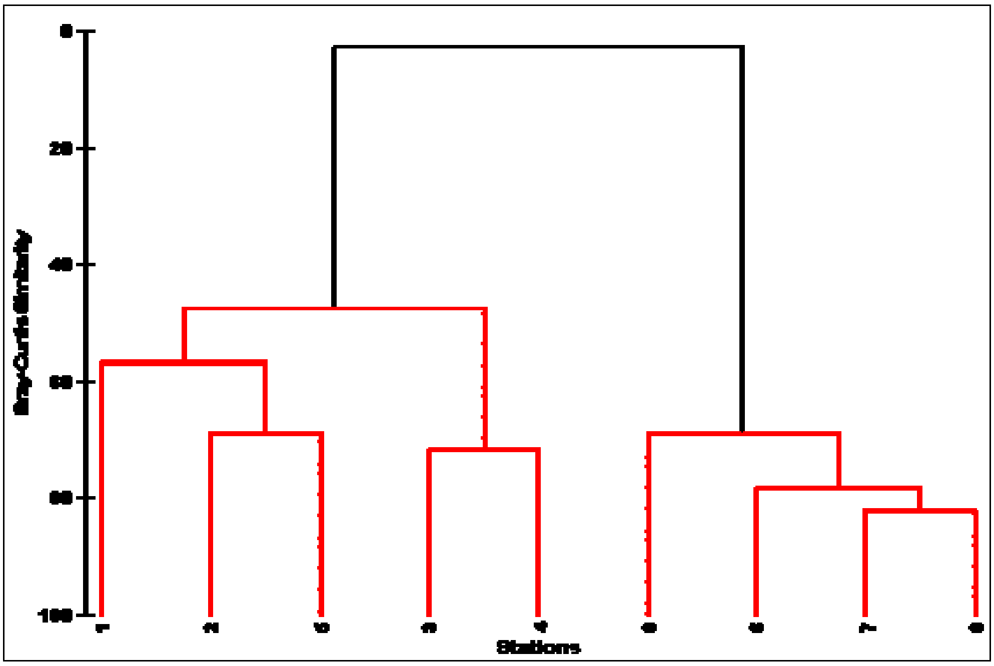


Figure 60. Bray-Curtis similarity dendrogram based on zooplankton composition and abundance at nine sampling sites in the Orange Estuary

The zooplankton data collected in September 2012 followed a very similar pattern to the two previous data sets. Group linkages shown by Bray Curtis Similarity clustering based on composition and abundance of the zooplankton using group average mode on fourth-root transformed data indicated two major clusters at a similarity level of 23.4% (Figure 61). Data represent September 2012 late winter sampling trip. The red hatched lines indicate those sites that do not vary significantly from each other in multivariate structure (p>0,.5%). Stations 1 – 2 grouped separately from Stations 3–9, with a significant split between the groups (p<0,5; SIMPROF test). Within the two groups, no significant substructures were identified between sites (p>0,5). Again, Sites 3 and 4 along the northern shore developed weak structuring from other sites in the lower estuary.

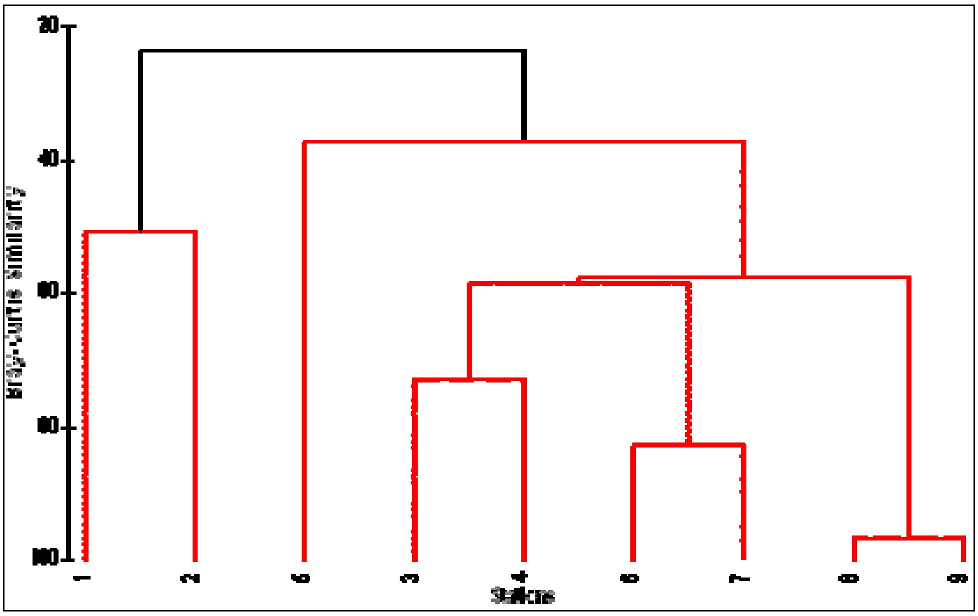


Figure 61. Bray-Curtis similarity dendrogram based on zooplankton composition and abundance at nine sampling sites in the Orange Estuary

In broad summary, Bray-Curtis Similarity analysis for the three sampling trips indicates two broad categories of mesozooplankton in the Orange Estuary. The distribution of these two groups is probably linked primarily to the volume of freshwater flowing into the estuary at the time of sampling. Freshwater inflow will impact the extent of tidal penetration into the estuary. A typical euryhaline zooplantonic community is not well established and is represented by relatively few species that occur at low population densities. At upper estuarine sites, a freshwater associated community is present and extends downstream in relation to salinity distribution at the time of sampling. Multidimensional scaling plots were also constructed for each of the three sampling trips, but these supported the patterns illustrated by Figures 59 – 61 and are not presented here.

5.4.3 Hyperbenthos

The hyperbenthic community was numerically dominated by the mysid shrimp, *Mesopodopsis wooldridgei* on the first two sampling occasions, although they were present in very low numbers in Sept 2012 (Tables 22 and 24). In August 2004, the species was distributed throughout the estuary, with maximum abundance in the middle-upper reaches. In February 2005 and September 2012, no mysids were recorded in the freshwater dominated upper estuary (Stations 7 – 9, Figure 55). Between five and eight species were recorded on each occasion.

Compared to zooplankton samples, mysid abundance was relatively high in the hyperbenthos, suggesting a close association with the substrate. Mysids are also relatively mobile and their presence in the estuary is probably transitory, moving into the system from the nearshore when conditions become favourable. The presence of *Mysidopsis major* in the estuary is probably of shorter duration compared to *Mesopodopsis wooldridgei* and linked to high water, moving back to the marine environment on the ebbing tide.

Table 22. Species recorded (ind. m³) in the hyperbenthos in August 2004

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Mysidacea									
Mesopodopsis wooldridgei	1	0.1	0.2	94	80	119	51	25	1
Isopoda									
Atylus sp.	0.1	0.1	0	3	0	0	0	0	0.1
Amphipoda									
Afrochiltonia capensis	0	0.1	0	0	0	0	0	0	0
Insectivora									
Chironomid larvae	0	0	0	0	0	0	0	0	7
Pisces									
Syngnathus temminkii	0	0	0	0	0	0	0.1	0	0

Table 23. Species recorded (ind. m³) in the hyperbenthos in February 2004

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Mysidacea									
Mesopodopsis wooldridgei	47	67	362	0	1	16	0	0	0
Mysidopsis major	0	0	0	1	0	0	0	0	0
Brachyura									
Zoea larvae	0	0	0	0	0	4	0	0	0
Insectivora									
Insect larvae	0	0	0	0	0	0	0.2	0.5	1
Chironomid larvae	0	0	0	0	0	0	0.1	0.1	1
Pisces									
Gilchristella eggs	0	1	0	0	0	12	0	0	0
Gilchristella larvae	0	6	0	0	0	33	0.1	0	0
Gobiid larvae and juvs	1	0	0	0	0	0	0	0	0

Table 24. Species recorded (ind. m³) in the hyperbenthos in September 2012

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Ctenophora									
Ctenophora	1	0	0	0	0	1	0	0	0
Mysidacea									

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Mesopodopsis wooldridgei	0	1	2	6	3	2	6	2	2
Mysidopsis major	2	0	0	0	0	0	0	0	0
Amphipoda									
Amphipod sp. juvs	0	0	0	0	1	0	0	0	0
Melita zeylanica	0	1	0	0	0	0	0	0	0
Caridea									
Palaemon sp. juv.	0	0	1	0	0	0	0	0	0
Pisces									
Fish larvae	44	0	0	0	0	0	0	0	0

5.4.4 Macrozoobenthos

The macrozoobenthic community was poorly represented, with only four species present in August 2004, seven in February 2005 and three in September 2012 (Tables 25 –27). Polychaetes were the dominant group, with the ubiquitous *Ceratonereis keiskama* and *Desdemona ornata* numerically dominating the community. *D. ornata* was the more abundant species, attaining maximum densities of 40,283, 37,972 and 6,333 m² during each of the three sampling periods respectively. These two polychaete species were widely distributed along the estuary, also present under very low salinity conditions. Abundance levels were also high during the first two sampling trips, further indicating their wide tolerance range to the extreme variability of the physic-chemical environment in the Orange Estuary. In September 2012, relatively low abundance of the macrobenthic species may be due to ever flooding a few months previously and the populations were still in a recovery phase.

Table 25. Macrozoobenthos recorded in the Orange Estuary in August 2004

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Polychaeta									
Ceratonereis keiskama	0	4050	56	1544	278	2844	122	139	156
Desdemona ornata	2822	3478	7322	23639	8372	13933	21861	40283	1361
Insectivora									
Insect larvae	0	0	0	0	0	0	0	0	17
Chironomid larvae	11	0	83	0	0	6	11	44	1900

Table 26. Macrozoobenthos recorded in the Orange Estuary in February 2005

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Polychaeta									
Ceratonereis keiskama	0	339	311	578	222	1217	639	617	561
Desdemona ornata	228	18922	37972	17039	6706	11250	3372	6	22
Oligochaete sp.	0	394	0	0	0	0	11	67	583
Orbinia angrapequensis	0	0	6	0	0	0	0	0	0
Insectivora									
Chironomid larvae	0	339	0	94	17	22	83	100	411
Mollusca									
Bivalve spat	0	0	6	0	0	0	0	0	11
Solen capensis	0	0	200	0	0	0	0	0	0

Table 27. Macrozoobenthos recorded in the Orange Estuary in September 2012

Station	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Polychaeta									
Ceratonereis keiskama	298	1129	5878	355	603	254	239	103	127
Desdemona ornata	6333	437	928	3837	3132	5366	5488	2249	2184
Penaeidea									
Acetes sp.	3	0	0	0	0	0	0	0	0

5.4.5 General discussion

The invertebrate fauna of the Orange Estuary is considered to be species poor and atypical of tidal estuaries along the west coast of Southern Africa. Those few species resident in the estuary are widely 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). Fauna of the Orange Estuary is considered to be species poor in comparison to tidal estuaries along the west coast of Southern Africa. Species resident in the estuary are obviously widely tolerant of a highly variable physic-chemical environment, although populations probably fluctuate significantly in terms of abundance between seasonal flooding (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. Even under present day conditions, 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 28) and species that often dominate euryhaline mesozooplankton communities were absent (e.g. *Acartia longipatella*) or present in very low numbers only (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 (Table 28). Mysids (and other invertebrates), probably move actively between the marine nearshore and the estuary. Among the two polychaete species in the Orange, *Desdemona ornata* filter feeds from short tubes constructed on the surface of the substrate, while *Ceraonereis keiskama* is highly predaceous in the benthos. Larvae present in the zooplankton were probably representative of these two polychaete species.

Table 28. Comparison of the maximum abundance of species present in the euryhaline mesozooplankton (ind. m³), hyperbenthos (ind. m³) and benthos (ind. m²) of West Coast tidal estuaries and for which data are available.

Estuary	***Great Berg***	***Olifants***	***Orange***
Zooplankton			
Copepods			
Acartia longipatella	**15107**[2]	2234	–[1]
Pseudodiaptomus hessei	**50667**	40836	5
Hyperbenthos			
Mysids			
Mesopodopsis wooldridgei	**704**	1	362
Benthos			
Polychaetes			
Ceratonereis keiskama	14166	**25167**	5878
Desdemona ornate	9875	4233	**40283**
Orbinia angrapequensis	83	**128**	6
Amphipod			
Corophium triaenonyx	**84183**	40933	–

1 Indicates absence.
2 Bold refers to the maximum abundance among the three estuaries.

6. Estuarine Fish

6.1 Import features of the Orange Estuary for fish

The Orange Estuary, approximately 2,300 ha in extent comprises about 14% of the available estuary habitat area (both open water and floodplain) for fish and other biota in the cool-temperate bioregion on South Africa's west coast. It is also one (32% of habitat area) of only three predominantly open estuaries in the cool-temperate region. In contrast to the Berg and Olifants estuaries to the south which fall within the winter rainfall zone, most of the Orange catchment falls within the summer rainfall zone with a MAR of 10,833 Mm^3 or 83% of total MAR reaching the sea from all catchments on the west coast. The closest permanently open estuaries are the Olifants 400 km to the south and Cunene 1,360 km to the north, the latter in the warm-temperate bioregion on the Namibia-Angola border. The Orange has experienced a 56% (6,780 Mm^3) reduction in MAR reaching the estuary and which amounts to 90% of the total reduction in MAR from all catchments reaching the sea on the cool-temperate west coast. In all, Orange-Senqu catchment flows are likely the greatest determinants of the distribution and abundance of estuary-associated fish on the west coast as well as that of some exclusively marine species in the adjacent nearshore.

The Orange Estuary is predominantly open with a deep tidal basin, braided channels and extensive but degraded saltmarsh. The 'estuary proper' extends as far the Sir Ernest Oppenheimer Bridge where tidal variation may be discernible at spring high tide. Immediately above the bridge is a fast-flowing run and the start of the freshwater reaches. From an estuary-fish perspective, turbid, warm and well oxygenated water as well as extensive reed and aquatic macrophyte growth provide ideal habitat to at least Brand Kaross, 35 km upstream, albeit low salinity (Figure 62). This more than doubles the estuarine habitat available to fish to 1,000 ha or more. Suitable conditions persist even further upstream than this and estuary fish are known to occur as far inland as Vioolsdrift 220 km from the mouth.

Human activities, especially over the last six decades have had a profound impact on the distribution and abundance of fish and fish habitat in the estuary. Amongst other, mouth manipulation, causeways, dykes, bridges, golf courses and roads have either isolated or greatly reduced the spatial and temporal availability of fish habitat. A reduction in water quality and altered flows would have confused behavioural cues for recruitment or emigration and high fishing effort, both commercial gillnetting and recreational angling, have contributed to the overexploitation of some fish species. Recent 'mitigatory measures' such as partial removal of the causeway, have reconnected some fish habitat while reduced hydropower releases have helped re-establish at least some of the winter low-flow. Commercial gillnetting in the estuary has been prohibited since 1998 but there is still low-intensity illegal effort. On the other hand, recreational-angling effort has escalated beyond sustainable levels, largely due to effort displacement arising from proactive management and more stringent control of catches by South African anglers in Namibian waters.

Figure 62. Google image of the Orange Estuary with the 18 fish sampling sites from the mouth to Brand Kaross 35 km upstream

Table 29. Classification of South African fish 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.

6.2 Fish of the Orange Estuary

The range of benefits and habitats provided by estuaries is considerable including abundant food resources that exceed those of coral reefs, tropical forests and most other ecosystems (Costanza et al., 1997). Fish in estuaries benefit from high productivity, low predation, salinity gradients, and refuge from adverse conditions in the marine environment such as low temperatures or oxygen levels – thus improving body condition, growth and/or survival (de Decker and Bennett, 1985, Potter et al., 1990, Robins et al., 2006). Estuary-association or the degree to which fish utilise or are dependent on estuaries varies amongst species and between populations in different biogeographical regions (Lamberth et al., 2008). Accordingly, fish may also be grouped into various categories of estuary-dependence (Whitfield, 1994; Table 29). Biotic and abiotic factors influencing the abundance and diversity of estuarine-associated fish, including latitude, seasonality, catchment size, estuary size, salinity gradients, habitat diversity, mouth condition, dissolved oxygen levels, turbidity, food resources, flooding and anthropogenic impacts. The last of these can be direct, such as pollution, dredging, bait collection and fishing; or indirect, such as upstream impoundments, water abstraction and marine fishing. Impoundments trap sediment, reduce freshwater flow and obstruct the upstream migration of catadromous species whereas overexploitation in the marine environment will reduce recruitment of estuarine-associated species into estuaries (Lamberth and Turpie, 2003). In all, the response of estuarine fish assemblages to environmental and ecological change makes them good indicators of anthropogenic stress (Whitfield and Elliott, 2002).

Thirty-six species of fish representing 19 families have been recorded from the Orange Estuary (Brown, 1959; Day, 1981; Cambray, 1984; DWAF, 1986; Morant and O'Callaghan, 1990; Harrison, 1997; Seaman and van As, 1998; and this study (Table 30). 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, 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.

Table 30 lists all 36 species and 19 families recorded in the Orange Estuary by (a) Harrison, 1997; (b) Day, 1981; (c) Seaman and Van As, 1998; (d) Cambray, 1984; (e) Brown, 1959; (f) DWAF, 1986; (g) Morant and O' Callaghan, 1990; and (h) this study. The species are classified into five major categories of estuarine-dependence as suggested by Whitfield, 1994, Table 29. Species recorded caught by anglers marked with an asterisk (*).

Table 30. A list of all fish species and families recorded in the Orange Estuary

Family					
	Species	***Common name***	***Dependence category***	***Recorded by***	***% Samples reported***
Anguillidae					
	Anguilla mossambica	Longfin eel	Va	f *	14
Atherinidae					
	Atherina breviceps	Cape silverside	Ib	h	7
Austroglanididae					
	Austroglanis sclateri	Rock catfish	IVa	d	14
Carangidae					
	Lichia amia	Leervis	IIa	c,h	14
Cichlidae					
	Oreochromis mossambicus	Mozambique tilapia	IVa	a,c,d,g,h	57
	Pseudocrenilabris philander	Southern mouthbrooder	IVa	a,c,d,h	43
	Tilapia sparrmanii	Banded tilapia	IVa	d,h	14
Clariidae					
	Clarias gariepinus	Sharptooth catfish	IVa	c,d,g,h	43
Clinidae					
	Clinus sp.	Klipvis	Ib	f	14
	Clinus superciliosus	Super klipvis	Ib	h	1
Clupeidae					
	Gilchristella aestuaria	Estuarine round-herring	Ia	a,c,h	29
	Sardinops sagax	Sardine	III	a,h	14
Cynoglossidae					
	Cynoglossus capensis	Sand tonguefish	III	h	1
Cyprinidae					
	Barbus hospes	Namaqua barb	IVa	d,h	14
	Barbus paludinosus	Straightfin barb	IVa	c,d,h	29
	Barbus trimaculatus	Threespot barb	IVa	d,h	14
	Cyprinus carpio	Carp	IVc	c,h	29
	Labeo capensis	Orange River mudfish	IVa	c,d,h	29
	Labeo umbratus	Moggel	IVa	g,h	14
	Labeobarbus aeneus	Smallmouth yellowfish	IVa	a,b,c,d,g,h	71
	Labeobarbus kimberleyensis	Largemouth yellowish	IVa	c,d,h	43

Family					
	Species	***Common name***	***Dependence category***	***Recorded by***	***% Samples reported***
	Mesobola brevianalis	River sardine	IVa	c,d,h	29
Gobiidae					
	Caffrogobius nudiceps	Barehead goby	Ib	a,h	14
	Caffrogobius saldhana	Commafin goby	Ib	a,h	3
Mugilidae					
	Liza richardsonii	Southern mullet / harder	IIc	a,b,c,d,e,f,g,h	100
	Mugil cephalus	Flathead mullet	IIa	a,b,c,e,h	57
Poecillidae					
	Gambusia affinnis	Mosquito fish	IVc	h	
Pomatomidae					
	Pomatomus saltatrix	Elf	IIc	c,h	14
Rajidae					
	Raja spp.	Skates	III	g	14
Sciaenidae					
	Argyrosomus coronus	West coast dusky kob	III	*	
	Argyrosomus inodorus	Silver kob	III	a,b,c,g,h	57
Sparidae					
	Diplodus cervinus	Wildeperd / zebra	III	c	14
	Lithognathus aureti	West coast steenbras	III	*,h	1
	Lithognathus lithognathus	White steenbras	IIa	b,c,g	43
Syngnathidae					
	Syngnathus temminckii.	Longsnout pipefish	Ib	h	1
Triglidae					
	Chelidonichthys capensis	Cape gurnard	III	h	1

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 their mouths only having 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. This contributes disproportionately towards the effort directed at these species.

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; Lamberth et al., 2008). 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.

6.3 Factors affecting the fish assemblage

Factors affecting estuarine fish communities are generic across all estuaries but vary in intensity and relative importance between systems, often according to estuary type, flow regime and between biogeographic regions.

6.3.1 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. Predominantly summer recruitment of fish into the Orange coincides with that of the Olifants, Berg and temporarily open/closed estuaries to the south even though it experiences high-flow as opposed to summer low-flow of other west coast systems. Elevated flow may actually enhance recruitment above that of the other systems. 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. Whilst closed, inundated floodplain and saltmarsh areas will increase available foraging habitat. Prolonged mouth closure will likely see salinity levels decrease and freshwater species moving into the lower reaches of the estuary.

6.3.2 Retention time of water masses

Larval growth and survival, especially of estuary breeders, will increase with longer retention times of water masses 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.*

6.3.3 Flow velocities (tidal and river inflow)

During floods and high flows fish tend to find refuge in the shallow marginal areas on the floodplain and/or amongst saltmarsh and reedbeds. In the Orange Estuary, flow velocities are higher during the summer months. High flow velocities generate numerous eddies that provide refuge and concentrate prey as well as standing waves, small and large, 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, zooplankton and benthic algae production, fish will benefit from this abundant prey.

6.3.4 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 *Argyrosomus* spp. and steenbras *Lithognathus* spp. 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. Alternative reasons may be to subject parasite loads to osmotic shock or use of the estuary plume as a waypoint for coastwise movement. Freshwater fish also occur in the surf-zone at these times.

6.3.5 Salinity

The Orange is predominantly open so fish distributed according to their salinity preference, rather than tolerance, in the system but temperature and oxygen may play a larger role than 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. Consequently, those of the latter group in the Orange are euryhaline and tolerant of prolonged mouth closure and hypersalinity and hyposalinity, an arid-adapted character shared with fish assemblages to the south and east. Depending on flow, stenohaline estuary–independent marine species move in and out of the estuary with the tidal plug. Stenohaline freshwater species escape upstream. 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. This said, the dominant species in the system *L. richardsonii* is an opportunistic species tolerant of both hypo- and hyper-salinity and able to remain isolated from the sea or within disconnected river reaches for extended periods. Consequently, changes in the salinity regime are unlikely to see noticeable changes in abundance or biomass of fish in the estuary but will see a drop in diversity with the loss of species that have more narrow salinity tolerances or preferences.

6.3.6 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 (due to plant decay or night-time respiration) 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. Again, this is assuming that the estuary-proper does not become isolated from the upstream reaches.

6.3.7 Turbidity (in the water column)

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*, a selective feeder that prefers clearer waters.

6.3.8 Subtidal, intertidal and supratidal habitat

Fish spend most of the time in the subtidal and forage in, or on the margins of, the intertidal during the flood and ebb tides. 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.

6.3.9 Sediment characteristics (including sedimentation)

Benthic burrowing invertebrates such as sandprawn *Callichirus kraussi (Callianassa kraussi*) are rare or non-existent in the Orange Estuary as are gobies such as Knysna sandgoby *Psammogobius knysnaensis* that are often commensally associated with the burrows of these species. *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 and detritus, 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.

6.3.10 Phytoplankton and zooplankton biomass

At times when zooplankton is sparse, phytoplankton probably provides a major component of the diet of *G. aestuaria* and *A. breviceps*. The juveniles of most fish species, including *L. richardsonii*, prefer to feed on zooplankton. Relatively low zooplankton biomass in the Orange Estuary is probably the reason that juveniles of species such as *M. cephalus* and *L. lithognathus* are usually rare in the estuary-proper or further upstream in the freshwater reaches where freshwater zooplankton are relatively more abundant.

6.3.11 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.

6.3.12 Aquatic macrophyte cover

Excluding reedbeds, aquatic macrophyte cover is limited to patches of *Ulva* in the lower reaches and filamentous algae and pondweeding 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.

6.3.13 Fish biomass

The fish biomass is dominated by *Liza richardsonii* which in the Orange Estuary are mostly feeding (grazing) on benthic algae, benthic invertebrates and detritus. 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. High biomass of the adults and juveniles of small forage fish most notably *L. richardsonii*, means that prey availability is seldom limiting for piscivorous species.

6.4 Seasonality, spatial and temporal distribution and abundance

Fish abundance in the Orange Estuary is fairly seasonal with the highest catch-per-haul being in the spring and early summer (Table 31). This is likely to be 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 densities of the more dominant species are lower but diversity is similar with 22 to 24 species in winter and summer respectively. The summer fish assemblage comprises only estuary-associated (10 species) and freshwater fish (14 species) whereas that of winter comprises estuary-associated (6), marine (6) and freshwater (12) species tolerant of high salinities.

Table 31. Species composition (%), total catch and occurrence (%) in seine and gill net samples in the Orange Estuary during the period autumn 1993 – summer 1994 (after Harrison (1997), Seaman and Van As (1998) and this study summer, winter 2004, 2005 and winter 2012

	Autumn 1993 – Summer 1994 (Seaman and Van As)						**Spring 1993 (Harrison)**				**Summer, winter, 2004, 2005, 2012**			
	% Catch (seine & gill net)				**Total catch**	**% Occ**	**% Catch**		**Total catch**	**% Occ**	**% Catch (seine)**		**Total catch**	**% Occ**
	Autumn	**Winter**	**Spring**	**Summer**			**Gill net**	**Seine**			**Summer**	**Winter**		
Liza richardsonii	15.07	60.85	26.73	26.53	678	58	48.00	97.33	8442	85	92.46	97.22	100705	94
Labeobarbus aeneus	15.07	17.45	16.04	34.81	512	54	48.95	0.37	288	23	0.65	0.80	769	44
Mugil cephalus	7.88	13.19	26.21	17.83	478	63		0.01	1	5		0.01	3	2
Labeo capensis	21.58	3.4	12.09	10.27	281	38					0.07	0.01	42	10
Oreochromis mossambicus	14.73	3.4	11.92	2.28	203	58	2.48	0.02	15	19				
Gilchristella aestuaria				0.14	1	4		2.16	182	19	1.44	0.60	1082	37
Mesobola brevianalis	14.73		3.68		85	13					0.02	0.46	253	18
Labeobarbus kimberleyensis	2.4	1.28	1.14	2.14	38	46					0.05		25	6
Pomatomus saltatrix	1.71			3.57	30	21					0.05		28	8
Pseudocrenilabris philander	3.08		0.88		19	17		0.07	6	19	2.46	0.18	1382	31
Clarias gariepinus	3.08		0.88	0.71	24	25					0.01		1	1
Lithognathus lithognathus			0.35	1.43	14	8								
Argyrosomus inodorus		0.43		0.14	2	8	0.38		2	10				
Caffrogobius nudiceps								0.04	3	10	0.02		8	3
Barbus paludinosus			0.09		1	4					0.44	0.14	307	13
Cyprinus carpio	0.34				1	4					0.03	0.01	18	10
Diplodus cervinus	0.34				1	4								

	Autumn 1993 – Summer 1994 (Seaman and Van As)						***Spring 1993 (Harrison)***				***Summer, winter, 2004, 2005, 2012***			
	% Catch (seine & gill net)				***Total catch***	***% Occ***	***% Catch***		***Total catch***	***% Occ***	***% Catch (seine)***		***Total catch***	***% Occ***
	Autumn	***Winter***	***Spring***	***Summer***			***Gill net***	***Seine***			***Summer***	***Winter***		
Lichia amia				0.14	1	4					0.01		2	2
Sardinops sagax							0.19		1	5				
Caffrogobius saldhana											0.02		12	3
Tilapias sparrmanii											1.91	0.17	1095	22
Labeo umbratus											0.12	0.33	236	4
Barbus trimaculatus											0.11	0.02	68	10
Barbus hospes											0.12		64	4
Syngnathus acus												0.01	2	2
Lithognathus aureti												0.01	2	1
Chelidonichthys capensis												0.01	6	4
Cynoglossus capensis												0.01	1	1
Clinus superciliosus												0.01	3	1
Atherina breviceps											0.02	0.06	41	7
Gambusia affinnis												0.01	1	1
Number of species	**12**	**7**	**11**	**12**	**17**		**5**	**7**	**9**		**19**	**19**	**26**	
Total number of fish	**292**	**235**	**1141**	**701**	**2 369**		**525**	**8 415**	**8 940**		**52 469**	**53 685**	**106 154**	
Number per haul and/or set	**49**	**39**	**190**	**117**	**99**		**58**	**701**	**426**		**1 500**	**994**	**1 177**	

Catches throughout the year are dominated by the partially estuarine-dependent *L. richardsonii* which compromises about 50% of the adult or large fish component and more than 90% of the juvenile component of the fish assemblage. The remaining 10% of the fish assemblage is dominated numerically by the estuary-resident *Gilchristella aestuaria* and the freshwater *Labeobarbus aeneus*, *Labeo capensis*, *Tilapia sparrmanii and Pseudocrenilabris philander*.

Interestingly, spring catches reported by Harrison (1997) and Seaman and Van As (1998) bear absolutely no resemblance even though both samples were taken in September 1993 (Table 31). Much of this discrepancy is probably due to Seaman and Van As using predominantly gill nets and sampling 35 km upstream whereas Harrison sampled in the lower 10 km using gill nets and seines, the latter to sample the small and juvenile fish component more thoroughly. In turn, Harrison's visit was during mouth closure whereas the tidal variation in salinity reported by Seaman and Van As suggests that the mouth was open during their visit.

The presence of at least three size classes of *L. richardsonii* corresponding to 0 – 1 year-old, 2 year–old and 3 – 4 year–old fish suggests that the Orange Estuary is being utilized as a nursery for this species. Similarly, various size classes of the estuary-breeder *Gilchristella aestuaria* indicate that the estuary is supporting a viable population of this species. Catches of the other species able to breed in estuaries *Caffrogobius nudiceps*, *C. saldhana*, *Atherina breviceps*, *Clinus superciliosus* and *Syngnathus acus* were low but their presence suggests that they are using the Orange Estuary as a nursery. Catches of juvenile obligate estuary-dependant *Mugil cephalus* and *Lichia amia* and partially dependent *P. saltatrix* indicates that the same holds true for these species. Most freshwater species were also represented by juveniles.

The non estuarine-dependent pilchard (*Sardinops sagax*) and *A. inodorous* were both captured by Harrison (1997) during mouth closure suggesting that they easily survive these events. Salinity ranges were well within their tolerance levels, bottom salinity ranging from 29 ‰ near the mouth to 16 ‰ 6 km upstream. *S. sagax* has been recorded in salinities less than 10 ‰, 40 km from the mouth of the Berg Estuary whereas *A. inodorous* has been recorded in salinities of less than 5 ‰ 10 km upstream in the Olifants Estuary (Lamberth et al., 2008). The remaining non estuary-associated marine species *Lithognathis aureti*, *Chelidonichthys* capensis and *Cynoglossus capensis* were only caught in the lower part of the estuary during the winter low-flow period.

Upstream distribution of the species caught during autumn-winter and spring-summer was largely a function of the estuarine-dependence category to which they belong (Table 31, Figure 62). During the winter low–flow season, peak-abundance of the estuary-resident *Gilchristella aestuaria* was 2 – 6 km from the mouth at the start of the REI zone but it also occurred throughout the estuary from the mouth to 20 km upstream. Peak abundance during summer was 0 – 1 km from the mouth but catches were made throughout the estuary to the Brandkaros freshwater reaches. *G. aestuaria* was more abundant during the summer months but more juveniles were evident in winter samples indicating that most spawning probably takes place during the low-flow period. Distribution and abundance of *Mugil cephalus*, a category IIa, facultative catadromous species that ventures far into freshwater, did not vary much between winter and summer. In both seasons there were three areas of 'high density' these being the 1 – 2 km, the REI zone 5 – 10 km and the freshwater reaches 35 km from the mouth respectively. This distribution is typical of this species in most permanently open estuaries on the west and south coast of southern Africa (Lamberth et al., 2008). *Lithognathus lithognathus* and *Lichia amia* both category IIa species dependent on estuaries for their first year of life were caught exclusively in the first two kilometres and only during summer in both past (Seaman and Van As, 1998) and present studies. This suggests that, despite summer flows being high, these two species may recruit during spring and remain throughout the year without being flushed from the system. Adults are also likely to enter the estuary during summer to escape cold upwelling events in the sea. Temperature differences between sea and estuary are often in the region of 10 – 15°C during summer.

Liza richardsonii, a category IIc species shows an upstream shift during the winter months probably in response to saltwater intrusion and expansion of the REI zone (Figure 62). During summer, higher flows see them concentrated nearer the river mouth with much of the population likely to be continuously moving between the estuary and adjacent surf-zone with the tides. Densities within the estuary are also likely to increase in response to upwelling events. This species also ventures far upstream with a few individuals caught in both summer and winter 35 km and even over 100 km from the mouth (Cambray, 1984). The response of *Pomatomus saltatrix* (category IIc) during summer high flows is unexpected. During winter, all catches were made in the lower 1 km of estuary whereas in summer they were caught at most sites and well into the freshwater reaches (Figure 62). Catches were represented by two perhaps three, year classes of 90 – 130 mm, 150 – 300 mm and 350 – 400 mm respectively. These are similar to those recorded in the Berg and Olifants Estuaries where the commercial 'bycatch' of *P. saltatrix* amounts to approximately 120 t per annum mostly during the summer months. This suggests that, despite the elevated summer flows in the Orange, recruitment of *P. saltatrix* follows similar patterns to that of the Berg and Olifants Estuaries the latter which fall entirely into a winter rainfall zone experiencing summer low flows. *Argyrosomus inodorus*, a category III marine species also shows a slight upstream shift during the summer which, although data are limited, may be another indication that it shows some degree of estuarine-dependence on the west coast and could probably be designated a category IIc species.

Category IV freshwater species such as *O. mossambicus*, *L. kimberleyensis* and *L. aeneus* showed a downstream shift into the estuary during the summer months and higher flows although the bulk of their populations remained above the REI zone during both seasons. *O. mossambicus* and *L. kimberleyensis* appear to be more tolerant of high salinities with both being found in the lower 2 m during winter. The latter species is also caught by shore-anglers in the adjacent surf-zone during high-flow and flood evens. *O. mossambicus* has been known to survive in salinities in excess of 100 ‰ and often takes advantage of adverse conditions such as poor water quality and low oxygen by moving into areas from which other fish have been excluded.

6.5 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.

Even in the absence of any changes in catchment flows, abundance and distribution of exploited fish species throughout the west coast of southern Africa is likely to have been different under reference including occurrence in the Orange Estuary. Overexploitation has impacted on the abundance of most species but simultaneously may have resulted in changes in distribution albeit range shrinkage or expansion or even extinction from a biogeographical region. By example, white steenbras *L. lithognathus* occurs from the Orange to Port Edward on South Africa's east coast. It is characterised by an annual spawning migration to the east coast in the warm temperate/subtropical transition zone. It was once one of the most abundant fish caught by the nearshore line and netfisheries on the west coast and subject to intensive fishing pressure from the late 1800s to the 1970s resulting in stock collapse. Evolutionary and archaeological histories as well as the occasional occurrence of small juveniles in west coast estuaries, including the Cunene, suggest that, prior to fishing; there was once a distinct west coast spawning population. The fluvial fan off the Orange Estuary is ideal in terms of sediment requirements and mouth may have been the destination for a west coast spawning migration of this 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 *Pomatomus 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.

In Figure 63 the percentage of total catch from the mouth of the Orange Estuary to Brand Kaross 35 km upstream during winter and summer. Winter catches are shown above, and summer catches below, each axis. Species arranged in order of their estuarine dependence category (Table 29). Note that the distance axis is not continuous.

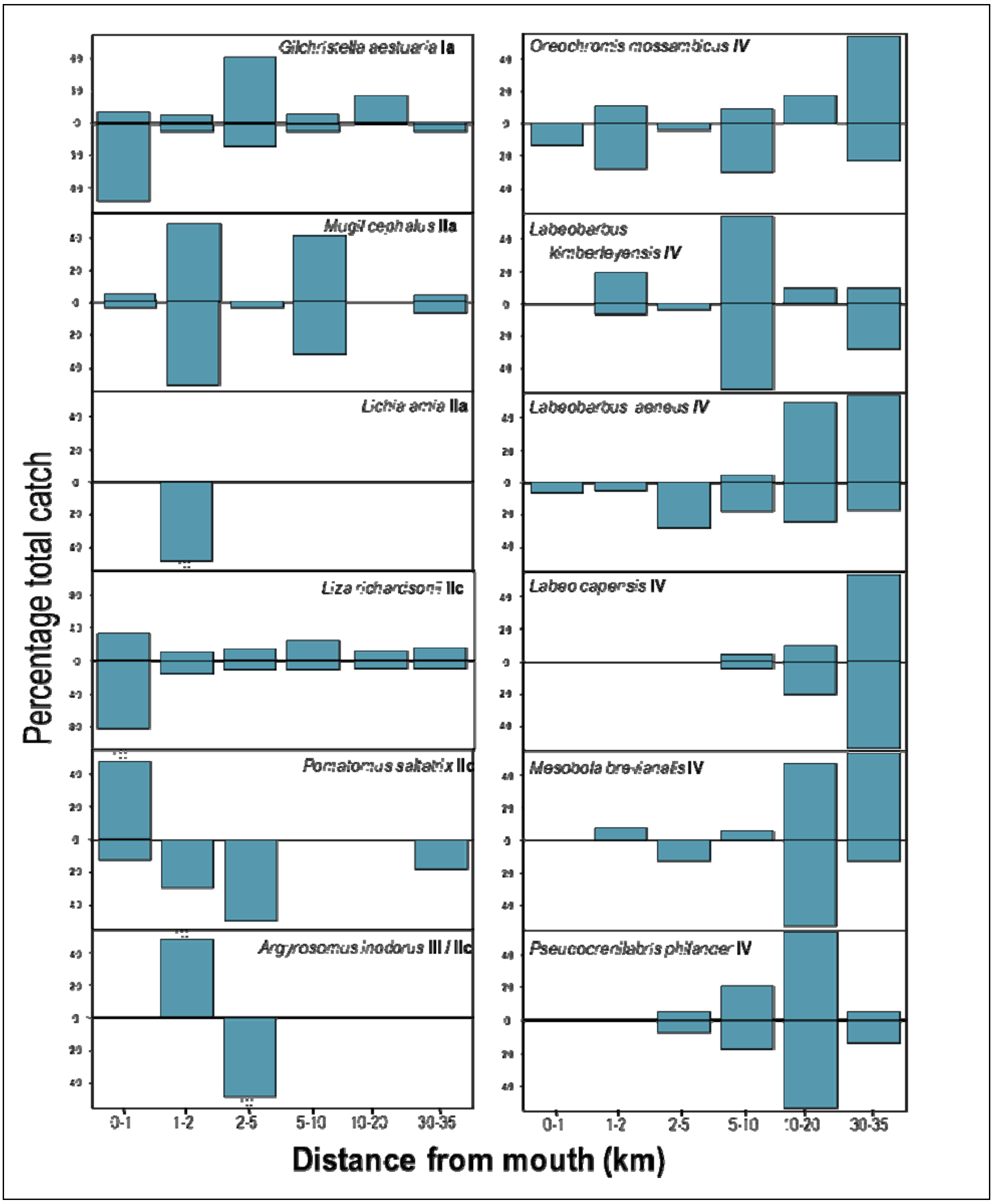


Figure 63. Percentage of total catch from the mouth of the Orange Estuary to Brand Kaross 35 km upstream during winter and summer

6.5.1 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.

6.6 Similarity of fish in the present state relative to reference condition

Species richness has remained relatively unchanged even though the Orange Estuary was freshwater dominated under reference but less so in the present day. 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. The freshwater component has the addition of two alien invasive species carp *Cyprinus carpio* and mosquito fish *Gambusia affinis*.

In terms of abundance *L. richardsonii* dominates (>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. The overall extent of juvenile nursery habitat has been much reduced by causeways and other obstructions in the estuary.

Community composition is similar to reference with the fish assemblage 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. Similarly, lower numbers of all generally larger exploited fish species are lower than under reference. This is a reflection of overexploitation and the state of fish stocks and populations throughout the South African and Namibian coastlines. Within the estuary, the impact of causeway, bridges and other obstructions on the recruitment, foraging and survival of juveniles in the estuary will have been severe.

7. Estuarine birds

7.1 Introduction

The South African side of the Orange Estuary was designated as a Wetland of International Importance (or Ramsar site) in 1991, because of (a) being one of only nine perennial coastal wetlands on the southern African west coast, (b) its supporting more than 20 000 waterbirds of about 60 species, (c) its supporting an appreciable assemblage of rare and endangered water bird species, and (d) supporting more an 1% of the world and southern African population of several species of waterbirds. It became a transfrontier Ramsar site in 1995 when Namibia ratified the Ramsar Convention. Following national bird counts in the 1970s and 80s, the estuary was recognised as being one of the most important estuaries in South Africa in terms of its waterbird populations (Turpie, 1995), and as a top priority in terms of its overall biodiversity conservation importance (Turpie et al., 2002; Turpie and Clark, 2007). It has also been designated as an Important Bird Area (Barnes and Anderson, 1998). Since its designation as a Ramsar site, however, numbers of birds on the estuary have declined dramatically, probably due to a combination of on-site and off-site factors (Anderson et al., 2003). These included reduced freshwater inflows and the loss of a large area of saltmarsh which became cut off from the estuary waters, as well as changes in fish resources in the marine environment.

The aims of this section were to describe the avifauna of the lower floodplain wetlands and estuary in terms of the spatial and temporal patterns of use, particularly in the light of possible future changes in freshwater inflow to the estuary. The following key questions were addressed:

- How does the avifaunal community vary spatially along the estuary and what determines this pattern?
- What is the interaction between the estuary and floodplain?
- What are the seasonal patterns in avifaunal community structure?
- How have numbers of birds varied over the longer term and to what extent are interannual variations linked to variation in freshwater inflow?

This study follows an earlier determination of the ecological flow requirement for the Orange Estuary on a Rapid level, based on published or readily available data (van Niekerk et al., 2003), for which a specialist study on birds was prepared (Anderson, 2003). Whereas such studies are often carried out at a low level of confidence because of lack of data, the birds of the estuary have been monitored regularly for a number of years, and the descriptions prepared by Anderson (2003) were detailed and were rated as having a high level of confidence. This study builds on and updates the detailed information and assessments presented by Anderson (2003). It is based entirely on these preceding reports and a site visit, since more recent count data (which have reportedly not been as comprehensive as earlier counts due to staff shortages – Elsabe Swart, Northern Cape Department of Environment and Nature Conservation, pers. comm.) were not available.

7.2 Study area and bird habitats

The estuarine area is about 2,700 ha with important bird habitats provided in **Error! Reference source not found.**2. Upstream of the Sir Ernest Oppenheimer Bridge, the estuary is largely confined to a single channel with intermittent sand banks that are generally not vegetated. *Phragmites autralis* then begins to appear along the southern banks one km upstream of the bridge where tidal variation of a few centimetres can be detected during spring tides (Chapter 1).

Further downstream, the estuary becomes more braided with sand banks, islands and numerous channels. Most of the habitat is salt marsh and reeds, but there are also numerous areas of intertidal banks. A large area on the southern bank near the mouth has become desertified marsh after being cut off by the construction of a causeway.

Table 32. Summary of important bird habitat in the Orange Estuary (see Chapter 3 for more detail)

Habitat type	***Area (ha)***	***Habitat type***	***Area (ha)***
Open surface water area	609	Supratidal salt marsh	602
Intertidal sand and mudflats	144	Desertified marsh area	511
Submerged macrophytes	<1	Reeds and sedges	316
Macroalgae	<1	Terrestrial vegetation	383
Intertidal salt marsh	144	**TOTAL**	**2,709**

Tere are also anthropogenic habitats within the estuary floodplain. These include a sewage works area and sports fields (golf and rugby). The sewage works was reportedly decommissioned at the end of 2012, and was not included in the count conducted during this study. More detailed descriptions of the estuary can be found in Anderson et al. (2003), Van Niekerk et al. (2003) and CSIR (2011). The area counted in previous Co-ordinated waterbird counts (CWAC) counts is shown in Figure 64.

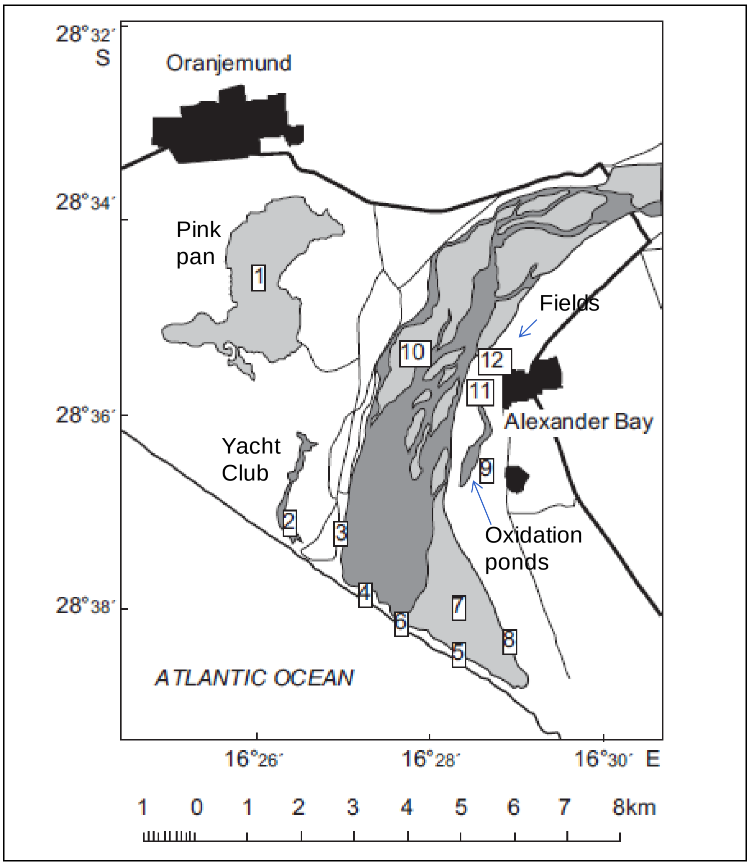


Figure 64. Area counted in CWAC counts, including peripheral wetlands named in the figure. Source: Anderson et al., 2003

7.3 Data and methods

This study is based on a desktop review of the literature, which includes published analyses of bird counts made under the CWAC volunteer programme and earlier counts conducted by researchers on the estuary, as well as a field visit and count conducted as part of this study. This study concentrates on non-passerine water-associated species, and excludes exotic species, vagrant species and extralimital species recorded on the estuary.

While there are a number of anecdotal accounts dating back to the 1940s (Plowes, 1943; Grindley, 1959; Courtenay-Latimer, 1963; Frost and Johnson, 1977; Siefgried and Johnson, 1977; Manry, 1978; Roberts, 1989), the earliest published comprehensive count of the Orange Estuary is from January 1980 (Ryan and Cooper, 1985). It was counted again in 1985 and 1986 (Williams, 1986), and again in 1994 and 1995 by Simmons (1994, 1995). The estuary was then counted bi-annually from December 1995. CWAC data from the Orange Estuary are not available, but are summarised in Taylor et al. (1999) and Anderson et al. (2003). Other studies on the estuary's birds include Velaquez's (1996) study of the effects of aircraft on waterbirds, and publications on marine and coastal birds (Crawford et al., 1995; Anderson, 2000). All of this information was summarised in Anderson (2008). It is important to note that comprehensive counting of birds on the estuary started only after all the major dam developments in the catchment had been completed (1938 – 1978).

In addition to a review of the above, a site visit was conducted on 13 – 15 November 2012, during which a count of all waterbird species on the estuary was made. The estuary was divided into four sections based on general habitat attributes and position within the estuary – the upper estuary, lower estuary, lower estuary saltmarsh and the estuary mouth area (Figure 65). The dates and ambient conditions when each section was surveyed are summarised in Table 33. Counts were undertaken from a boat and on foot using binoculars and telescope, using the route taken indicated in Figure 66. Coverage within each of the sections was comprehensive, except for the Lower section where the numerous islands and the widening of the estuary made it impractical to cover the entire extent of shoreline in the time available. Based on Google Earth imagery, it was estimated that approximately 20% of the shoreline within the lower section was not assessed.

Table 33. Dates and weather conditions when each section of the estuary was sampled

Section	***Date and time***	***Ambient conditions***
Salt Marsh	13 Nov 16H00 – 17H45	SW 25 km/h, partly cloudy, outgoing tide
	15 Nov 13H00 – 13H30	SW 15 km/h, overcast, low tide
Upper	14 Nov 06H00 – 10H50	SW 0 km/h strengthening to 40 km/h at 11H00, sunny
Lower	15 Nov 06H00 – 10H30	SW 0–5 km/h strengthening to 20 km/h at 11H00, overcast with fog, outgoing tide
Estuary Mouth	15 Nov 12H20 – 13H00	SW 20 km/h, overcast, low tide

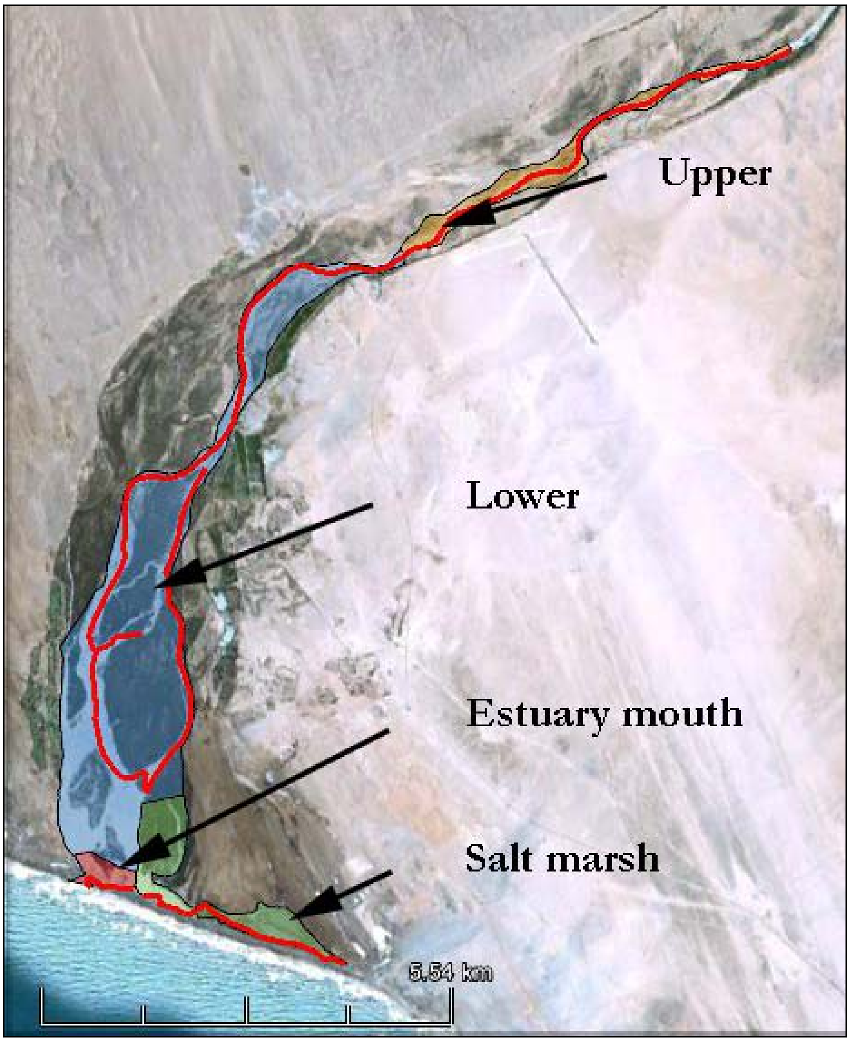


Figure 65. Four sections (indicated by different colours) that the Orange Estuary was divided into for bird counts. Red lines indicate the route that was taken during counts starting upstream at Pachtvlei

7.4 Abundance and composition in November 2012

A total of 2,647 water birds were counted on the estuary during November 2012 (Table 34). This may be an underestimate for certain species given that some 20% of the lower section was not counted. However, it is unlikely that the count missed any significant aggregations of birds in the area missed, given the nature of these habitats. The most abundant species were sandwich tern (430), Egyptian goose (266), little stint (219), Cape cormorant (187) and lesser flamingo (152). Noteworthy species that are considered to be uncommon or rare by Anderson (2006) that were recorded include the yellow-billed egret (2), African purple swamphen (1), African sacred ibis (1), Eurasian curlew (1), African black oystercatcher (1), grey plover (3), southern pochard (6), common sandpiper (7), common whimbrel (1) and African marsh harrier. Seven Red Data Book species listed as Near Threatened and one of Vulnerable were recorded.

Table 34. Frequency of each species recorded during bird counts for each of the four sections of the estuary.

Name	***Status[1]***	***Endemic status***	***Upper section***	***Lower section***	***Salt marsh***	***Mouth***	***Total***
Avocet, Pied *(Recurvirostra avosetta)*				3	30	6	39
Coot, Red-knobbed *(Fulica cristata)*				72			72
Cormorant, Cape *(Phalacrocorax capensis)*	NT	BE		4	11	172	187
Cormorant, Reed *(Phalacrocorax africanus)*				7	1		8
Cormorant, White-breasted *(Phalacrocorax carbo)*				26	2	36	64
Curlew, Eurasian *(Numenius arquata)*				1			1
Duck, Yellow-billed *(Anas undulata)*			7	8			15
Egret, Cattle *(Bubulcus ibis)*				1			1
Egret, Little *(Egretta garzetta)*				9	26		35
Egret, Yellow-billed *(Egretta intermedia)*				2			2
Fish-Eagle, African *(Haliaeetus vocifer)*				7			7
Flamingo, Greater *(Phoenicopterus ruber)*	NT		15	5	111	4	135
Flamingo, Lesser *(Phoenicopterus minor)*	NT				137	15	152
Goose, Egyptian *(Alopochen aegyptiacus)*			134	121	11		266
Goose, Spur-winged *(Plectropterus gambensis)*				4			4
Grebe, Little *(Tachybaptus ruficollis)*				4	1		5
Greenshank, Common *(Tringa nebularia)*			4	3	1	3	11
Gull, Hartlaub's *(Larus hartlaubii)*		E		40	4	43	87
Gull, Kelp *(Larus dominicanus)*			2	56	16	4	78
Heron, Grey *(Ardea cinerea)*			2	6		2	10

Name	*Status[1]*	*Endemic status*	*Upper section*	*Lower section*	*Salt marsh*	*Mouth*	*Total*
Ibis, African Sacred *(Threskiornis aethiopicus)*					1		1
Kingfisher, Malachite *(Alcedo cristata)*				1			1
Kingfisher, Pied *(Ceryle rudis)*			6	30	3		39
Lapwing, Blacksmith *(Vanellus armatus)*				21			21
Night-Heron, Black-crowned *(Nycticorax nycticorax)*				27			27
Oystercatcher, African Black *(Haematopus moquini)*	NT	BE				1	1
Pelican, Great White *(Pelecanus onocrotalus)*	NT			19	1	50	70
Plover, Chestnut-banded *(Charadrius pallidus)*	NT		82				82
Plover, Common Ringed *(Charadrius hiaticula)*			9	29	2	1	41
Plover, Grey *(Pluvialis squatarola)*			1	1	1		3
Plover, Kittlitz's *(Charadrius pecuarius)*			23	4	1	2	30
Plover, Three-banded *(Charadrius tricollaris)*				8			8
Plover, White-fronted *(Charadrius marginatus)*			15		1	4	20
Pochard, Southern *(Netta erythrophthalma)*				5			5
Sandpiper, Common *(Actitis hypoleucos)*			5	2			7
Sandpiper, Curlew *(Calidris ferruginea)*			36	61	25	3	125
Sandpiper, Marsh *(Tringa stagnatilis)*				4			4
Shelduck, South African *(Tadorna cana)*		BNE	16	20	32		68
Shoveler, Cape *(Anas smithii)*		NE		1			1
Spoonbill, African *(Platalea alba)*				1	42		43
Stilt, Black-winged *(Himantopus himantopus)*						2	2

Name	Status[1]	Endemic status	Upper section	Lower section	Salt marsh	Mouth	Total
Stint, Little *(Calidris minuta)*			79	33	106	1	219
Swamphen, African Purple *(Porphyrio madagascariensis)*				1			1
Teal, Cape *(Anas capensis)*			2	7	5		14
Teal, Red-billed *(Anas erythrorhyncha)*			2	5			7
Tern, Caspian *(Sterna caspia)*	NT		1	9		14	11
Tern, Common *(Sterna hirundo)*				7	4	24	16
Tern, Sandwich *(Sterna sandvicensis)*				10		420	287
Tern, Swift *(Sterna bergii)*			8	11	1	81	46
Wagtail, Cape *(Motacilla capensis)*			19	7	7	3	36
Harrier, African Marsh				1			1
Whimbrel, Common *(Numenius phaeopus)*				1			1
TOTAL No.			468	705	583	891	2,417
TOTAL No. of SPECIES			21	46	27	22	52

1 Status indicates category in the South African Red Data Book using latest International Union for Conservation of Nature (IUCN) criteria as Near Threatened (Barnes 2000) and indicates it is listed as Vulnerable. E = endemic, NE = near-endemic, BE = breeding endemic, BNE = breeding near-endemic.

A total of 52 species of water bird were seen in the estuary during the three-day site visit (Table 34). The upper estuary and the estuary mouth had the lowest number of species, 21 and 22 respectively, the salt marsh 27, while the lower section was the most diverse with 46 species (85% of all species recorded during the count).

Benthic waders were the dominant avifauna present, followed by piscivorous gulls and terns with these groups together comprising 64% of the birds on the estuary in November 2012 (Figure 66). Nevertheless, the avifaunal composition is relatively even, and most of the other groups described also make up significant components of the avifauna.

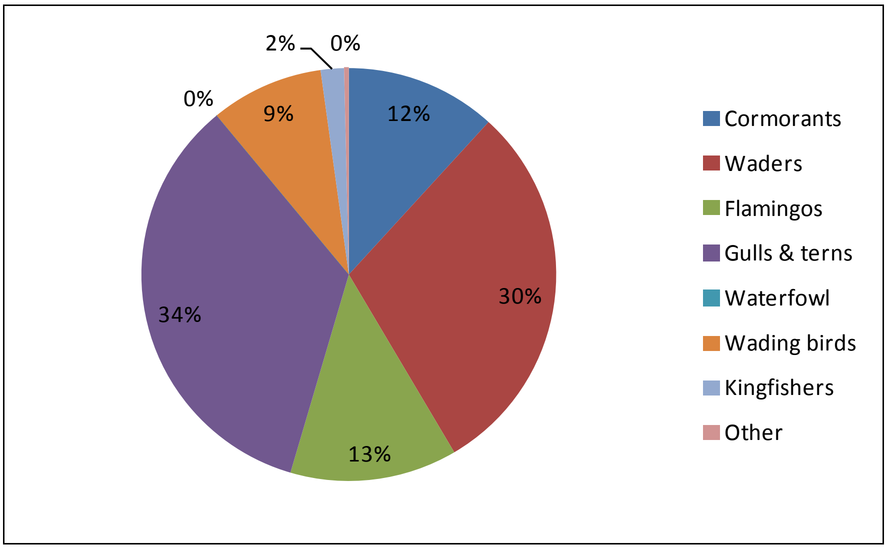


Figure 66. Avifaunal community structure in November 2012

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. Cormorants, gulls and terns were all concentrated in the immediate vicinity of the mouth (Figure 67).

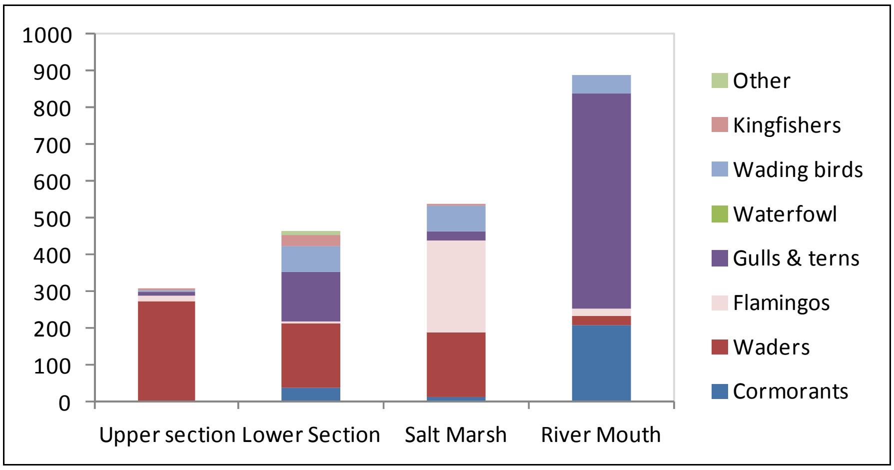


Figure 67. Distribution of bird groups in the estuary in November 2012

Because of the differences in area covered, this count is not strictly comparable with the CWAC counts which take the estuary to be from the bridge down, and to include peripheral habitats. For example, the numbers of Chestnutbanded Plovers were high in comparison with earlier CWAC counts, possibly because many were recorded above the bridge.

7.5 Historical trends and their likely causes

Figure 69 provides the numbers of waterbirds recorded in summer (blue squares) and in winter (white squares) during surveys from January 1980 to August 2005, relative to this latest study (denoted by asterik). Data reflected in Figure 69 is from Anderson in Van Niekerk et al. (2008) based on Ryan and Cooper (1995); Williams (1986) and undated; Simmons (1994; 1995); Underhill and Cooper (unpublished data) and Anderson, Kolberg and co-workers.

The count conducted during this study missed 5 – 10% of the estuary and did not include peripheral wetlands (pink pan, yacht basin and the oxidation ponds), and it was conducted in November, rather than the midsummer period when peak numbers would be expected. Thus the low numbers of birds recorded cannot be taken as confirmation of further decline in numbers. Nevertheless, comprehensive counts made up to 2005 suggest that the numbers of birds have declined dramatically since the 1980s (Figure 68). This is despite recent counts generally being more comprehensive (Anderson, 2006). These changes appear to have applied to the summer counts rather than winter counts, which have remained far more stable (Figure 68). The counts decreased from over 20,000 birds in the 1980s to an average of 6,891 in summer and 6,392 in winter over the period 2000 – 2005.

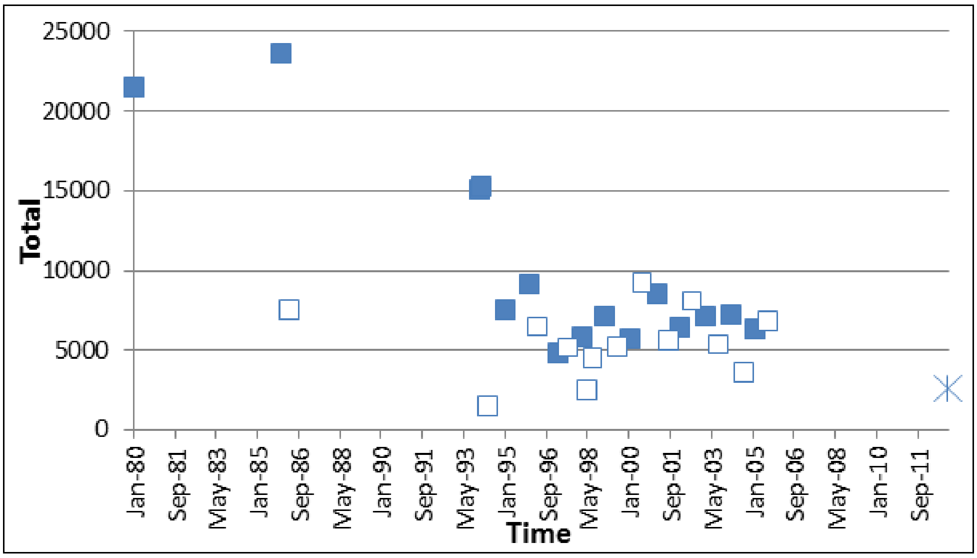


Figure 68. Numbers of waterbirds recorded in summer and in winter during surveys from January 1980 to August 2005, relative to this latest study

Figure 69 provides the numbers of waterbirds species recorded in summer (blue squares) and in winter (white squares) during surveys from January 1980 to August 2005, relative to this latest study (denoted by asterik).

In contrast, the numbers of different species of water birds recorded at the estuary have been fairly stable over the past 25 years (Figure 69). The average number of species recorded per count is 52 (Anderson, 2006). Variance appears relatively low, although a minimum of 41 and a maximum of

64 species have been reported per count within the space of a two-year period (Figure 69). There is also a consistent yet small seasonal shift in numbers of species, with a few more (<10) being recorded in summer than in winter. Our results are typical of the average number of water bird species recorded for the estuary.

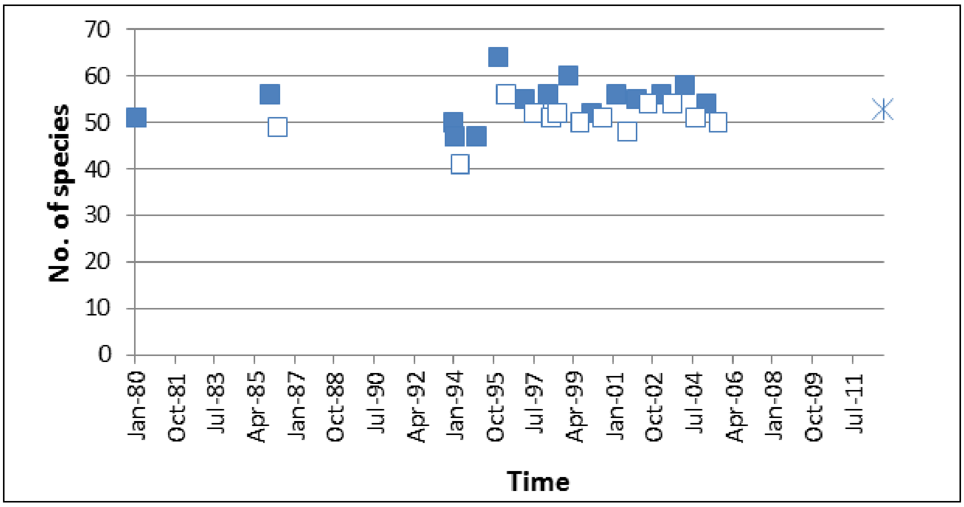


Figure 69. Numbers of waterbird species recorded in summer and in winter during surveys from January 1980 to August 2005, relative to this latest study

The composition of the avian community has also changed dramatically, as can be seen from a comparison of recent data with the first comprehensive count in 1980 (Figure 70). The largest discrepancies in community structure and abundance between initial and recent surveys are attributable to the considerable decrease in the numbers of cormorants, waders and terns. Anderson (2003) compared the average numbers in counts of 1980 – 1994, with numbers recorded from 1995 – 2001. Cape cormorants declined from an average of 6,400 (±3,861) to 212 (±612) individuals, and common terns declined an average of 3,928 (±3,678) individuals to 425 (±731) individuals.

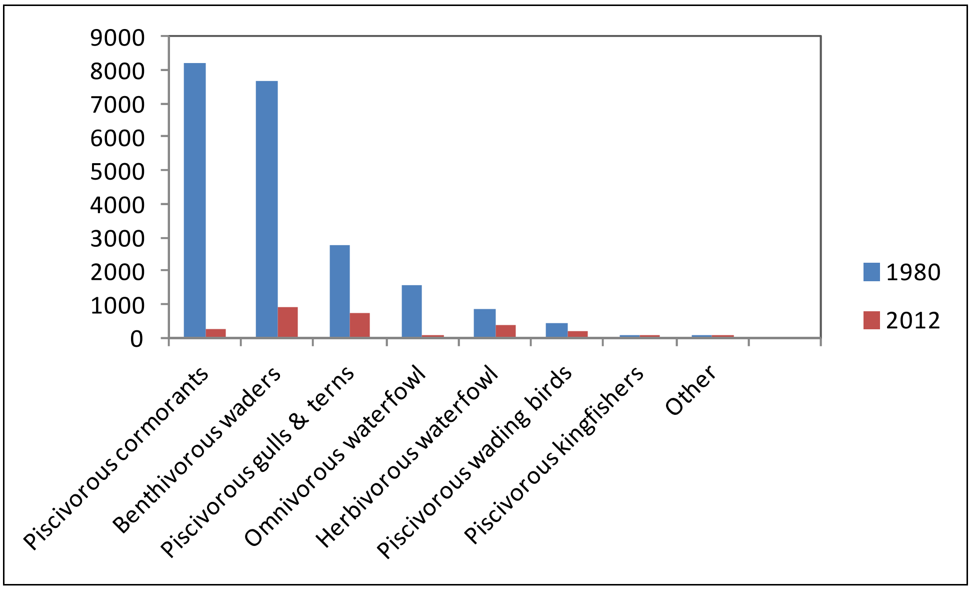


Figure 70. Comparison of community structure between counts in 1980 and 2012

Heath (2001) suggested that factors most likely affecting the abundance of terns, especially Common tern at the estuary were the abundance of suitable shoals of fish along the coast in the vicinity of the estuary, turbidity levels in the sea which are influenced by river flow and soil erosion from poor catchment management and whether the state of the sea and winds are suitable for terns to forage. Anderson et al. (2003) believe that the decline is largely due to local factors that have decreased the suitability of the estuary for roosting birds. These include increased levels of human disturbance and a change in the amount of suitable roosting sites due to changes in mouth architecture and islands. There is also evidence to suggest that other large nearby wetlands in Namibia are more suitable at present and attracting most birds in the region (Anderson et al., 2003). In addition, although global numbers of common tern had not declined significantly by the 1990s (Williams and Underhill, 1997), more recent studies indicate that numbers have decreased at many breeding sites, and its range has reduced (Nisbet, 2002).

The declining numbers of Cape cormorant appear to be caused by a slightly different combination of factors. It is endemic and listed as Near Threatened, and the present status of this species has been attributed to disease, oiling, declining fish stocks and disturbance at their breeding sites (Crawford, 1997; 2000). Most of the initial surveys (1980 – 1995) at the estuary recorded several thousand birds, but the next 20 surveys recorded an average of only 63 ± 217, with a maximum of 984 bird in 1999 (Anderson, 2006). Our survey recorded higher than average numbers compared to recent surveys, but still far below historical records.

The reasons why Cape cormorants no longer breed or use the estuary mouth for roosting in abundance are not clear, but there are several possible explanations which draw on both on- and off-site factors. These include (1) a general decline in the global (i.e. southern African) population of this species (Cooper et al., 1982; Crawford and Dyer, 1995; Crawford, 1999) largely due to the decline of its food source, the Cape anchovy (Crawford and Dyer, 1995; Crawford, 1997, 1999, 2000; Schwartzlose et al., 1999), but (2) also due to disease in the 1990s which may have been exacerbated by hunger (Crawford and Dyer, 1995; Hockey et al., 2005), (3) a change in the architecture of the river mouth which has resulted in fewer suitable roosting and breeding sites due to the large flood of 1988 (Barnes and Anderson, 1998); (4) increased levels of disturbance from humans and cattle as the Cape cormorant has a very low tolerance to this especially during breeding (Crawford, 1997; Williams, 1986); and or (5) better conditions elsewhere (Anderson et al., 2003). It is likely that a combination of these factors are responsible for the overall decline, but local factors attributable to the lack of birds at the estuary, particularly breeding colonies, are most probably due to disturbance from humans as well as cattle which graze in the Ramsar site.

Wader numbers also dropped dramatically after the 1980s, far more than one might expect given general global population declines. This suggests a loss of intertidal and shallow water habitat from the system. It is suspected that the degradation of the salt marsh area may have played a key role, as this habitat is ideal and highly depended upon by waders (Anderson et al., 2003).

Nevertheless, many species that use salt marsh habitat for foraging have not declined significantly, such as lesser flamingo and curlew sandpiper (Anderson et al., 2003). The reduction in the extent and health of the remaining salt marsh may however have been offset by the tidal influence that now dominates the system as a result of its permanently open mouth (Anderson et al., 2003). This has allowed extensive areas of intertidal mudflats to be maintained which are highly valuable as foraging areas for most of these benthivorous wading species.

Many waterfowl species have also declined significantly from early surveys, and this is probably linked to the estuary having moved from a relatively fresh state to a more saline system as freshwater inflows have been reduced. The black-necked grebe is one waterfowl species that was particularly numerous in early counts but rare in recent counts. known to be highly nomadic and there is probably no resident population in South Africa (Hockey et al., 2005) thereby making the abundance of this species in the estuary highly variable. While overall numbers of waterfowl have declined, numbers of certain species, such as Egyptian goose, have increased. It is likely that the irrigating of agricultural fields and a golf course adjacent to the river and estuary has contributed to these increases, as well as the fact that hunting has ceased (Anderson et al., 2003). It should also be noted that there is a highly seasonal pattern, with the majority of waterfowl being present in summer, when ephemeral wetlands in the region are dry. Our survey found that herbivorous waterfowl were the third largest component of the avifauna, mainly due to very high numbers of Egyptian geese. Our count of 290 individuals is one of the highest on record.

7.6 Reference condition

There are many anecdotal accounts of birds on the estuary prior to 1980, but they do not proide much indication of overall waterbird diversity and abundance. Anderson et al. (2003) assumed that the numbers recorded during the initial surveys were similar to the reference conditions.

However, it is important to note that the changes observed in count data since 1980 have all taken place after the major changes to the catchment and freshwater inflows had been affected. Damming in the catchment started in 1884, intensified in the 1930s, and all the dams on the system were in place by 1978. It is quite possible, therefore that the dramatic reduction in floods in the system played a major role in the loss of birds. The construction of the causeway that cut off the saltmarsh occurred well before the first bird counts in the 1960s. Thus the numbers of birds recorded in the 1980s may have already been depressed as a result of the loss of saltmarsh.

8. References

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Appendix A Hydrodynamic modelling of salinity distributions in the Orange Estuary under a range of river inflow scenarios

A.1 Approach and methods

The approach to the study has been to set-up a fully three-dimensional hydrodynamic model (Delft3D-Flow) capable of simulating the salinity distribution along the axis of the Orange Estuary for a range of existing and possible future river inflows. The range of scenarios is described in greater detail in section 2.6.

A.2 The hydrodynamic model

The Deltares three dimensional hydrodynamic modelling suite (Delft3D-flow) has been used for the study (Deltares, 2011[3]). The model incorporates the following processes:

- wind, wave and tidally driven flows;
- rotational effects (Coriolis) effects);
- vertical mixing based on sophisticated turbulence closure models;
- air-sea fluxes including evaporation.

Wind and wave effects as well as air-sea fluxes have been excluded from the model used in this study as these are deemed to be second order effects or superfluous for the purposes of the present study.

A curvilinear computational grid (Figure A1) is used in the model. A total of eight layers are used in the model that uses a sigma coordinate in the vertical (i.e. a co-ordinate where the vertical layers thicknesses are normalised to a local water depth (Deltares, 2011).

The model is forced by:

- tidal water levels specified at the offshore boundaries;
- freshwater river discharges into the estuary.

3 Deltares,2011. Comparison SWAN, PHAROS and radar wave observations. Deltares report 1204199-002-HYE-0009 dd 24 November 2011.

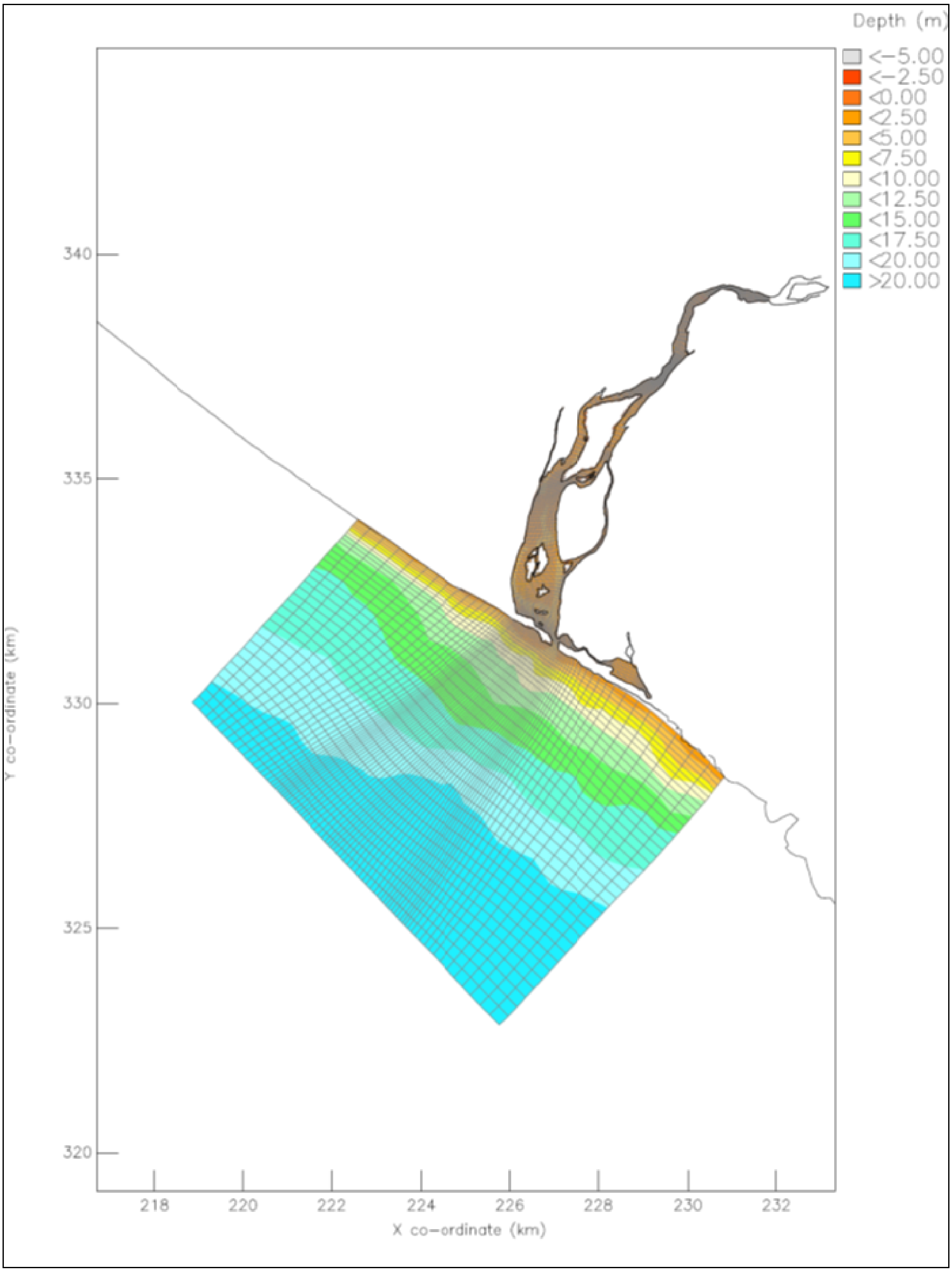

Figure A1. The computational grid and bathymetry used in the hydrodynamic model – full domain

A.3 Model bathymetry

A number of bathymetric sections were conducted at various locations along the estuary over a 2-day period in January 2013 (see Figure A2). These data were used to provide the bathymetry used in the hydrodynamic model (Figure A3 and A4). There were areas where the data were very sparse. In such cases the model bathymetries assumed were such that clear channels were maintained linking the obvious channels indicated in the measured bathymetry data.

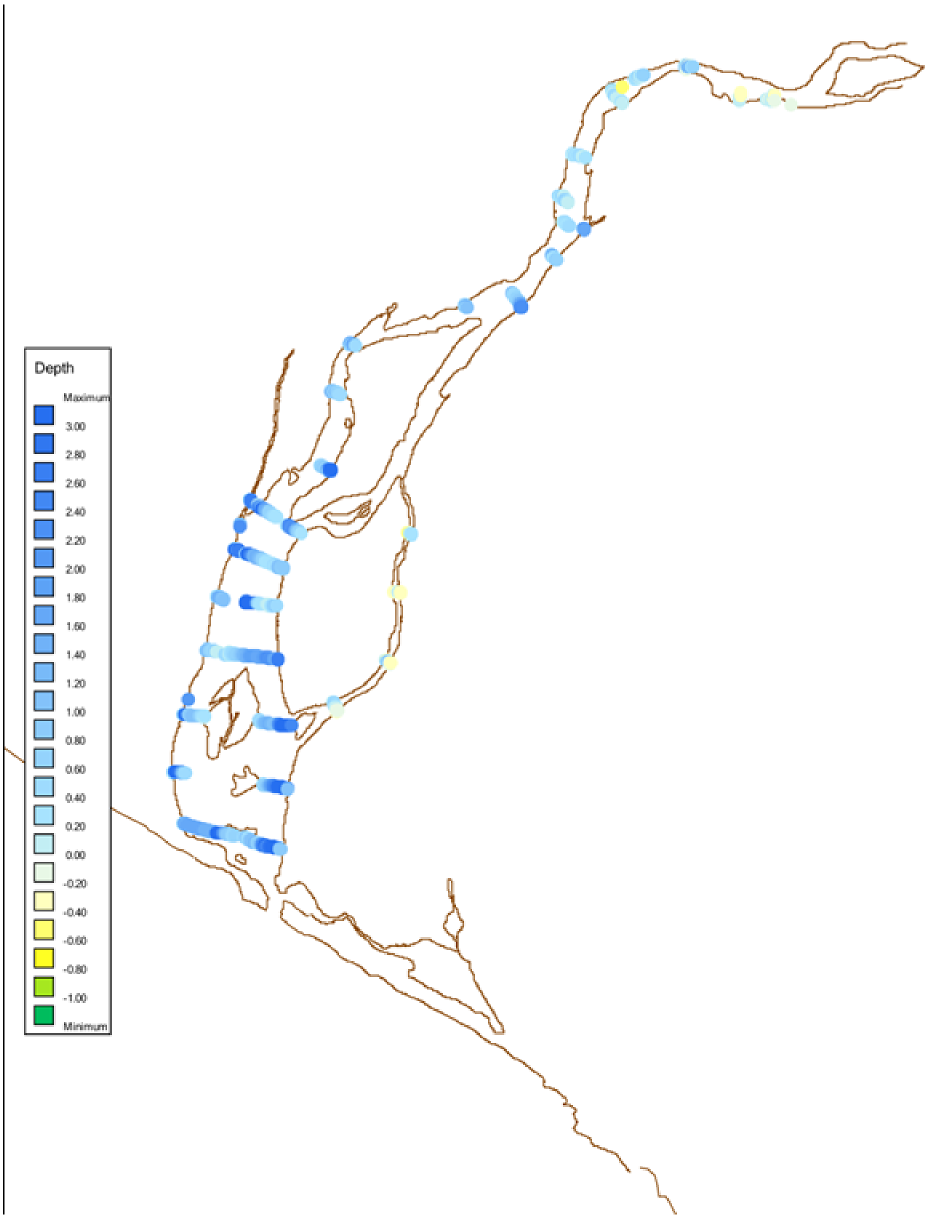

Figure A2. Schematic indicating the locations of the cross-sections where the bathymetry was measured during a two day survey period during February 2012

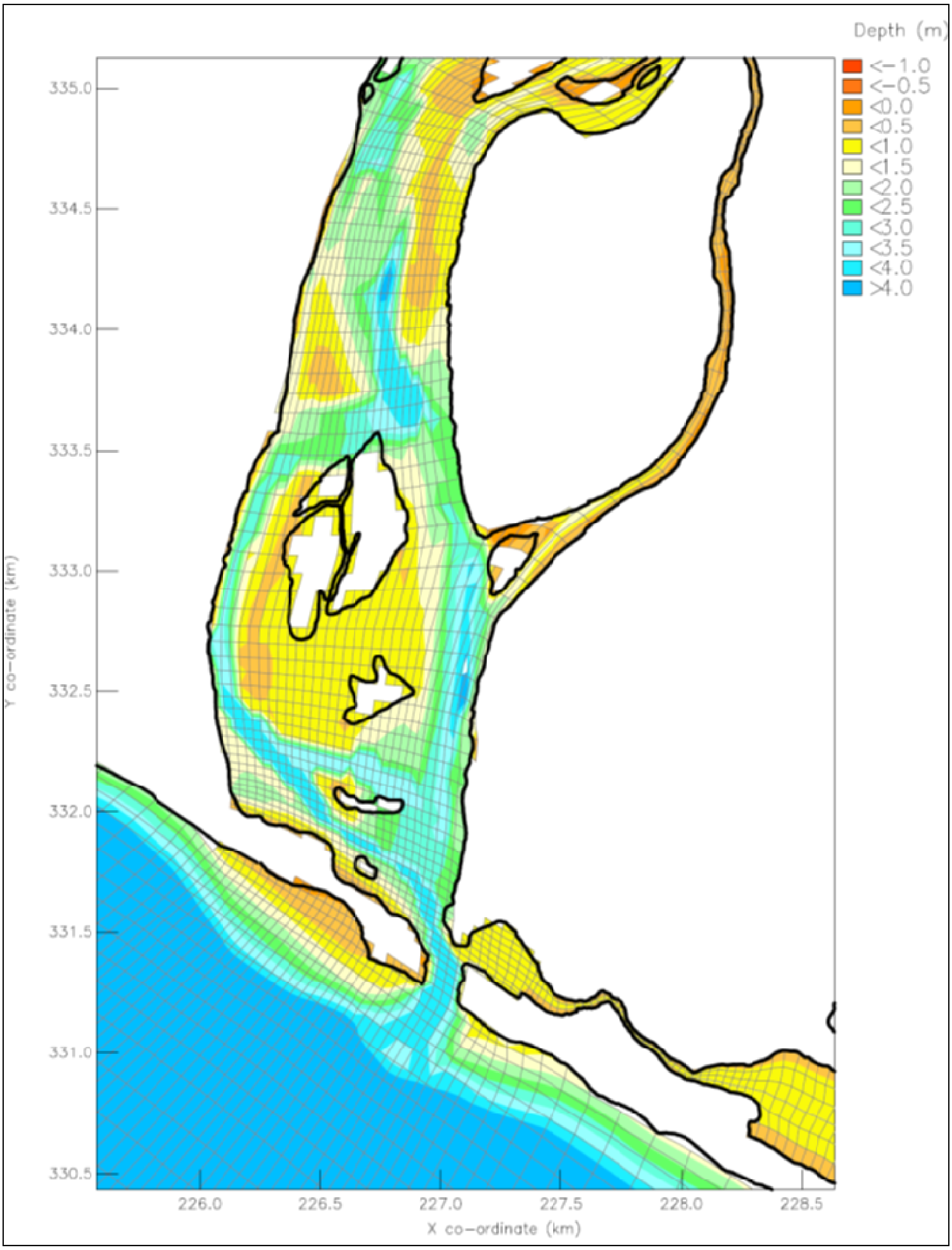

Figure A3. The computational grid and bathymetry used in the hydrodynamic model - Lower reaches of the estuary

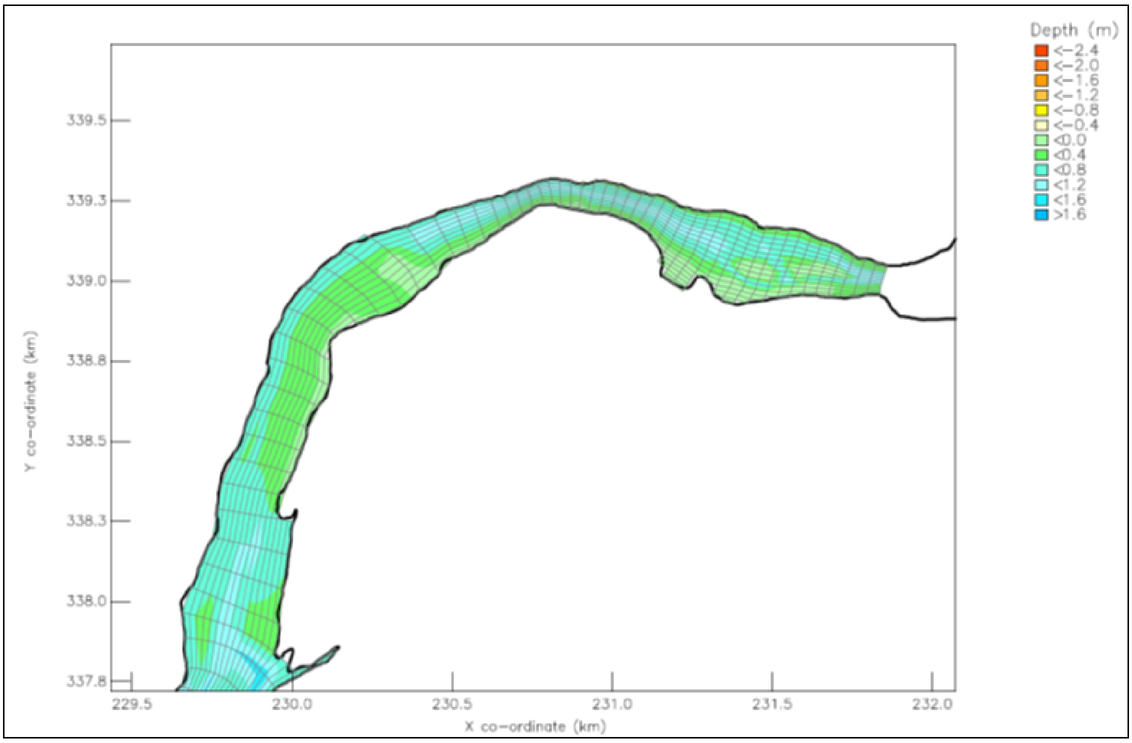

Figure A4. The computational grid and bathymetry used in the hydrodynamic model - Upper reaches of the estuary

A.4 Tidal forcing at the boundaries

The model was forced by tidal fluctuations applied at the oceanic boundaries. Rosenthal and Grant (1989), provides tidal constituent amplitudes and phase lags for nearby stations at Port Nolloth and Lüderitz. A linear averaging method based on the distance of each tidal station to the Orange Estuary mouth was applied to derive the amplitude and phase lag of the major tidal constituents. The tidal constituents applied to the open boundaries of the hydrodynamic model are given in Table A1 below.

Table A1. Tidal constituent amplitudes and phase lags applied to the hydrodynamic model

	Amplitude	***Phase***
M2	0.542396	91.05427
S2	0.229755	110.5931
N2	0.120407	78.07898
K2	0.065906	105.4056
K1	0.054561	119.8505
P1	0.013638	115.971
*m*2	0.021446	60.9006
O1	0.019406	250.4171

A.5 River inflow at the upstream boundary

The volume of water flowing into the estuary through the upstream river boundary river was simulated as a Total Discharge boundary comprising a series of model gridcell boundaries spanning the width of the river. The total discharge through the upper boundary was distributed across these single gridcell boundaries according to a depth-dependant relationship as recommended in the Deltares Flow manual (Deltares, 2011).

A.6 Model calibration and validation

The vertical salinity distributions observed in the model simulations were compared against measured salinity distributions for similar flow conditions reported in section 2.1.4. There is satisfactory agreement between the model simulations and these measured data.A typical comparison between the modelled and measured results are presented in Figures A5 (measured data) and A6 – A7 (model outputs) below. The salinity distributions for the flood tide on 7 February 2005 (approximately 2 days prior to full spring tide) are presented in Figure A5 below. The upstream flow conditions for the three weeks preceding these measurements ranged between 8 m^3/s and 58 m^3/s with and average flow of 28 m^3/s and a median flow of 22,7 m^3/s for this period. The flow on the day of the measurements was approximately 30 m^3/s. The simulated salinity distributions for peak high spring tide compare very well with these measured data. The simulated data indicate a slightly higher penetration of higher salinity waters upstream, however these discrepancies can be ascribed to the fact that the measured data were obtained during the flood tide and not necessarily at peak high tide.

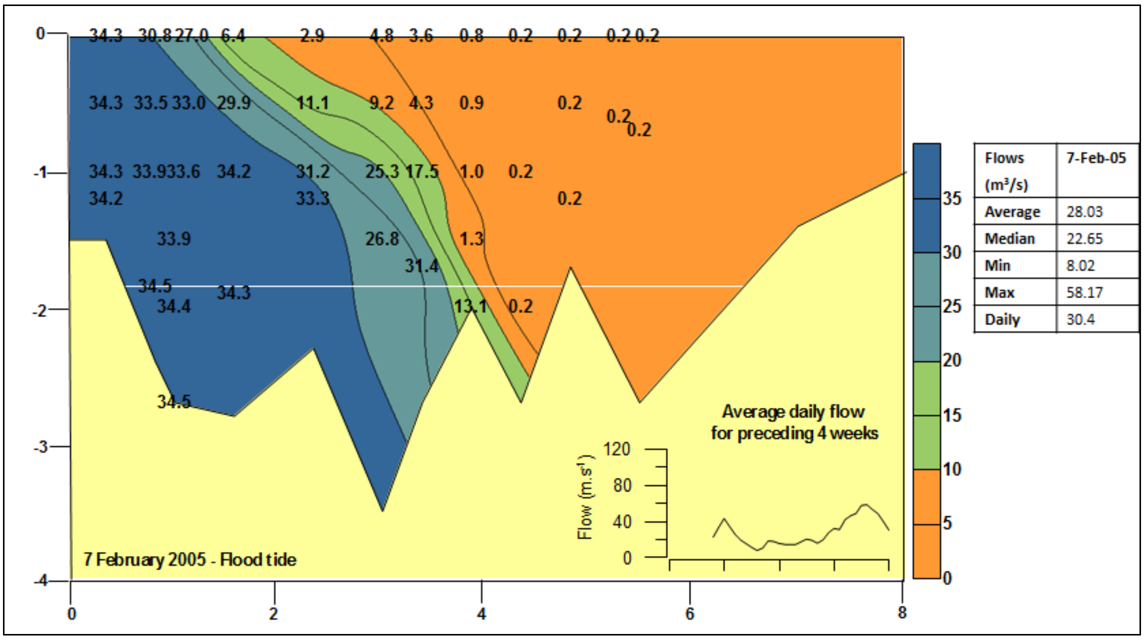

Figure A5. Salinity distribution in the Orange Estuary as measured during flood tide (under near spring tide conditions) on 7 February 2005

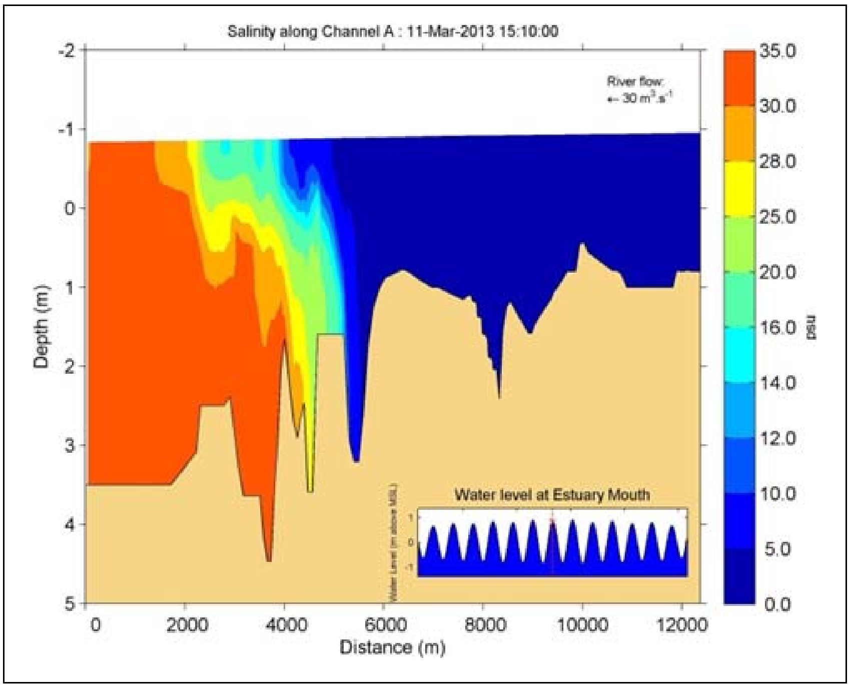

Figure A6. Salinity distribution at spring high tide along channel A for a river inflow rate of 30 m³/s

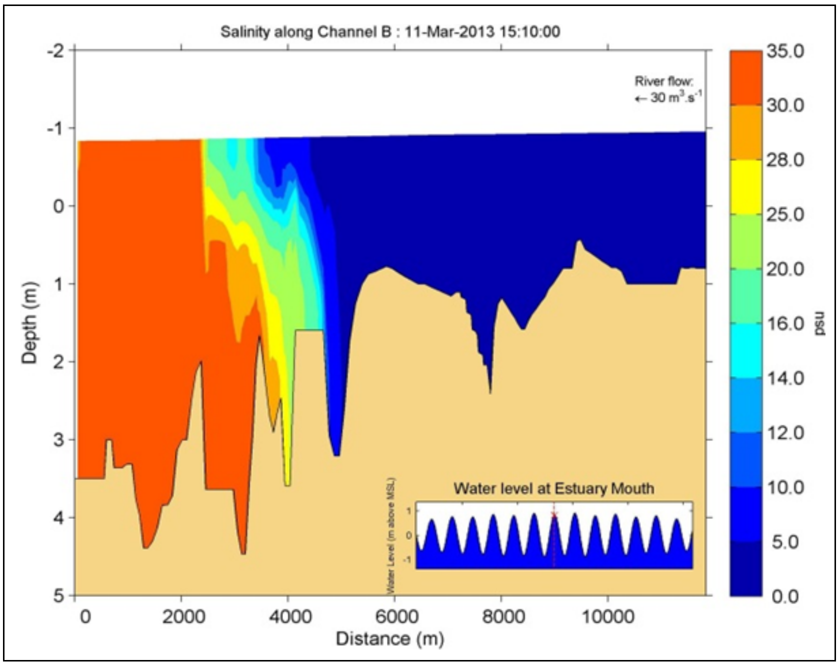

Figure A7. Salinity distribution at spring high tide along channel B (lower channel) for a river inflow rate of 30 m^3/s

A.7 Scenarios modelled

The scenarios simulated, comprising a discharge rate and duration of the discharge, are summarised in Table A2 below.

Table A2. Details of the river discharges for the different scenarios

Run ID	***Total river discharge (m^3/s)***	***Duration (weeks)***
04	0.5	16
03	1.0	12
05	2.0	12
06	3.0	8
07	5.0	4
08	10.0	3
09	20.0	3
10	30.0	3
11	50.0	3

A.8 Model results

The model results are reported as along-channel salinity distributions. Due to the presence of islets within the estuary, two possible channels were identified. The salinity distribution has been plotted as a function of distance from the mouth, along each of the channels (see Figure A8). These along-channel salinity distributions have been plotted for spring high and low tides and neap high and low tides (see Figures A9 to A44).

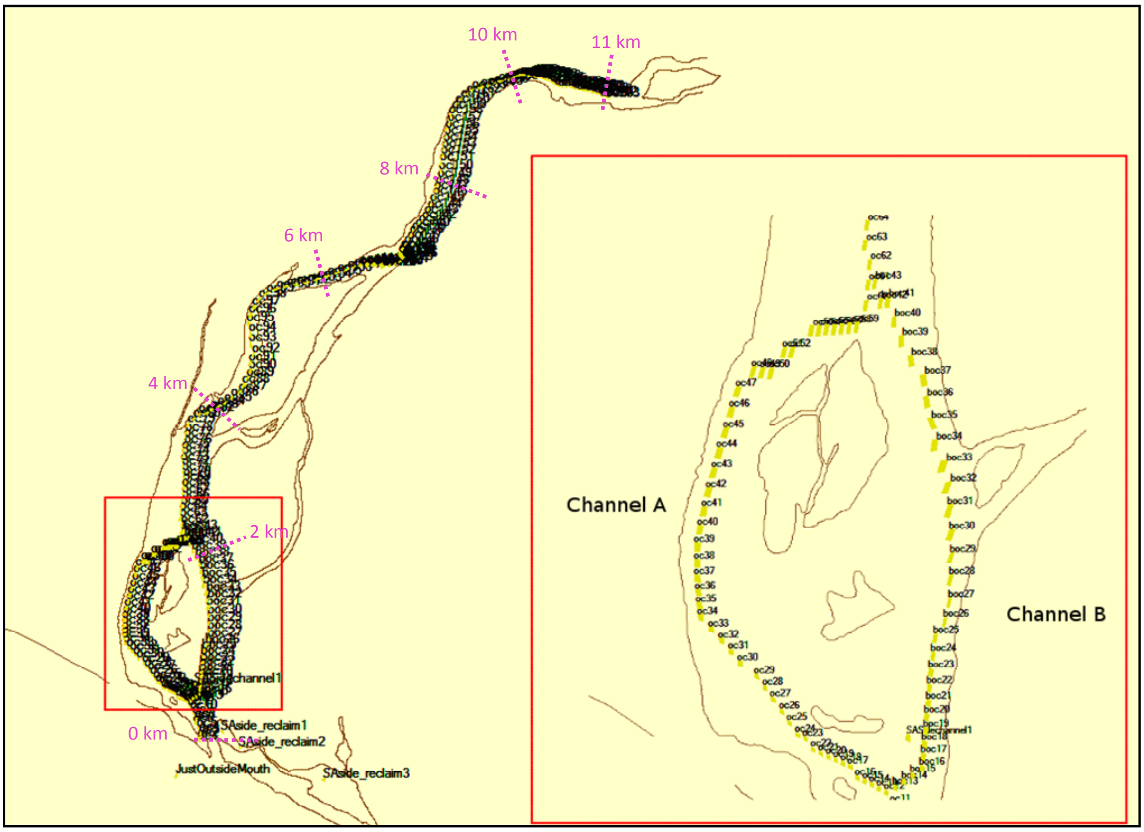

Figure A8. Diagram illustrating the paths along which the salinity distributions are reported. The inset shows the difference between channel A, on the left and Channel B, on the right of one of the islets in the estuary.

While the results primarily are presented as salinity distributions as a function of distance upstream of the mouth for peak high and low tides for both spring and neap tide conditions, animations have also been produced and are included in the electronic information data base.

The model results can be summarised as follows:

- The model results suggest a tidal excursion in the middle reaches of the estuary of 1,35 km during neap tides and approximately 3 km during spring tides.
- For steady flows of 50 m^3/s the surface waters in the estuary remain fresh except for during spring flood tides. However, higher salinity bottom waters extend approximately 2 km upstream of the mouth under neap flood tide and up to 4 km under spring flood tides.

- The salinity distributions for steady flows of 30 m^3/s are similar to those for steady flows of 50 m^3/s. Under these conditions higher salinity bottom waters now extend approximately 3,5 km upstream of the mouth under neap flood tide and up to 5 km under spring flood tides.
- For flows of 20 and 10 m^3/s the lower 4 km of the estuary typically are highly stratified, however the higher salinity waters do not seem to extend upstream of 6 km from the mouth under these conditions.
- At flow of 5 m^3/s and 3 m^3/s the higher salinity waters penetrated upstream of 6 km from the mouth. Under flows of 3 m^3/s the higher salinity waters penetrate upstream of 8 km from the mouth during spring high tides.
- The salinity distribution for flows of 2 m^3/s are similar to those for flows of 3 m^3/s, however flow flows of 1 m^3/s the higher salinity water penetrate approximately 9 km upstream and beyond, particularly under spring tides. Under neap tides the higher salinity waters typically do not extend beyond 8 km upstream.
- For very low flow conditions 0,5 m^3/s higher salinity waters are observed at 10 km upstream and beyond during spring tides. During neap tides the higher salinity waters extend only approximately 9 km upstream.

A.8.1 Spring tides: Flow rate of 0.5 m3/s

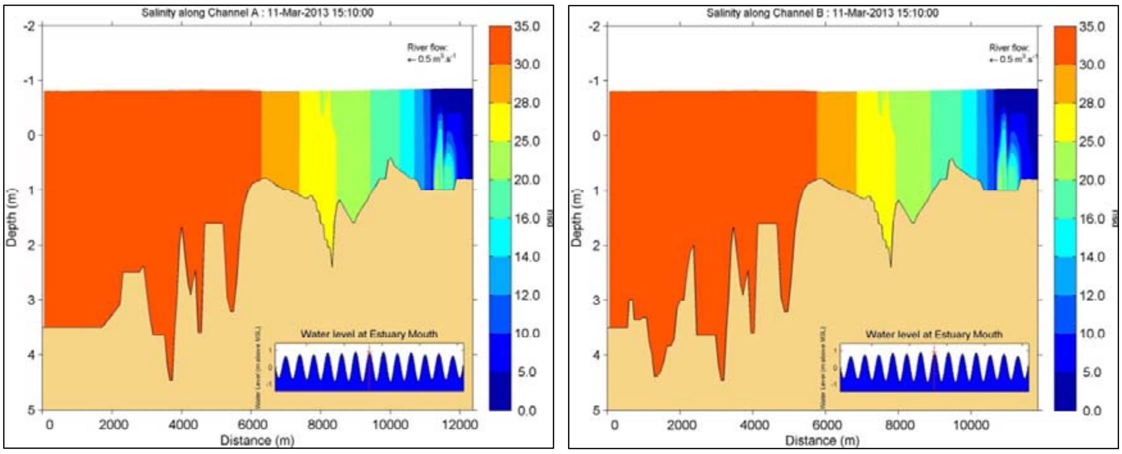

Figure A9. Salinity distribution at spring high tide along Channel A (left) and Channel B (right) for a flow rate of 0.5 m³/s

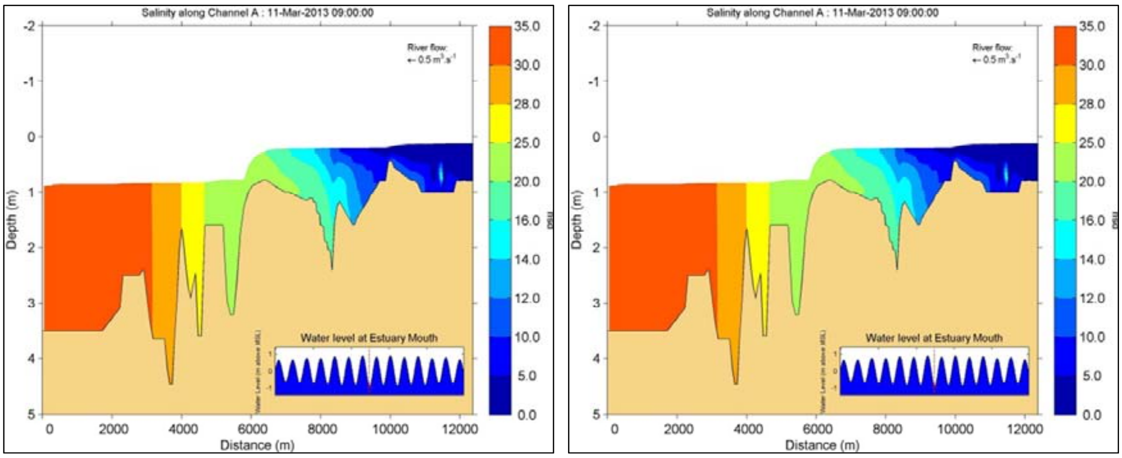

Figure A10. Salinity distribution at spring low tide along channel A (left) and channel B (right) for a flow rate of 0.5 m³/s

A.8.2 Neap tides: Flow rate of 0.5 m^3/s

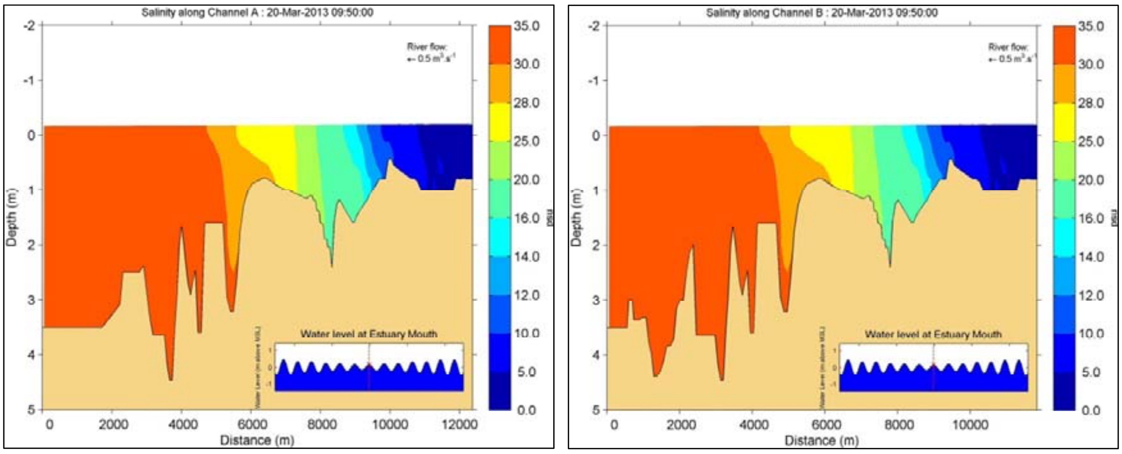

Figure A11. Salinity distribution at neap high tide along channel A (left) and channel B (right) for a flow rate of 0.5 m^3/s

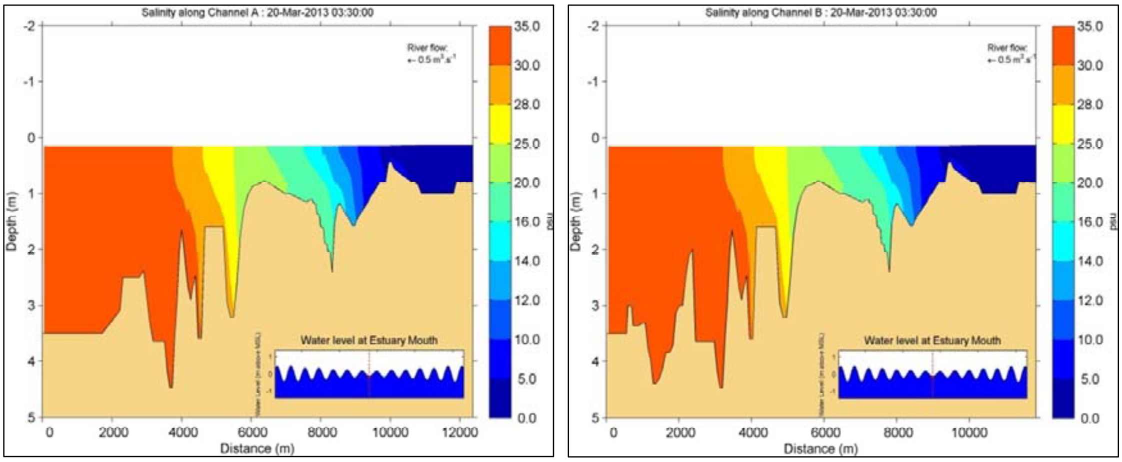

Figure A12. Salinity distribution at neap low tide along channel A (left) and channel B (right) for a flow rate of 0.5 m^3/s

A.8.3 Spring tides: Flow rate of 1.0 m^3/s

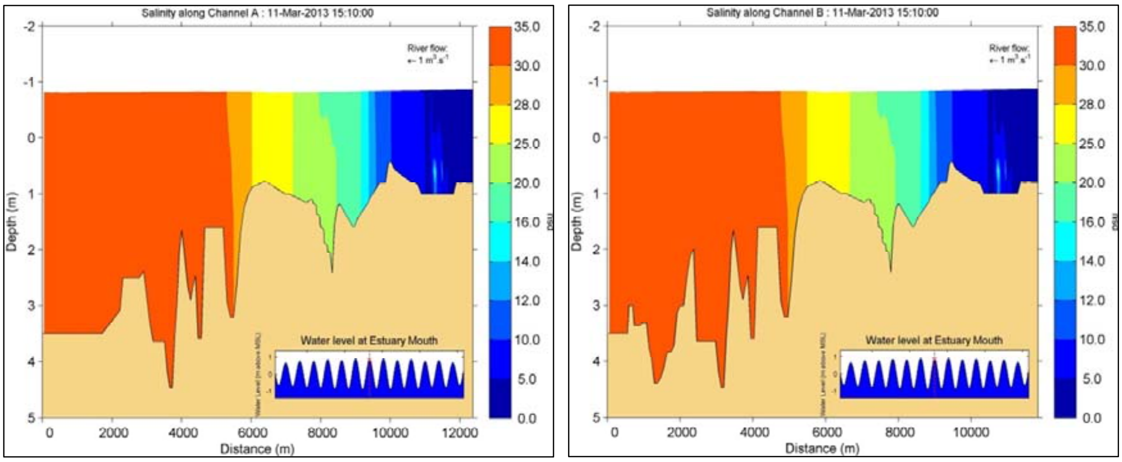

Figure A13. Salinity distribution at spring high tide along channel A (left) and channel B (right) for a flow rate of 1 m^3/s

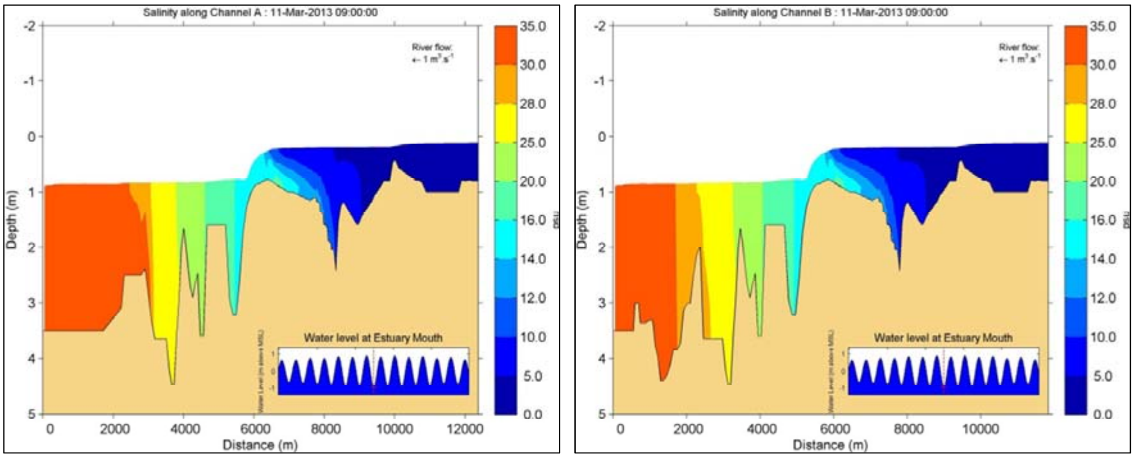

Figure A14. Salinity distribution at spring low tide along channel A (left) and channel B (right) for a flow rate of 1 m^3/s

8.1.1 *Neap tides: Flow rate of 1.0 m^3/s*

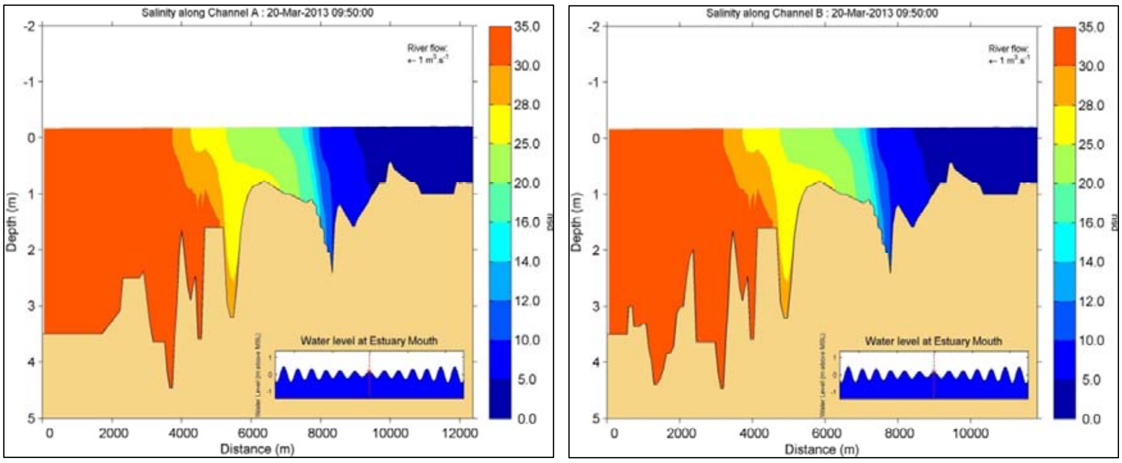

Figure A15. Salinity distribution at neap high tide along channel A (left) and channel B (right) for a flow rate of 1 m^3/s

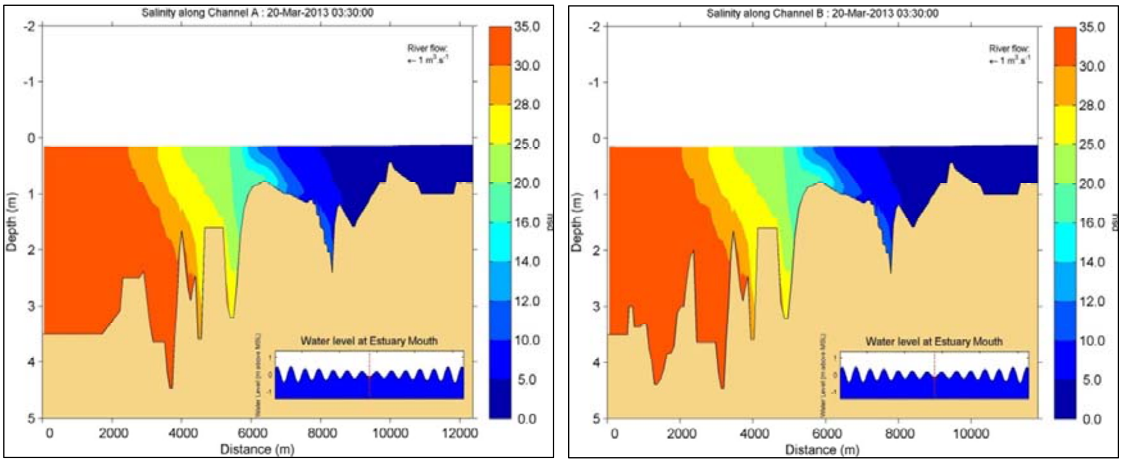

Figure A16. Salinity distribution at neap low tide along channel A (left) and channel B (right) for a flow rate of 1 m^3/s

A.8.4 Spring tides: Flow rate of 2.0 m^3/s

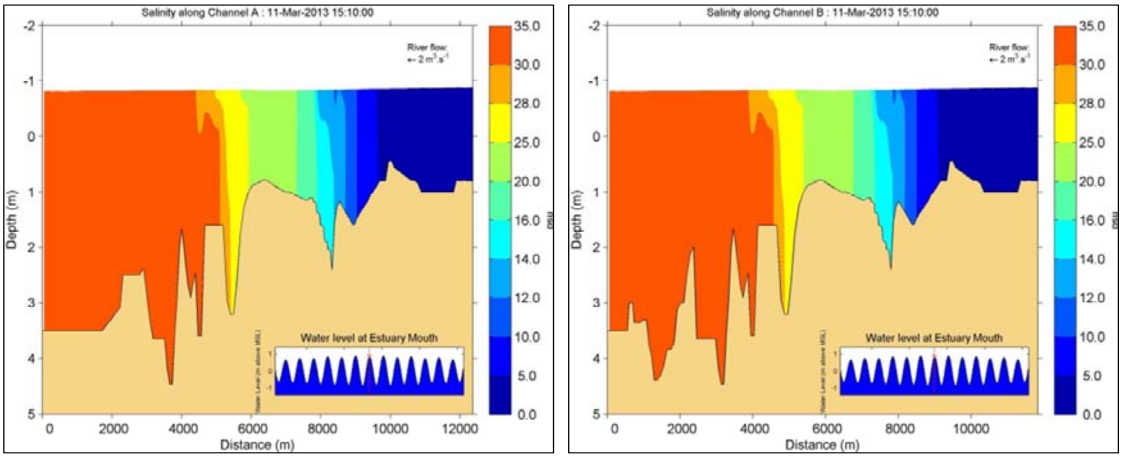

Figure A17. Salinity distribution at spring high tide along channel A (left) and channel B (right) for a flow rate of 2 m^3/s

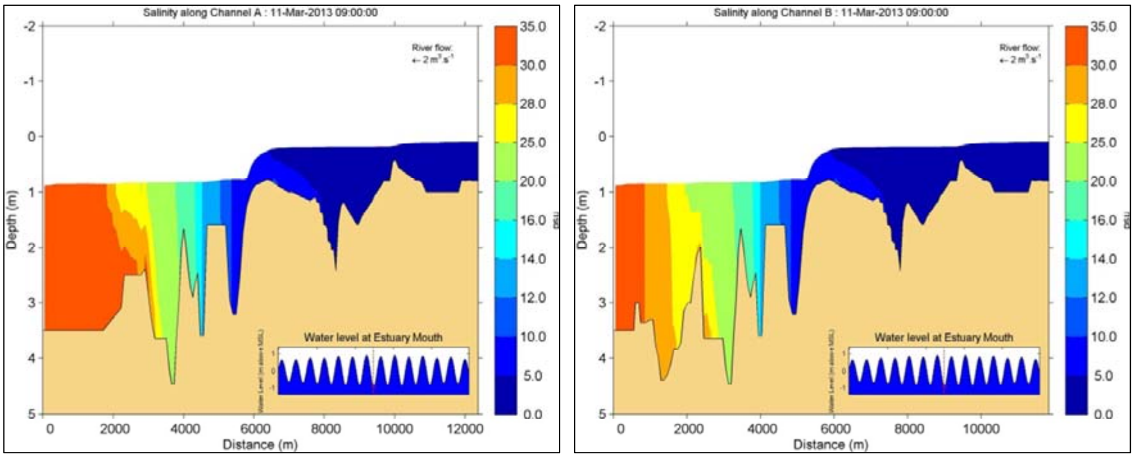

Figure A18. Salinity distribution at spring low tide along channel A (left) and channel B (right) for a flow rate of 2 m^3/s

A.8.5 Neap tides: Flow rate of 2.0 m^3/s

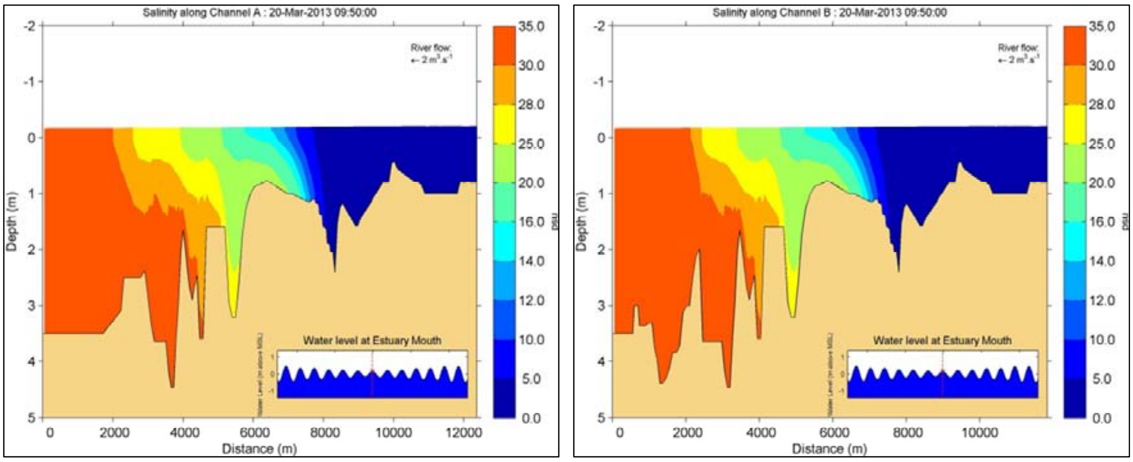

Figure A19. Salinity distribution at neap high tide along channel A (left) and channel B (right) for a flow rate of 2 m^3/s

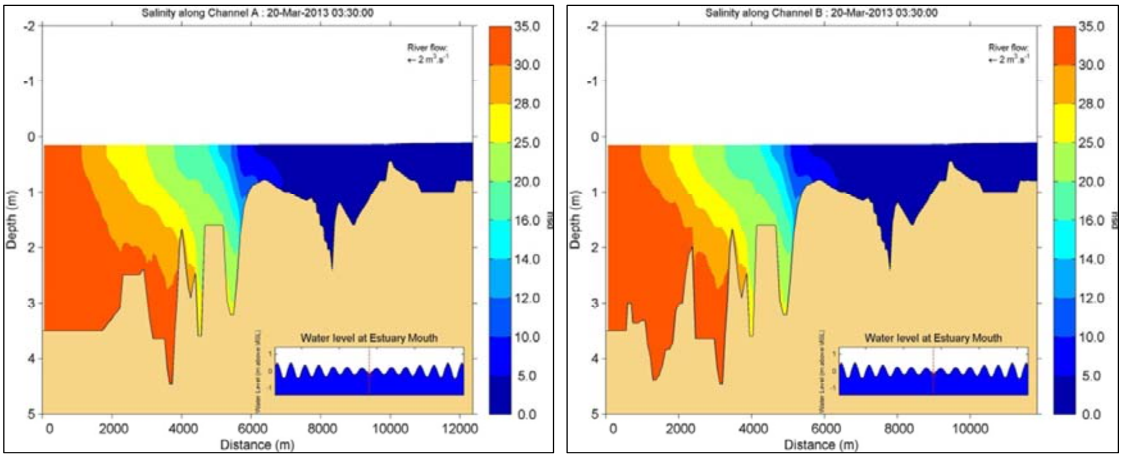

Figure A20. Salinity distribution at neap low tide along channel A (left) and channel B (right) for a flow rate of 2 m^3/s

A.8.6 Spring tides: Flow rate of 3.0 m³/s

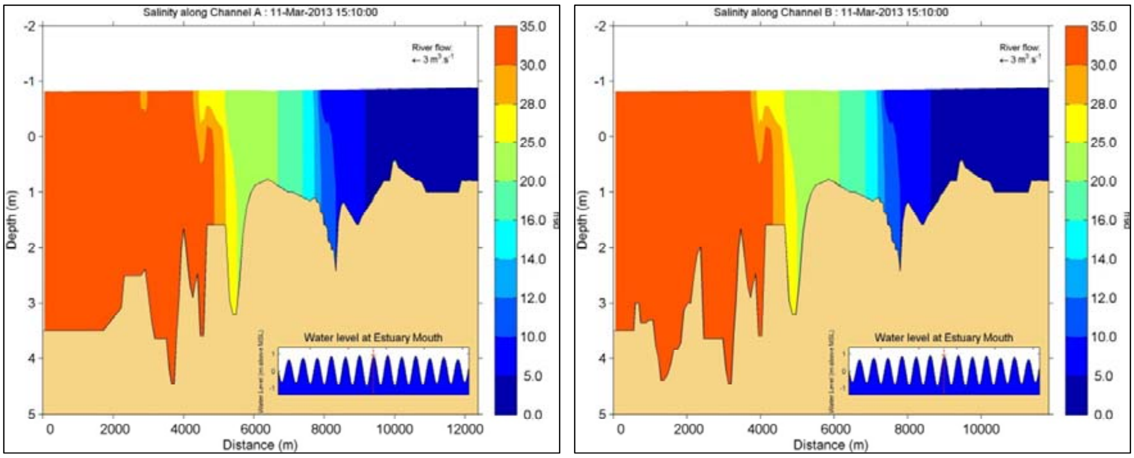

Figure A21. Salinity distribution at spring high tide along channel A (left) and channel B (right) for a flow rate of 3 m³/s

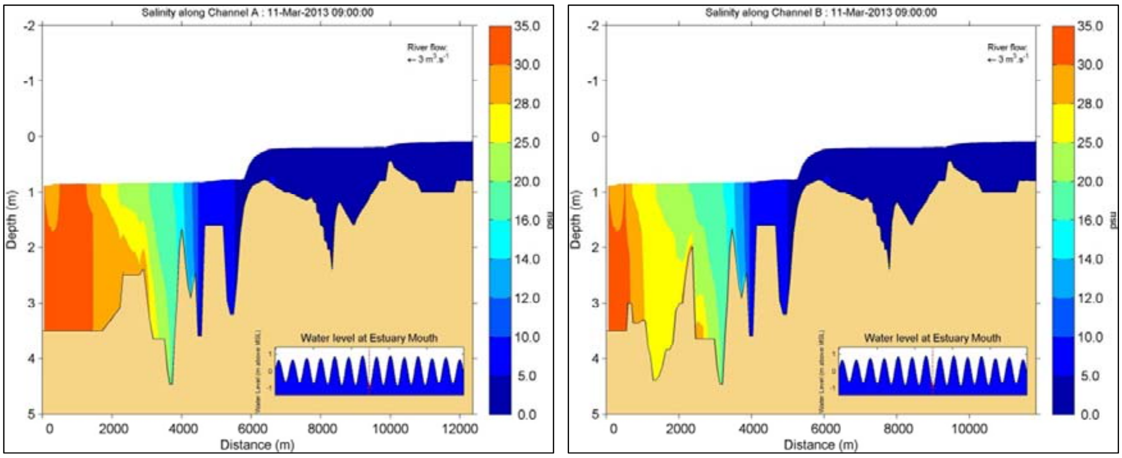

Figure A22. Salinity distribution at spring low tide along channel A (left) and channel B (right) for a flow rate of 3 m³/s

A.8.7 Neap tides: Flow rate of 3.0 m^3/s

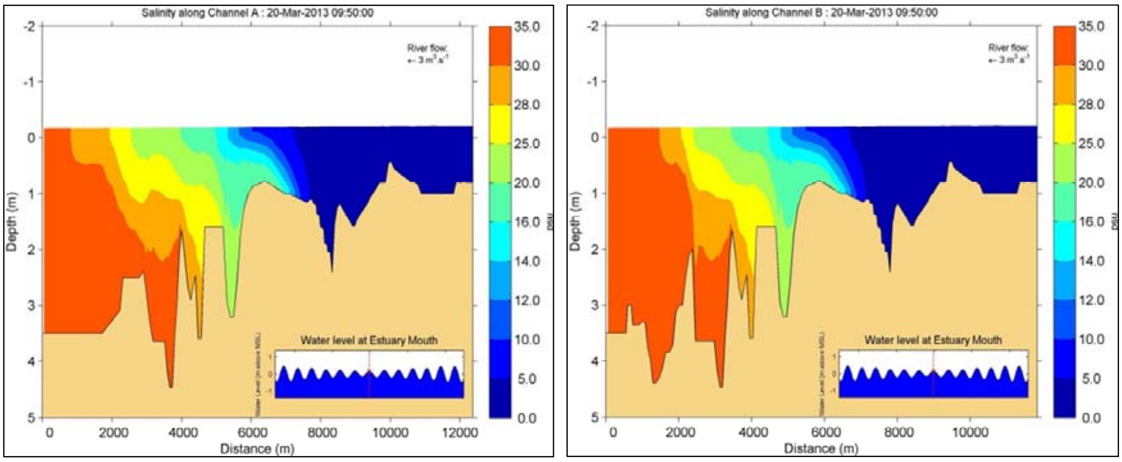

Figure A23. Salinity distribution at neap high tide along channel A (left) and channel B (right) for a flow rate of 3 m^3/s

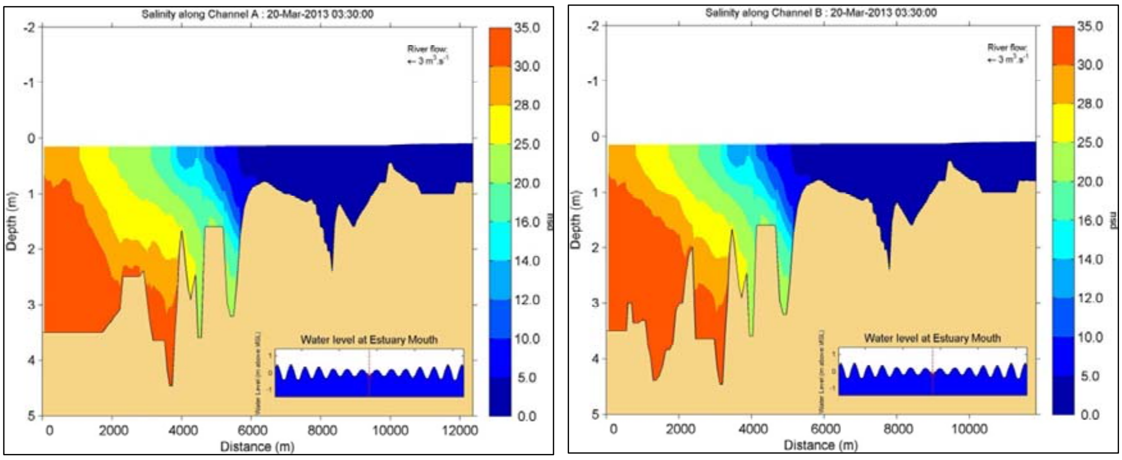

Figure A24. Salinity distribution at neap low tide along channel A (left) and channel B (right) for a flow rate of 3 m^3/s

A.8.8 Spring tides: Flow rate of 5.0 m³/s

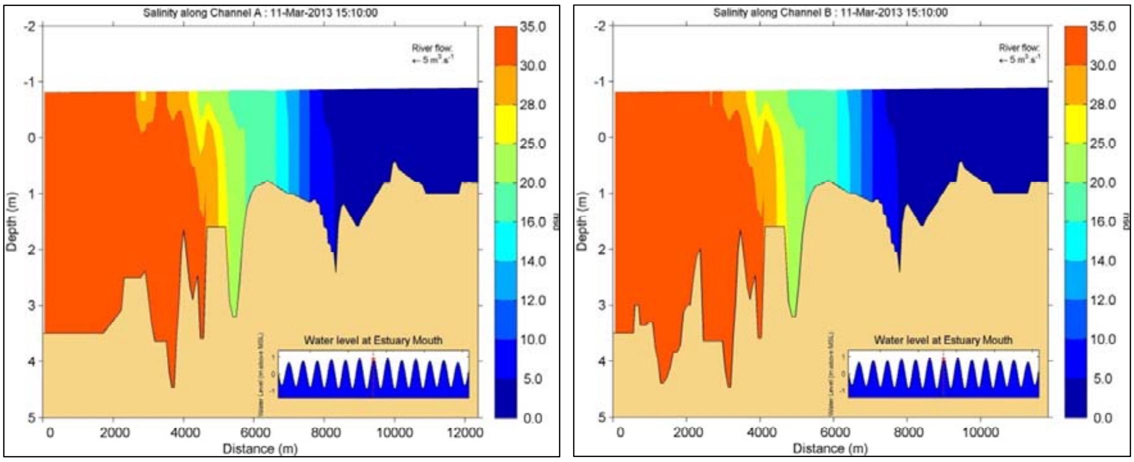

Figure A25. Salinity distribution at spring high tide along channel A (left) and channel B (right) for a flow rate of 5 m^3/s

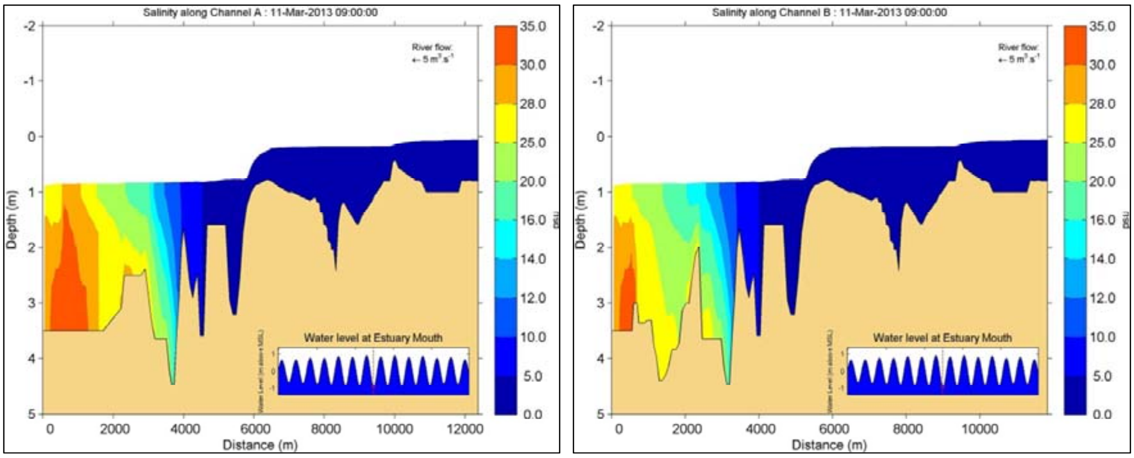

Figure A26. Salinity distribution at spring low tide along channel A (left) and channel B (right) for a flow rate of 5 m^3/s

A.8.9 Neap tides: Flow rate of 5.0 m^3/s

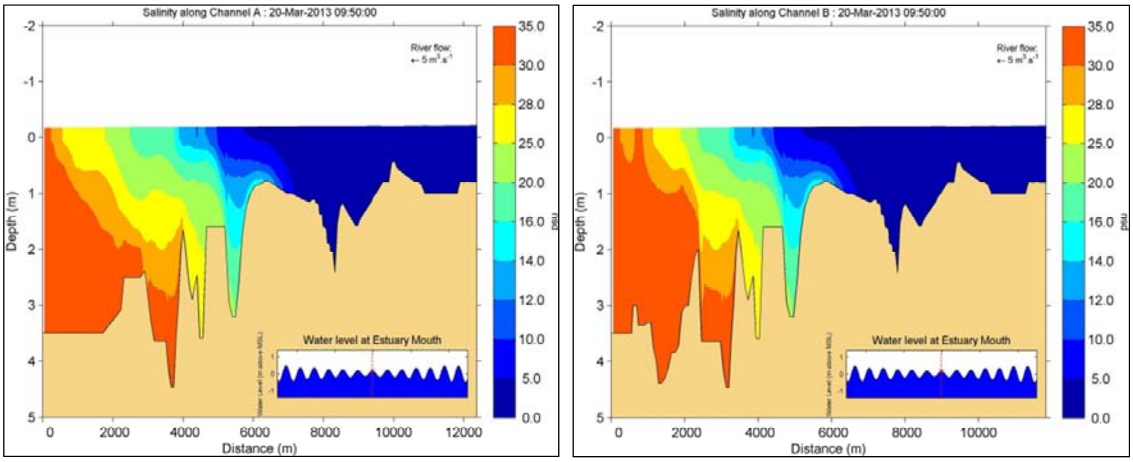

Figure A27. Salinity distribution at neap high tide along channel A (left) and channel B (right) for a flow rate of 5 m^3/s

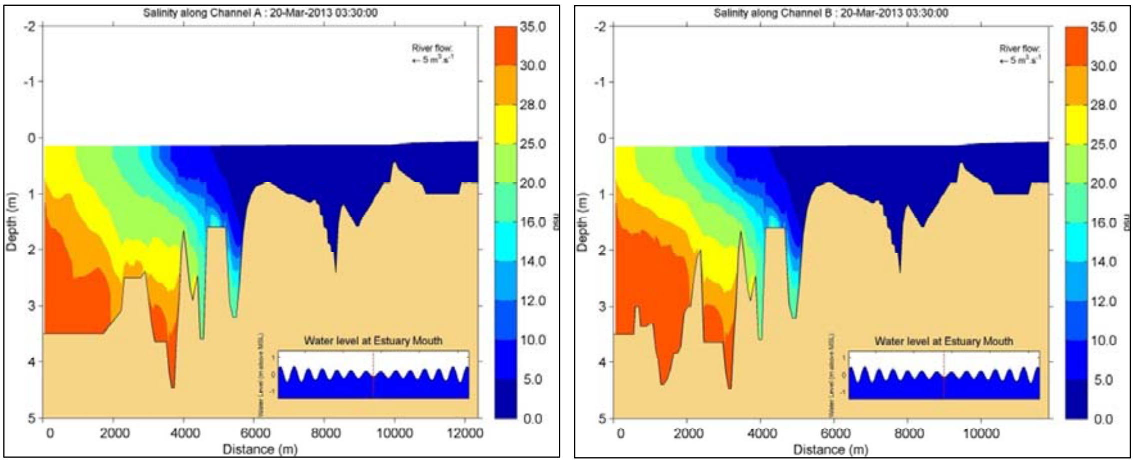

Figure A28. Salinity distribution at neap low tide along channel A (left) and channel B (right) for a flow rate of 5 m^3/s

A.8.10 Spring tides: Flow rate of 10.0 m^3/s

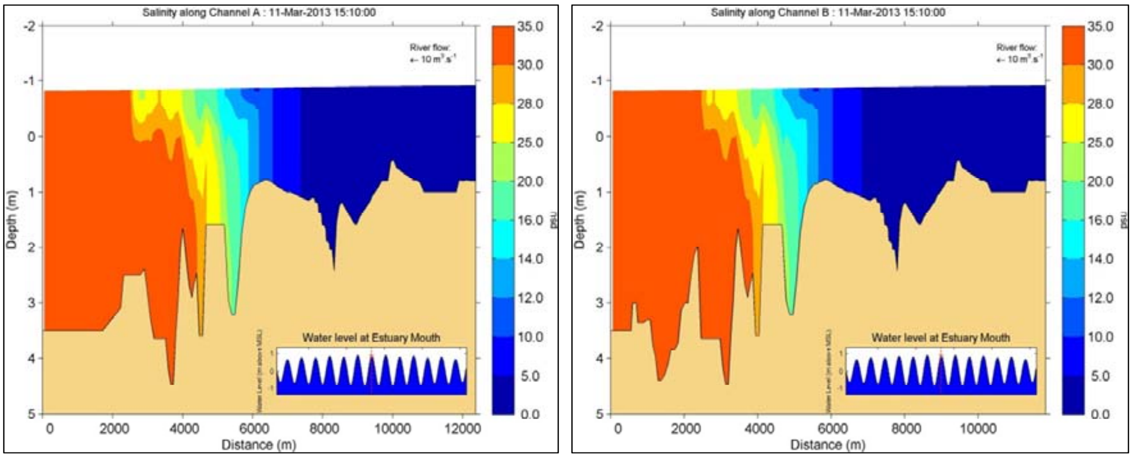

Figure A29. Salinity distribution at spring high tide along channel A (left) and channel B (right) for a flow rate of 10 m^3/s

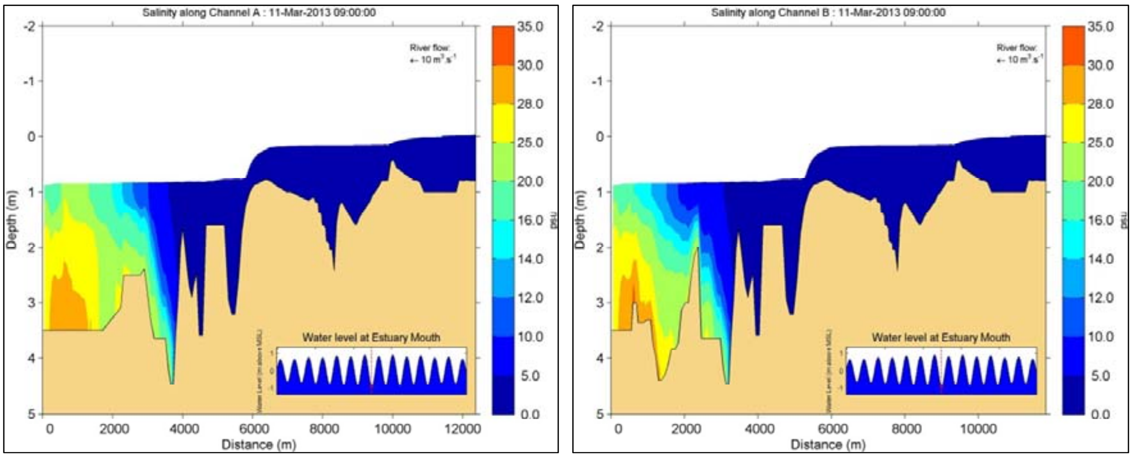

Figure A30. Salinity distribution at spring low tide along channel A (left) and channel B (right) for a flow rate of 10 m^3/s

A.8.11 Neap tides: Flow rate of 10.0 m^3/s

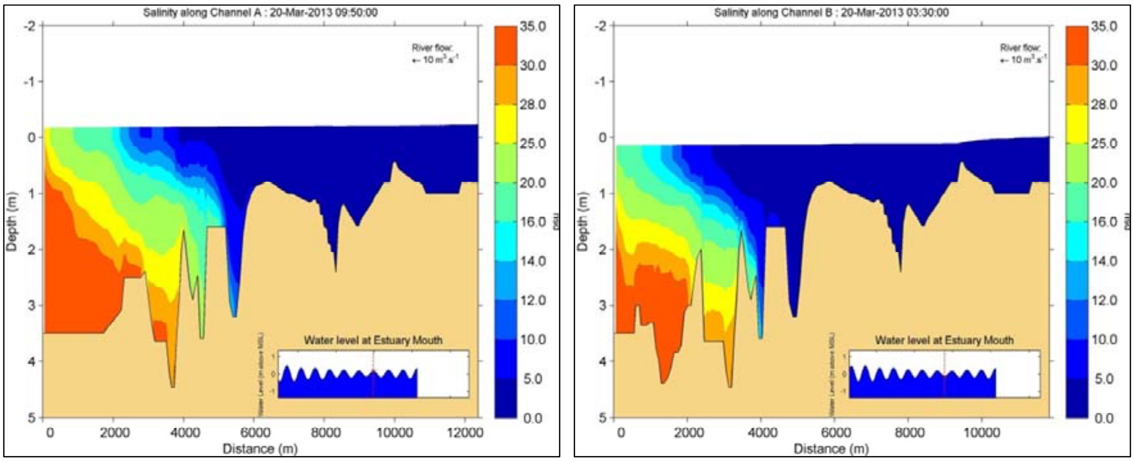

Figure A31. Salinity distribution at neap high tide along channel A (left) and channel B (right) for a flow rate of 10 m^3/s

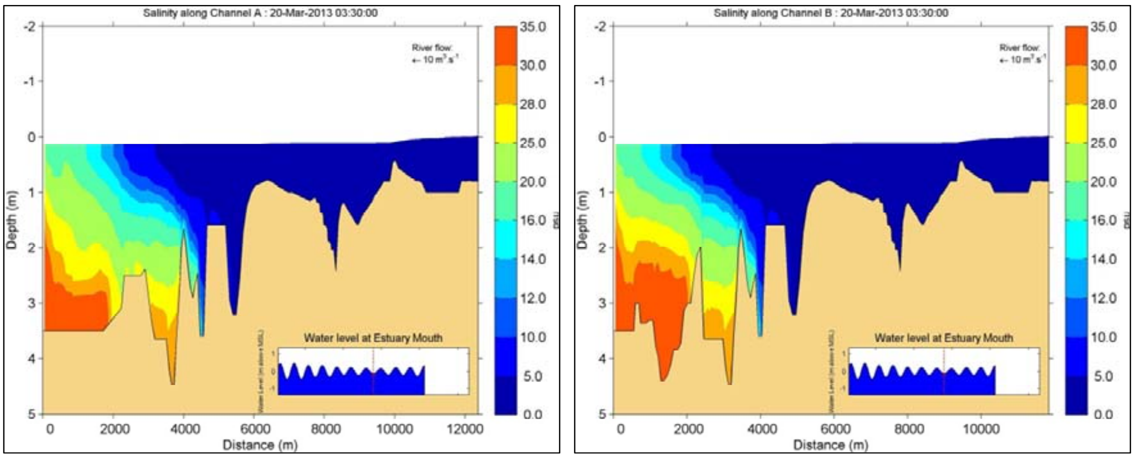

Figure A32. Salinity distribution at neap low tide along channel A (left) and channel B (right) for a flow rate of 10 m^3/s

A.8.12 Spring tides: Flow rate of 20.0 m³/s

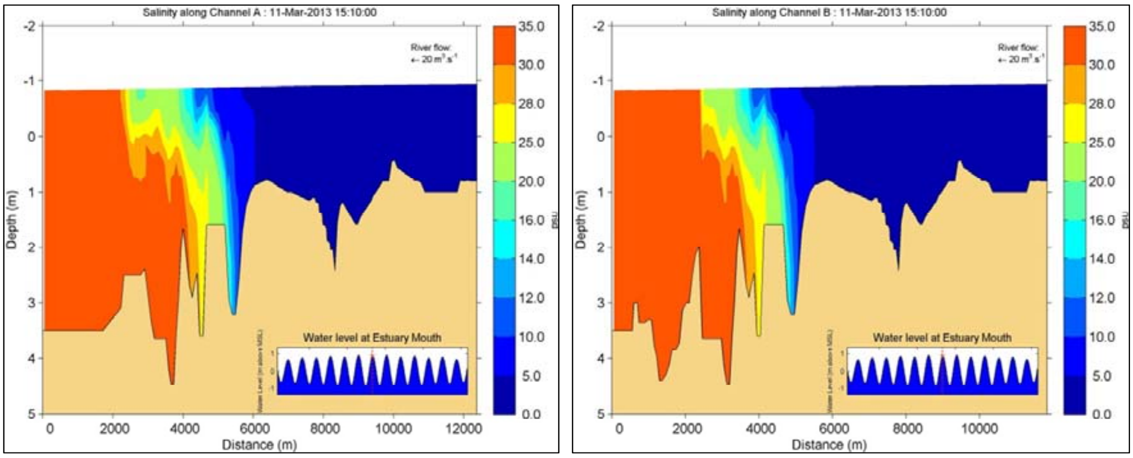

Figure A33. Salinity distribution at spring high tide along channel A (left) and channel B (right) for a flow rate of 20 m³/s

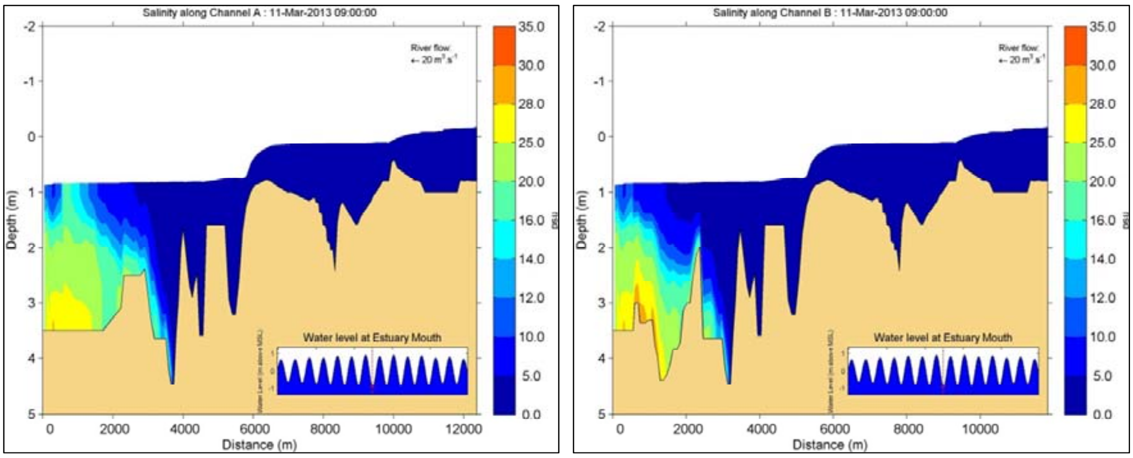

Figure A34. Salinity distribution at spring low tide along channel A (left) and channel B (right) A for a flow rate of 20 m³/s

A.8.13 Neap tides: Flow rate of 20.0 m³/s

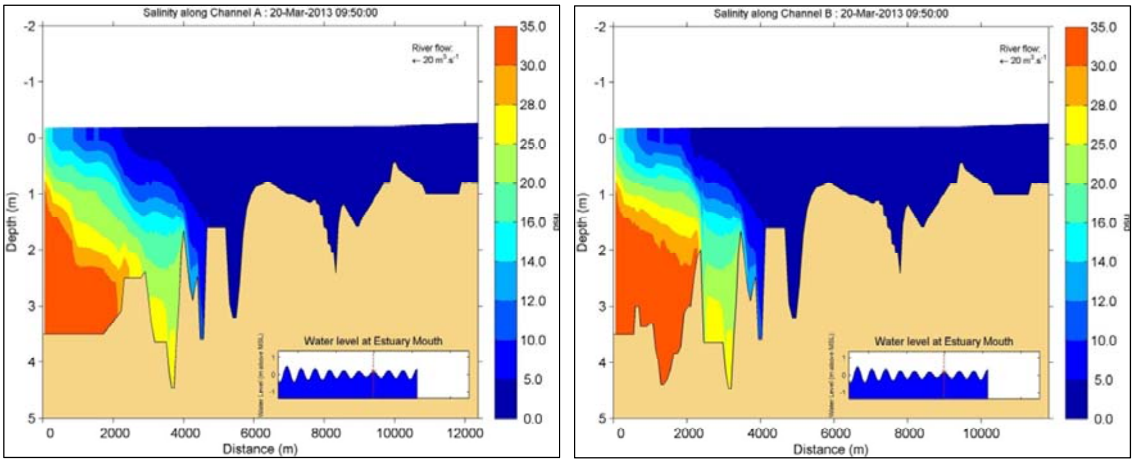

Figure A35. Salinity distribution at neap high tide along channel A (left) and channel B (right) for a flow rate of 20 m³/s

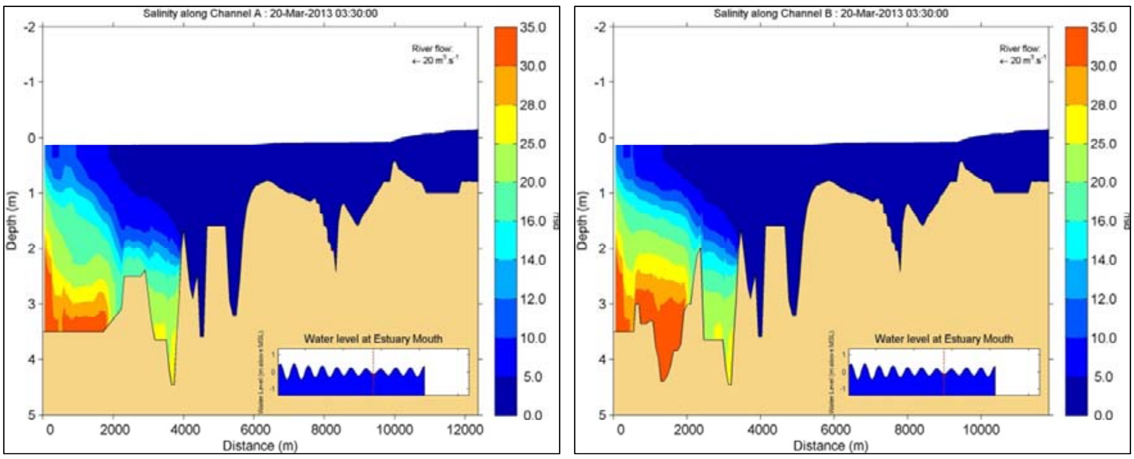

Figure A36. Salinity distribution at neap low tide along channel A (left) and channel B (right) for a flow rate of 20 m³/s

A.8.14 Spring tides: Flow rate of 30.0 m^3/s

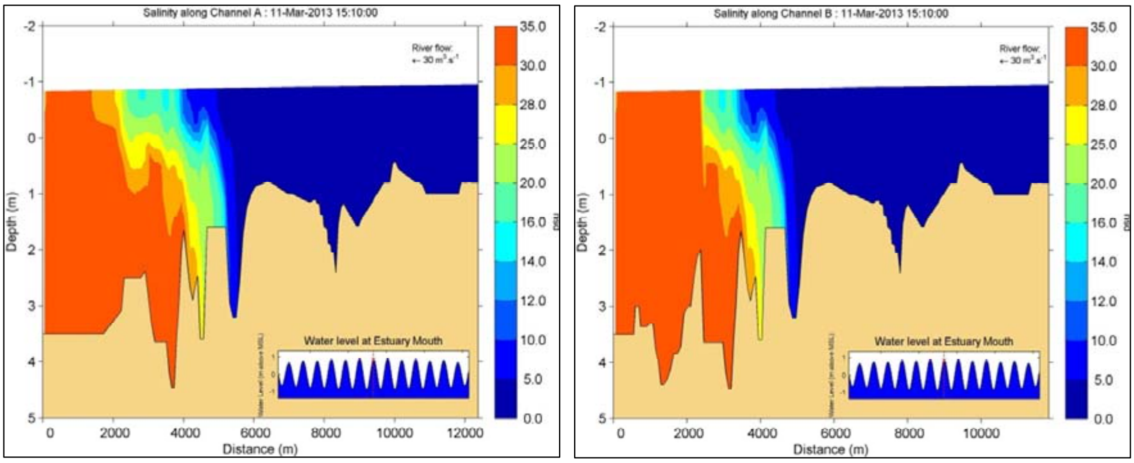

Figure A37. Salinity distribution at spring high tide along channel A (left) and channel B (right) for a flow rate of 30 m^3/s

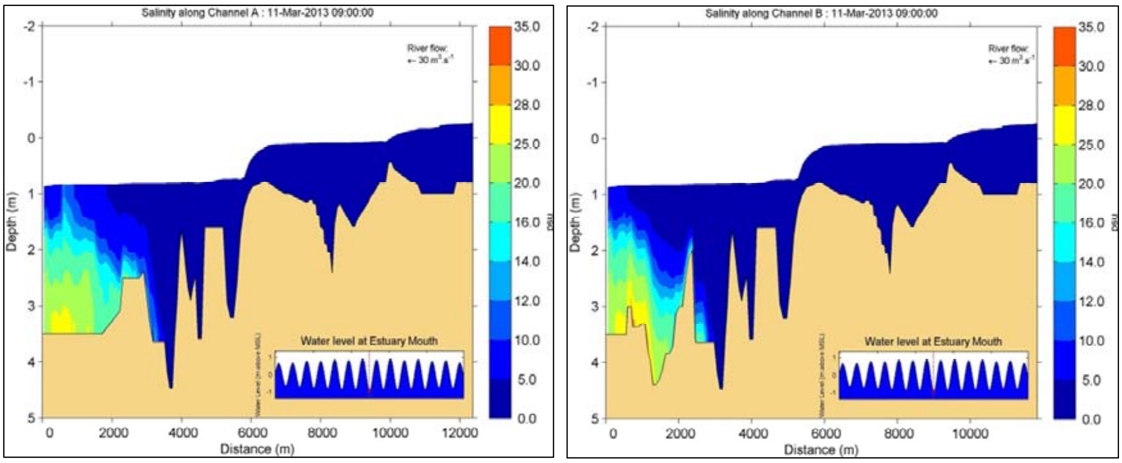

Figure A38. Salinity distribution at spring low tide along channel A (left) and channel B (right) for a flow rate of 30 m^3/s

A.8.15 Neap tides: Flow rate of 30.0 m^3/s

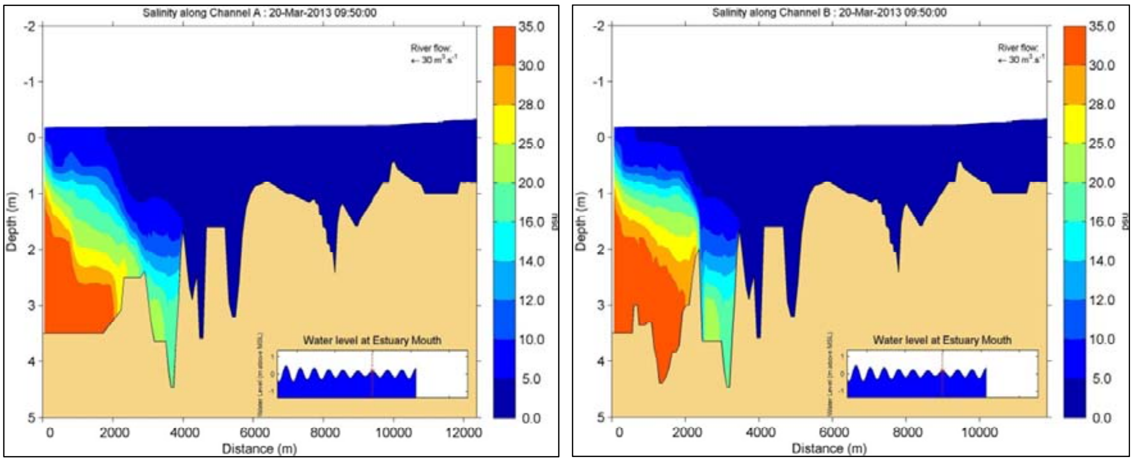

Figure A39. Salinity distribution at neap high tide along channel A (left) and channel B (right) for a flow rate of 30 m^3/s

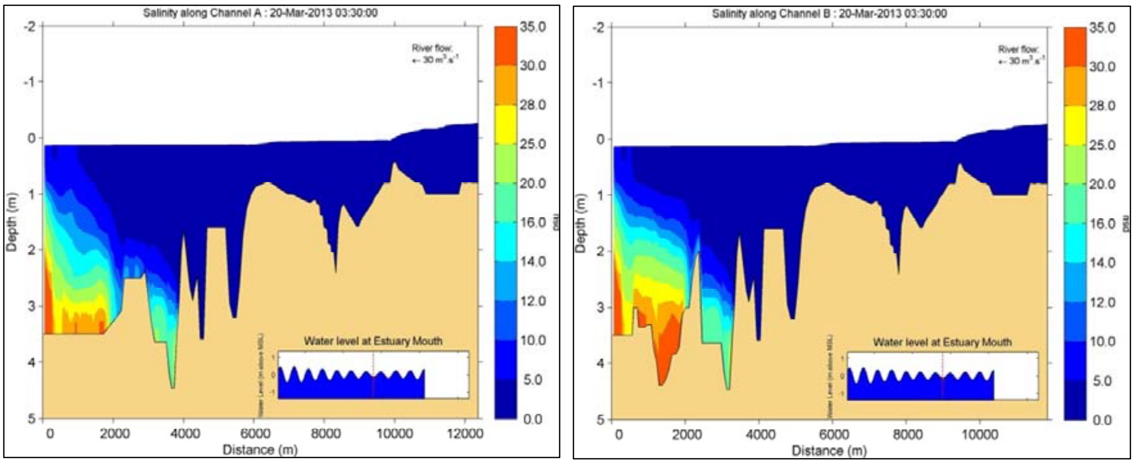

Figure A40. Salinity distribution at neap low tide along channel A (left) and channel B (right) for a flow rate of 30 m^3/s

A.8.16 Spring tides Flow rate of 50.0 m^3/s

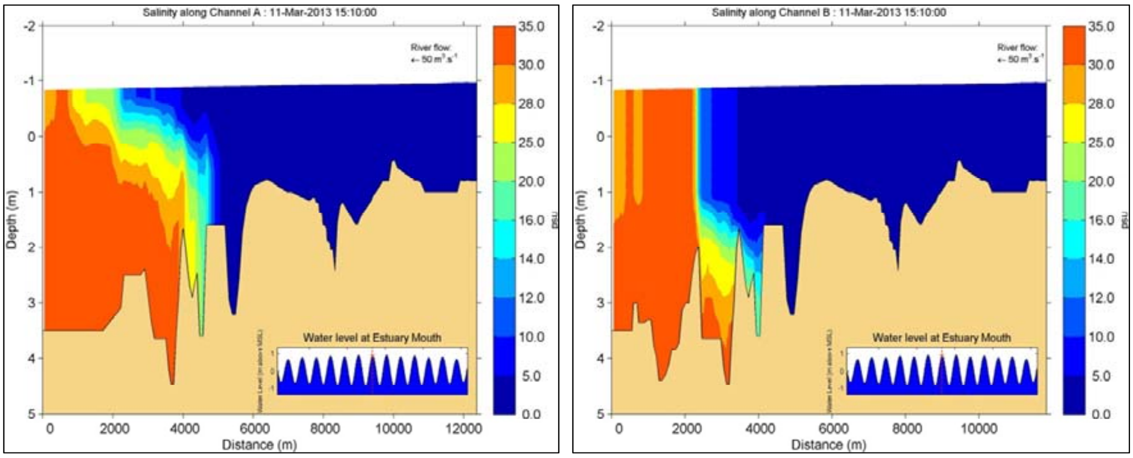

Figure A41. Salinity distribution at spring high tide along channel A (left) and channel B (right) for a flow rate of 50 m^3/s

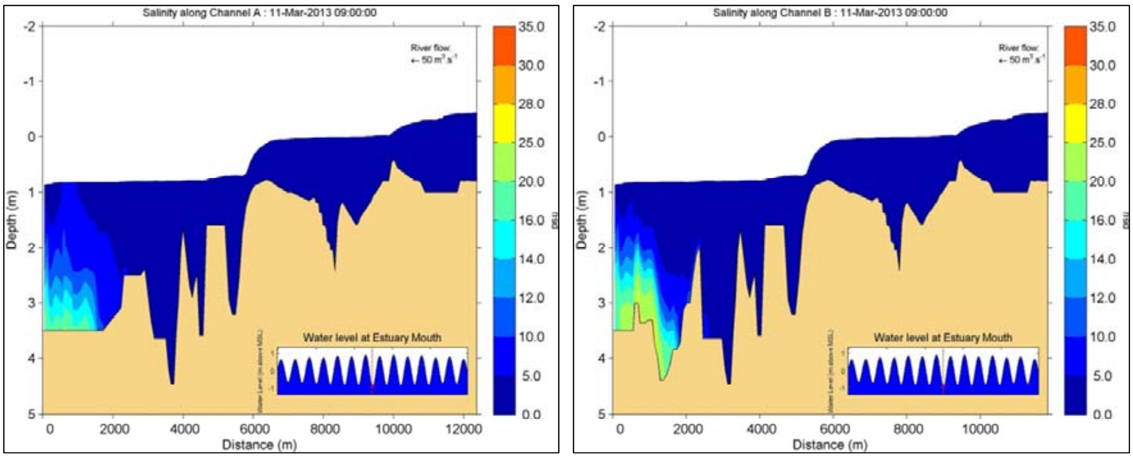

Figure A42. Salinity distribution at spring low tide along channel A (left) and channel B (right) for a flow rate of 50 m^3/s

A.8.17 Neap tides: Flow rate of 50.0 m³/s

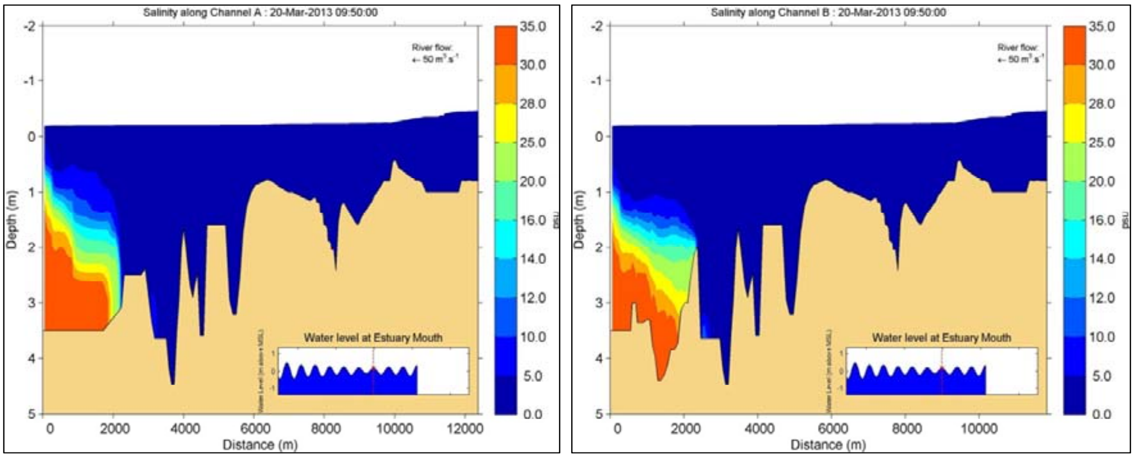

Figure A43. Salinity distribution at neap high tide along channel A (left) and channel B (right) for a flow rate of 50 m³/s

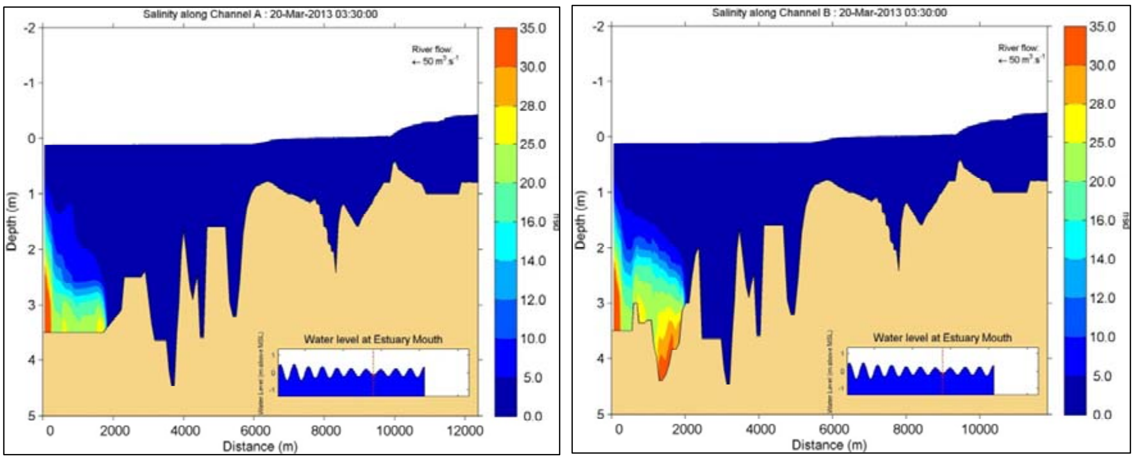

Figure A44. Salinity distribution at neap low tide along channel A (left) and channel B (right) for a flow rate of 50 m³/s

A.9 Conclusions and recommendations

The hydrodynamic model set up for this project is able to simulate adequately the expected salinity distributions in the Orange Estuary for a wide range of river inflow scenarios. In so doing the model has provided information on the along-channel salinity distributions for a much wider range of river inflows conditions than possible from measurements alone. Important insights have been gained into the expected salinity distributions for the extremes (both high and low) of expected river inflows.