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)

Scoping a Ridge to Reef Approach:

Interaction between the Orange-Senqu River Basin and the Benguela Current Large Marine Ecosystem

Technical Report 1
Rev 1, 23 September 2010

UNDP-GEF
Orange-Senqu Strategic Action Programme

Scoping a Ridge to Reef Approach

Interaction between the Orange-Senqu River Basin and the Benguela Current Large Marine Ecosystem Scoping Report

This report has been prepared by:

Dr Barry Clark

Anchor Environmental Consultants
Suite 8, Steenberg House, Silverwood Close, Tokai 7945, South Africa
Tel: +27 (21) 701 3420; Fax: +27 (21) 701 5280
barry@anchorenvironmental.co.za; http://www.anchorenvironmental.co.za

This report has been issued and amended as follows:

Revision	Description	Date	Signed
0	Draft for discussion at workshop on 16 Aug 2010	6 Aug 2010	CB
1	Updated draft for discussion with TTT	23 Sep 2010	CB, mor

Project executed by:

UNOPS

Contents

List of Tables

List of Figures

Glossary

Acronyms and abbreviations

BCLME	Benguela Current Large Marine Ecosystem
BC	Benguela Current
BCC	Benguela Current Commission
BSC	Commission on the Protection of the Black Sea Against Pollution, Black Sea Commission
CFCs	Chlorofluorocarbons
CSIR	Council for Science and industrial Research, South Africa
DWAF	Department of Water Affairs and Forestry, South Africa, now DWA
EC	European Communities
GEF	Global Environment Facility
ICPDR	International Commission for the Protection of the Danube River
IPCC	Intergovernmental Panel on Climate Change
LME	Large Marine Ecosystem
MAR	Mean annual runoff
N	Nitrogen
ORASECOM	Orange-Senqu River Commission
P	Phosphorus
POP	Persistent Organic Pollutants
REC	Recommended Ecological Category
SADC	Southern African Development Community
SEA	Strategic Environmental Assessment
TDA	Trans-boundary Diagnostic Analysis
TEQs	Toxic Equivalent Factors
UNDP	United Nations Development Programme
WRCS	Water resource classification system

1. Introduction

The Orange-Senqu River is the third largest river basin in southern Africa. It is located within in the territories of Botswana, Lesotho, Namibia and South Africa. The Orange-Senqu drains in to the Atlantic Ocean at the border between South Africa and Namibia, where it forms a large estuarine delta. This estuarine delta (or estuary) represents a unique ecosystem on what is otherwise a wave exposed, hyper-arid coast with few freshwater inputs. The Orange-Senqu River estuary is recognised as an internationally important wetland for migratory birds and was accorded Ramsar Status in 1991 (Cowan 1995). However, in September 1995, Orange-Senqu River Mouth was placed on the Montreux Record following the collapse of the salt marsh component of the estuary. The rapid degradation of the salt marsh was the result of a combination of impacts, both at and upstream of the wetland. Efforts are currently underway to resolve the management arrangements for the site, in order to institute a comprehensive rehabilitation and management programme.

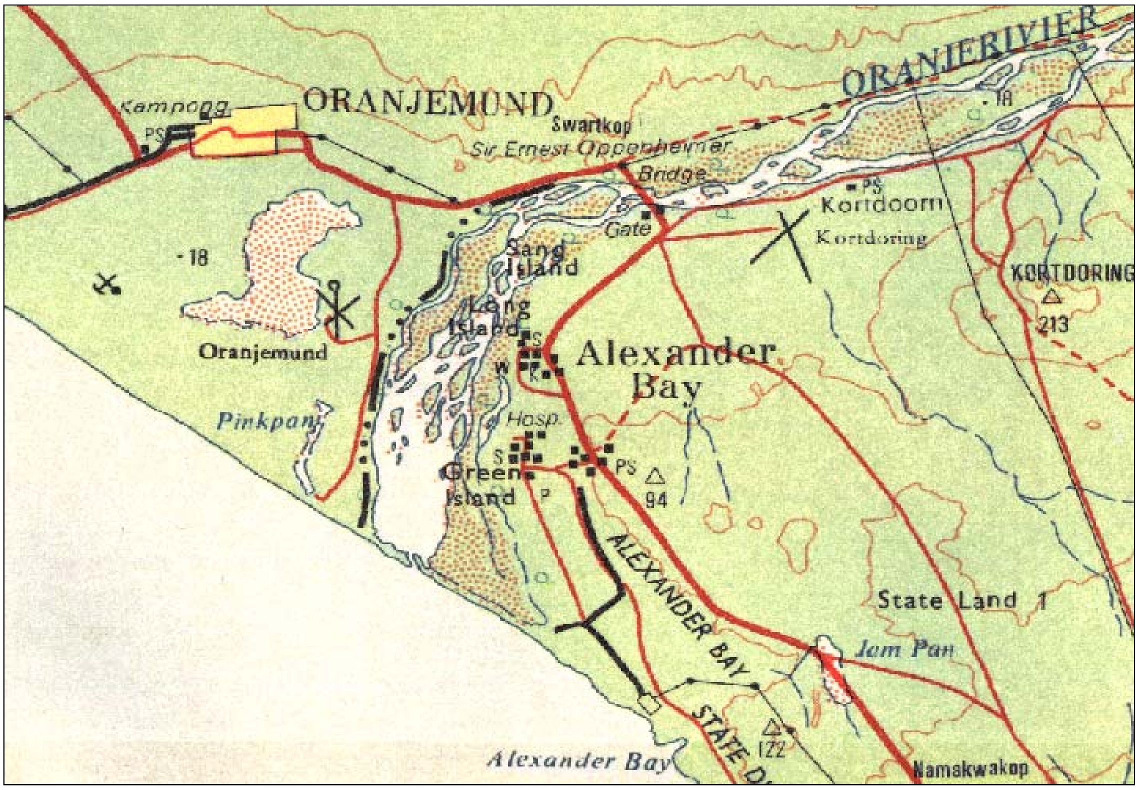

Figure 1. Orange-Senqu River Mouth

It is the only large estuarine nursery area in the region, supporting significant populations of estuarine and marine invertebrate and fish species (Taljaard *et al.* 2003). It is ranked among the ten most important system in South African in terms of conservation importance (Turpie *et al.* 2002).

Freshwater, sediment, organic matter and nutrients discharged through the estuary mouth also make a potentially important contribution to the Benguela Current Large Marine Ecosystem (BCLME) that surrounds the mouth of the estuary.

A recent study commissioned by the Department of Water Affairs in South Africa and Department of Water Affairs in Namibia (Taljaard *et al.* 2003) concluded that the Present State of the estuary was in a condition described as largely modified (D+) and was on a negative trajectory of change. The current freshwater inflow is less than 50% of the natural inflow, while the occurrence of significant floods and even elevated flows is very much reduced.

Localised anthropogenic impacts such as the construction of causeways, dykes, slimes dams near the mouth, have further degraded the estuary. Little research has focused on changes in the flow regime of the Orange-Senqu River and its impacts on the degradation of the estuary and the broader Benguela Current System.

This scoping report summarises the major interactions between the Orange-Senqu River and the Benguela Current LME based on a review of relevant scientific literature and data, and includes inputs received in a workshop with key stakeholders held in Windhoek on 16 August 2010.

This approach adopted for the study follows the GEF International Waters trans-boundary diagnostic analysis (TDA) approach, involving the following steps:

- An analysis of institutional and socio-economic context;
- To identify the major (environmental) interactions between the Orange-Senqu River system and the Benguela Current Large Marine Ecosystem (BCLME);
- Conduct a causal chain analysis to understand (and if possible quantify) the major impacts and clarify mechanics behind these impacts;
- Prioritize the issues; and
- Provide a tentative catalogue of 'who could do what'.

2. Institutional context

2.1 Benguela Current Large Marine Ecosystem

The Benguela Current region is located along the southwestern coast of Africa, bordering three countries – Angola, Namibia and South Africa. Historically, and particularly prior to the promulgation of the United Nations Convention on the Law of the Sea in 1982 (United Nations 1983), fisheries resources in the Benguela Current region were heavily depleted by foreign fleets. As developing nations, the three countries bordering the Benguela Current region were struggling to deal with this historic legacy, as well as the need to jointly manage the many shared fish resources in the region, and thus sought assistance from the Global Environment Facility (GEF) in developing a large marine ecosystem (LME) management initiative for the Benguela Current:, the BCLME Programme. Foundation for the programme were laid in 1999 with the preparation of a Transboundary Diagnostic Assessment (BCLME TDA 1999) and a Strategic Action Programme (BCLME SAP 1999). The programme itself ran for 6 years (2002-2008).

One of the most important results from the BCLME Programme was the establishment of the Benguela Current Commission (BCC), a formal institutional structure the purpose of which is to facilitate the understanding, protection, conservation and sustainable use of the BCLME by the three countries (Angola, Nambia and South Africa) and to further the objectives recorded in the Strategic Action Programme of the BCLME. The three Member States of the BCC signed an Interim Agreement in 2006 and 2007 respectively, and have agreed to negotiate for a permanent Convention that will be ratified and enter into force not later than 31 December 2012.

2.2 Orange-Senqu River Basin

Recognising the regional importance of the Orange-Senqu River System, the governments of the riparian states Botswana, Lesotho, Namibia and South Africa established the Orange-Senqu River Commission (ORASECOM) through the signing of the '*Agreement for the Establishment of the Orange-Senqu Commission*' in 2000 (Earle et al. 2005). ORASECOM is the first commission to be established following the regional ratification of the SADC Revised Protocol on Shared Water Course Systems of 2000. This Protocol promotes the establishment of shared watercourse agreements and institutions and enshrines the principles of reasonable use and environmentally sound development of the resource. ORASECOM is structured into the Council (technical advisor to the Parties on matters related to development, utilisation and conservation of the water resources of the basin, comprised of three representatives from the respective government agencies responsible for water affairs in the member countries), a Secretariat (responsible for programme coordination and management) and Task Teams (comprising representatives from the member States and providing assistance on financial, legal, technical, and communications matters). ORASECOM promotes the equitable and sustainable development of the resources of the Orange-Senqu River and provides a forum for consultation and coordination between its member states

2.3 Protection of aquatic environment versus marine environment

Both the 1997 UN Watercourse Convention and the 2000 Revised SADC Protocol contain provisions dealing specifically with the protection and preservation of the environment. Whereas the rest of the provisions on this matter are identical in the two instruments, there is a difference between the UN Convention's Article 23 and the equivalent Article 4(2)(d) of the Revised SADC Protocol.

Article 23 of the UN Convention obliges states to take all necessary measures to protect and preserve the "marine environment," including estuaries. Article 4(2)(d) of the revised SADC Protocol on the other hand, whereas being otherwise identical with Article 23 of the UN Convention, uses the term "aquatic environment" instead of "marine environment". If the obligation set forth in this provision was meant to have the same scope as the one of Article 23 of the UN Convention, there was no need to change the terminology, particularly seeing the Articles otherwise have identical wording. The replacement of the term "marine" by the drafters of the Protocol therefore suggests that they preferred a more limited protection obligation compared to the one in the UN Convention.

While there is no universally accepted definition for aquatic ecosystems, these are considered to include riverine systems, estuarine systems, coastal marine systems, wetland systems, floodplains, lakes and groundwater systems (Masundire & Mackay, 2002). Following this definition the SADC Protocol obligation would extend only to coastal marine systems but not include impacts that occur in the open sea, i.e., beyond coastal areas (Malzbender *et al*.., 2007)

2.4 International best practice

The need for improved and proper management of river mouths and estuaries (otherwise known as transitional waters) has recently achieved a high level of prominence in the international literature and management forums. With the publication of the Water Framework Directive of the European Communities in 2000 the term "transitional waters" first came to prominence as a means of completing the continuum between freshwater s and coastal waters. "Transitional waters" under the Directive are defined as "*bodies of surface water in the vicinity of river mouths which are partially saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows*".

The Directive commits European Union member states to achieve good qualitative and quantitative status of all water bodies (including coastal waters) by 2015. It defines 'surface water status' as the general expression of the status of a body of surface water, determined by the poorer of its ecological status and its chemical status. To achieve 'good surface water status' (defined locally as being lower than a theoretical reference point of pristine conditions, i.e. in the absence of anthropogenic influence) both the ecological status and the chemical status of a surface water body need to be at least 'good'.

The Water Framework Directive of the European Communities is widely considered to encompass best practice in respect of management of transitional (estuarine and coastal) waters (Gamito 2008).

As far as can be seen, the term 'transitional waters' has not yet entered the water management, administration and legislation of areas other than the European Union. While US and Australian legal acts and documents talk about wetlands and waters which are transitional, they do not use this term. The US Federal Water Pollution Control (Clean Waters) Act 1977 and the Estuaries and Clean Waters Act 2000 tend to merely refer to estuaries. The latter are then simply defined as "that part of a river or stream or other body of water having unimpaired connection with the open sea, where the sea water is measurably diluted with fresh water derived from land drainage. The term includes estuary-type areas of the Great Lakes" (US Code Collection, 2006). South Australia, an area with arguably as complex a set of estuarine areas as anywhere else, also avoids the use of the term transitional waters and keeps to the definition of an estuary as "A partially enclosed coastal body of water, including its ecosystem processes and associated biodiversity, which is either permanently, periodically, intermittently or occasionally open to the ocean within which there is a measurable variation in salinity due to the mixture of seawater with water derived from on or under the land" (McLusky *et al.*., 2007).

Guided by the principles of the Water Framework Directive the International Commission for the Protection of the Danube (ICPDR) and the International Commission for the Protection of the Black Sea (BSC) have established a Memorandum of Understanding. The work programme of a joint technical working group includes *inter alia:* (i) assessment of existing monitoring systems and development of an integrated monitoring programme and harmonisation of standards to assure comparable assessment; (ii) development of ecological status indicators, reporting on ecological status; (iii) recommendation to limit nutrient loads (the mid-term goal is to avoid nutrient loads exceeding those in the mid 1990ies) and discharge of hazardous substances; and (iv) development of methodological approach and coordination mechanisms for the implementation of the Water Framework Directive in coastal areas.

3. Impacts on the Orange-Senqu Estuary

This section provides a brief account of the Present State of the Orange-Senqu Estuary, and likely changes in the system from the Reference Condition (or natural state), based on information provided in these references and general literature and knowledge on estuarine ecology and functioning.

The ecological functioning and health of the Orange-Senqu Estuary was assessed by Taljaard *et al.* (2003) using methods prescribed by the South African Department of Water Affairs and Forestry (DWAF 1999), for the determination of freshwater requirements of estuaries in South Africa. This study looked at the full suite of abiotic (hydrology, hydrodynamics, sediment processes, and water quality) and biotic (microalgae, macrophytes, invertebrates, fish and birds) ecosystem components of the estuary. This study was undertaken at a desktop level (relied on available information only) but did include simulated hydrology for the entire system. The authors considered that anthropogenic developments in the estuary (i.e. non-flow related modifications) preclude the attainment of a Recommended Ecological Category (REC) Category A (i.e unmodified or natural) through flow restoration alone. They thus recommended that the best attainable state for the system was a Category C (i.e. moderately modified), but included a strong recommendation that mitigating actions to reverse modifications caused by the non-flow related activities and developments in the estuary be investigated. Estimated change is flow required to restore the Orange-Senqu estuary from its Present State of a Category D (largely modified) to a Category C, required that flow during spring and summer (September to February) be increased by up to 154% (average for all months is 106%) and that flows during autumn and winter be reduced by up to 69% (average for all months is -9%).

Historic information available on the Orange-Senqu Estuary at the time that this study was undertaken includes that on water quality (Brown 1959, Day 1981, CSIR 1984, 1985, 1988, Harrison 1997, Seaman and van As 1998), vegetation (O'Callaghan 1984, Burns 1989, Morant and O'Callaghan 1990, Raal 1996, Anon 2002, Bornman 2002), invertebrate fauna (Brown 1959, Morant and O'Callaghan 1990), fish (Brown 1959, Day 1981, Morant and O'Callaghan 1990, Harrison 1997, Seaman and van As 1998) and birds (Ryan and Cooper 1985, Anderson *et al.* 2003). More recently, additional information has been collected on water quality (van Niekerk *et al.* 2008), vegetation (Bornman *et al.* 2004, Shaw *et al.* 2008, and Bornman and Adams 2010, van Niekerk *et al.* 2008), fish fauna (van Niekerk *et al.* 2008) and birds (van Niekerk *et al.* 2008) of the estuary.

3.1 Impacts on the abiotic characteristics of the estuary

Most of the catchment Orange-Senqu River System is arid to semi-arid in nature, where mean annual potential evaporation vastly exceeds mean annual precipitation. Nearly all the runoff in the catchment (98.2%) is derived from the upper portion of the catchment, above the Vaal Orange confluence (Kriel 1972, Benade 1988). Significant volumes of water are abstracted from river, mostly from the 30 or so large dams that have been constructed on the system. Mean annual runoff (MAR) under the Present State is approximately 4,744 million m^3, but has been reduced by almost 60% from the Reference Condition (10,833 million m^3). Further reductions in MAR for the system may be anticipated in the future, due to the escalation in demands for water for irrigation and other uses (van Niekerk *et al.* 20008).

Historically the Orange-Senqu Estuary experienced a strong seasonal pattern of flows, with low flow or no-flow conditions generally coinciding with dry periods in the catchment in winter (August to September), while the system was flushed by small to severe floods during the summer season (Brown 1959, Williams 1990, Taljaard *et al.* 2003). However, abstraction of water from the river, flow regulation and seasonal releases by the major dams in the catchment has diminished the flow pattern to the extent that no discernable flood season has been experienced in years (Taljaard *et al.* 2003). The highest average monthly flows have been reduced by almost 30% in the Present State relative to the Reference Condition, while the incidence of actual flood events (those with a return period greater 1 in 5 years) have been reduced by almost 50% (Taljaard *et al.* 2003).

Floods are important for the long-term functioning of estuaries. Small floods play an important role in influencing the channel configuration, while large floods scour out tidal deltas and re-set the mouth conditions (Schumann *et al.* 1999). Under the current flow regime, whereby a more controlled and constant flow reaches the estuary, with major dams absorbing most of the smaller floods and buffering the effects of medium floods, only severe floods can effectively flush the system (Williams 1990, Bornman and Adams 2010). These floods play an important role in estuaries in that they erode accumulated sediment, temporarily deepening the channel in such systems and thus prolonging the period for which the mouth of the estuary remains open (Cooper *et al.* 1999). Back floods, resulting from the build-up of water levels in the estuary during periods when the estuary mouth is closured, are also essential to estuarine health. Due to the sustained release of water from dams during winter and the artificial control of the mouth, the state of the estuary mouth has changed from one that closed periodically to one that now remains permanently open thereby preventing back flooding (Bornman and Adams 2010). The mouth of the Orange-Senqu used to close approximately once every four years on average during periods of low river flow, before the commissioning of the major dams on the river (Taljaard *et al.* 2003). On occasions when the mouth has closed in recent decades, it has often been breached either by the diamond mining concession holders on either side of the river (Namdeb and Alexcor) in an effort to protect low-lying infrastructure from being flooded.

But other anthropogenic flood control measures at the mouth have also contributed to a reduction in inundation of salt marsh surrounding the estuary. A causeway was constructed through the salt marsh to provide easy access to the beach from Alexander Bay, on the south side of the estuary. This causeway stands about 1.5 m above the adjacent salt marsh (CSIR 1991), and has effectively cut off of many of the river channels extending through the southern edge of the marsh, and ultimately has contributed to the destruction of this saltmarsh (Taljaard *et al.* 2003). Reportedly, this causeway has now been removed, at least in parts.

Further to this, a number of dykes were also constructed across the flood channels extending down into the marsh starting in 1974 in an effort to protect Alexkor agricultural land on the southern side of the mouth from flooding (CSIR 1991). These dykes have also served to reduce the penetration of flood water into the salt marsh on this side of the mouth. Dykes were also constructed by Namdeb on the north bank in 1974, to protect the golf course from flooding (CSIR 1991). The dykes on both banks constrict flow during floods, leading to local increases in river flow velocity and increased erosion along bends in the river course (Taljaard *et al.* 2003). Alexkor have constructed a slimes dam to the east of the salt marsh. Fine material (from the slimes dam and other mining activities in the area) is transported by wind into the salt marsh. Seepage of saline water from the dam into the adjacent salt marsh has resulted in localised incidence of hypersalinity (CSIR 1991). These effects together have also contributed to the die-back of marsh vegetation surrounding the mouth of the estuary.

Although the major impoundments on the Orange-Senqu River System trap much sediment and reductions in flow velocity and volume have reduced the sediment carrying capacity of the system, river sediment still dominates over that from the sea in the estuary. It is reasoned that the loss of sediment inputs from the upper catchment are balanced by enhanced inputs resulting from increased erosion in the mid and lower catchment. Variability in morphology and sediment processes in the estuary are probably somewhat reduced though, due to the reduced resetting of the estuary by floods, while the intrusion of marine sediments into the estuary has most likely extended slightly further up the estuary (Taljaard *et al.* 2003). Sand banks in the estuary are likely to be more permanently exposed in the Present State, and as a consequence have become vegetated.

Water quality data available for the Orange-Senqu Estuary indicate that it exhibits strong seasonal variation with winter temperature being typically lower (around 15°C) than summer temperatures (around 25°C) except during periods of intense upwelling when cool water (12 to 16°C) from the sea enters the estuary. Oxygen levels in the estuary are mostly high (around 8mg/l) except on occasions when algal blooms occur in dams upstream, and this oxygen depleted water makes its way down into the estuary (Taljaard *et al.* 2003). Very little data are available on the salinity structure of the estuary, but Taljaard *et al.* (2003) surmise that the estuary is generally well stratified except when it is closed and that saline waters do not penetrate more than 7km upstream even under low flow conditions. Under high flow conditions (i.e. >50m^3/s) they predict that estuary is likely to be fresh throughout, with very limited saline intrusion at the mouth at times. Reduced levels of stratification have been reported during periods when the mouth is closed, except in the deeper parts of the estuary where salinity will remain close to that of sea water (~30PSU).

Nutrient loading in the estuary (nitrogen, phosphorus and silicate) in the Present State is believed to be little different from that under Reference conditions. Taljaard *et al.* (2003) surmise that although nutrient inputs from agricultural activities along the river are likely to contribute to nutrient loading in the system, the lack of significant agricultural inputs in the lower reaches of the system allows for these nutrients to be taken up before they reach the estuary.

There is relatively little information on pollutant transport, other than sediment and nutrients, by the Orange-Senqu to the estuary. There are reportedly significant anthropogenic sources of pollution in the basin, particularly in the Vaal catchment which is highly urbanised and contains much of south Africa's heavy industry. The Orange-Senqu River and other smaller catchment are not as heavily developed but do receive discharges from waste water treatment works in the numerous small towns and urbanised areas along the river, many of which are not in compliance with the waste water discharge standards (ORASECOM 2008). Taljaard *et al.* (2003) presents data on trace metal concentrations in water at the Rosh Pinah, about 70 km upstream from the mouth of the estuary, for the period 1998 to 2003, and trace metal concentrations in the sediments in the estuary collected in 1997. These data are presented in Table 1 Concentrations of trace metals in the water entering the estuary are above guideline limits specified for the BCLME region (BCLME 2006), while those in the sediments are lower than the guideline limits. This suggests that most of the trace metal contaminants are not retained in the estuary, and are rather exported directly to the marine environment. Once these contaminants enter the marine environment they are likely to be rapidly diluted and are unlikely to pose a major risks to marine biota. Data on concentrations of other toxic substances in the water from the Orange-Senqu River, including Persistent Organic Pollutants (POPs), is even more limited than that for trace metals. Vosloo and Bouwman (2005) surveyed a number of sites in the Orange-Senqu catchment and found that concentrations were elevated well above guideline limits. Total concentrations of Toxic Equivalent Factors (TEQs), calculated as the sum of individual compounds, were high in some parts of the catchment (up to 22 ng/kg), but were low near the mouth (0.23 ng/kg), well below the action level determined for the USA.

Table 1. Trace metal concentrations in the Orange-Senqu River near the top of the estuary and in sediments in the estuary (from Taljaard et al. 2003).

	Water		**Sediment**		**BCLME Guidelines**	
	Mean	**Range**	**Mean**	**Range**	**Water**	**Sediment**
Fe	947	10-5200	-	-	-	-
Mn	40	10-200	-	-	-	-
Cu	33	10-80	10.8	7.8 – 17.2	1.3	18.7
Zn	32	10-80	23.1	14.7 – 51.9	15	124
Cd	<10	5.5-0.68	0.032	0.017 – 0.06	5.5	0.68
Pb	<20	4.4-30.2	5.4	2.4 – 8.7	4.4	30.2

3.2 Impacts on the estuary biota

From a botanical perspective, the Orange-Senqu Estuary is described as a delta-type river mouth comprising of a wide range of habitats including braided troughs interspersed with sand and mud banks, pans, channel bars and small islands, and a tidal basin and a saltmarsh on the southern bank (Taljaard *et al.* 2003). Estuarine wetland occupies approximately 1 842 ha around the Orange Senqu mouth (Bornman and Adams 2010). The common reed Phragmites australis along with the submerged macrophyte Potamogeton pectinatus dominate around the mouth, while species such as Sporobolus virginicus (brakgras) and Scirpus maritimus dominate on the islands further upstream. Peripheral marshes are dominated by Sporobolus viginicus, along with various herbs, sedges and grasses such as Cotula coronopifolia, Juncus kraussii (sharp rush), Apium graveolens and Cyperus laevigatus. The salt marsh areas comprise a mosaic of species including Cotula coronopifolia, Triglochin spp., Juncellus laevigatus, Sporobolus virginicus and Sarcocornia pillansii, with the latter species dominant in the salinized lower floodplain areas. Taljaard *et al.* (2003) estimated that approximately 90% of the biota of the salt marsh area on the southern bank of the estuary has been lost due to anthropogenic influences, and is now a barren saline desert.

No comprehensive surveys of phytoplankton have been conducted for the Orange-Senqu Estuary. Taljaard *et al.* (2003) are of the opinion that prior to the development of large impoundments, high flows and flushing would have mostly likely have prevented the establishment of resident phytoplankton populations, while benthic microalgae biomass may have been high in backwater areas. Increased retention time in the estuary under Present day conditions, resulting from reduction and alteration of flows as well as nutrient enrichment, would most likely promote the growth of phytoplankton. The proliferation of phytoplankton would be at the expense of large plant species, as the phytoplankton reduces the amount of light reaching the larger rooted plant species, thereby inhibiting their growth. In addition, the decomposition of phytoplankton may lead to oxygen depletion or hypoxia, which in turn can kill fish and invertebrates, and can cause a general reduction in biodiversity.

The earliest surveys of the fauna of the Orange-Senqu Estuary, conducted between 1956 and 1958, indicate that the estuarine invertebrate fauna were extremely depauperate and that the Orange-Senqu River in fact lacked an estuarine component (Brown 1959). It was reasoned that this lack of an estuarine component was a due to the fact that the Orange-Senqu River possessed no true estuary, as river flows dominated and no appreciable variation in salinity, caused by the sea, existed within the lower reaches of the river (Brown 1959). This is considered by most authors to be representative of the Reference condition of the system (Taljaard *et al.* 2003, van Niekerk *et al.* 2008). The situation is substantially different in the Present State where van Niekerk *et al.* (2008) recorded 16 and 25 zooplankton and 4 and 7 benthic macrofauna taxa in summer and winter respectively (compared with only 3 zooplankton and 4 benthic macrofauna taxa recorded by Brown 1959). Similarly, the number of fish taxa and abundance of fish in the estuary seems to be dramatically higher in the Present State than under Reference conditions. Detailed surveys conducted by Harrison (1997), Seaman and Van As (1998), and van Niekerk *et al.* (2008) revealed the presence of at least 33 species of fish in the estuary, compared with only two species recorded by Brown (1959), albeit from what was most likely less sampling effort.

At least a third of the fish species (34%) recorded in recent surveys are estuary associated species (i.e. able to breed in estuaries or use them to some extent as a nursery area), one quarter (24%) are marine species that are probably feeding in the estuary, and the rest (42%) freshwater species (van Niekerk *et al.* 2008). Historically, the number of marine species utilising the estuary and their residence time is likely to have been much lower than in the Present State due to sustained freshwater flows during winter, while it is anticipated that freshwater species, which previously retreated to the upper reaches of the estuary in response to increased salinity, would now persist in the estuary throughout winter. The impacts that an altered flow regime (75% seasonal reversal) may have had on recruitment, migratory or spawning cues are currently unknown.

There are no historic (pre-1980s) data available on birds of the Orange-Senqu Estuary, other than anecdotal notes provided by Brown (1959), who recorded the presence of Greater and Lesser flamingos, a number of duck species and waders (Avocet). Detailed bird count data are available from 1980 only, and present a rather disturbing picture of declining bird numbers. Numbers have declined from over 20,000 individuals in the 1980's to an average of around 6,000 individuals in the period 1995-2001 (Anderson *et al.* 2003). This decline has been attributed mostly to the collapse of populations of Cape Cormorants and Common Terns frequenting the estuary, thought to be due to a combination of factors including depleted food reserves, increased disturbance by humans, changes to the morphology of the mouth and islands with a consequent effect on roost site availability, disease and oiling (Anderson *et al.* 2003). Several other waterbird species, both freshwater and saline species, and several waders that were particularly numerous in the 1980s (Ryan and Cooper 1985) have not subsequently attained their original numbers. The reason for this is unclear, but it is thought to be related to the deterioration of the saltmarsh and the corresponding decrease in available mud-flat habitat for many of these species (Anderson *et al.* 2003).

3.3 Climate Change

The notion that the earth's climate is changing as a result of anthropogenic forcing is now widely accepted. The Intergovernmental Panel on Climate Change (IPCC), in its most recent assessment (IPCC 2007), states with confidence that global average surface temperatures have already increased as a result of anthropogenic production of greenhouse gases, notably CO_2, methane, nitrous oxide and CFCs, and are likely to continue doing so. They also note that global mean sea level is rising as a consequence of the thermal expansion of the oceans, that the concentration of ozone in the stratosphere has decreased, particularly over Antarctica, that annual average precipitation has changed in certain areas, and that world climates have become more variable and the intensity and frequency of extreme weather events appear to have increased. Implications of observed and projected impacts of climate change on the Orange-Senqu Basin and on the flow of the river are summarised in ORASECOM (2008). Land surface temperature in the basin has increased by 0.5 to

1.0°C (Hughes and Balling 1997, Hulme 1996), the incidence of extreme rainfall events in southern Africa has increased (Hulme, 1996, Warburton and Schulze 2005a, b, ORASECOM 2008), and the magnitude of drought flows (lowest flows over sequential 10 year periods) have increased particularly in the lower reaches of the river (Warburton and Schulze 2005b). Less information is available on future projected changes in temperature, rainfall and streamflow, but it is suggested in the South African Country Study on Climate Change (Kiker, 1999) that a significant decrease in river flow can be expected in the western catchments of South Africa, including the lower reaches of Orange-Senqu (10% decrease in runoff by the year 2015) and a 12 to 16% decrease by 2050. These projected reductions in flow will come on top of the existing substantial reductions in streamflow reaching the estuary at present, and will serve to greatly exacerbate many of the impacts highlighted earlier.

A further impact of changing global climates likely to have far reaching impacts on the Orange-Senqu Estuary, is that of rising sea levels. Tide gauge measurements from South Africa indicate that sea levels have risen by approximately 1.2mm/year over the last three decades, and are in close agreement with international estimates (Brundrit 1995). The current trend of rising sea level is expected to accelerate in the future, with recent estimates indicating a 12.3cm rise by 2020, 24.5cm rise by 2050 and 40.7cm rise by 2080 (Nicholls *et al.* 1999). The potential impacts of sea-level rise on coastal environments include increased coastal erosion, inundation, increased saltwater intrusion, raised groundwater tables and increased vulnerability to extreme storm events (Klein and Nicholls 1999). Impacts on estuaries in southern Africa, where much of the production is linked to the salt marsh ecosystems, are predicted to be severe (Clark 2006). Further change, and possible loss in some areas, of salt marsh on the Orange-Senqu Estuary can be expected. The lower lying marshes are likely to become water logged or completely inundated, and species unable to tolerate these conditions or the increased salinity from marine waters will die back and expose the underlying sediments to further erosion. Rising water levels may, however, assist with the restoration of some of the existing desiccated salt mashes.

4. Impacts on the Benguela Current Large Marine Ecosystem

Aside from the impacts that the Orange-Senqu River has on its estuary, there are a number of impacts on the broader coastal and marine environment. These impacts are addressed in this section following a brief description of the marine environment in this region, otherwise known as the Benguela Current Ecosystem.

4.1 Impacts on the physical oceanographic processes

The marine ecosystems off the south west coast of Africa are influenced by the Benguela Current (BC), which extends along the eastern edge of the southern Atlantic Ocean between Cape Agulhas (South Africa) and the Congo River Mouth (Angola). The BC is one of four major eastern-boundary current systems that are characterised by the wind-driven upwelling of cold, nutrient rich water (Shannon and O'Toole 1998). The Benguela Current originates from the South Atlantic Circulation, which circles just north of the Arctic Circumpolar Current. The system is bounded by two warm currents; the Agulhas Current in the south and the Angola Current in the north.

The naturally cool temperature of the Benguela Current (average temperature 10 to 14°C) is enhanced by the upwelling of cold nutrient-rich deep water (Shannon 1985). The upwelling system is driven by strong southerly and south-easterly winds which are deflected by the Coriolis Force (the rotational force of the earth that causes objects in the southern hemisphere to spin anticlockwise). These prevailing conditions deflect the surface waters offshore allowing cold, nutrient rich water to well-up along the coast. The upwelling intensity is dependent on the strength and continuity of these winds and has been found to vary interannually. In the southern section of the BC the south-easterly trade winds are highly seasonal with their maximum in spring and summer. Upwelling intensity also varies geographically, according to the width of the continental shelf and intensity of southerly winds, such that upwelling is most intense where the wind is strongest and the shelf is narrowest (Sakko 1998). Water temperature, salinity and nutrient levels in the marine environment are strongly influenced by upwelling intensity, with minimum temperatures and maximum nutrient levels occurring in conjunction with upwelling events (Branch and Griffiths 1988).

The Orange-Senqu River drains into the southern section of the BC adjacent to the widest part of the continental shelf and at the southern boundary of the Lüderitz-Orange-Senqu River Cone upwelling cell. This upwelling cell forms the boundary between the northern and southern Benguela Currents and is characterised by strong winds, high turbulence, strong offshore transport and low phytoplankton levels (Hutchings *et al.* 2009). The discharge from the Orange-Senqu Estuary typically forms a plume of buoyant, nutrient-rich freshwater where it drains into the sea, the nature of which, is shaped by the discharge volume and prevailing wind conditions (Shillington *et al.* 2006, Gan *et al.* 2009).

Buoyant discharge plumes have been known to modify alongshore and cross-shelf upwelling circulation in the upper water column, and can strongly influence near-shore circulation patterns (Gan *et al.* 2009). During upwelling favourable conditions, the surface-trapped plumes move offshore becoming thinner, thereby strengthening the seaward transport of the plume and the shoreward transport beneath. The actual upwelling intensity is unaffected, however, as there is little to no effect on the water column below 20m (Gan *et al.* 2009, Chao and Boicourt 1986). During down-welling favourable conditions, the freshwater plume typically forms a downwind coastal jet which elongates, accelerates and deepens along the coast (Gan *et al.* 2009, Chao and Boicourt 1986). Alongshore currents are enhanced geostrophically along the inshore edge of the plume and weakened along the off-shore edge, due to pressure gradients created by differences in buoyancy between the plume and seawater (Gan *et al.* 2009).

Under normal circumstances, the flow from the Orange-Senqu River is so small that it plays no role in determining near-shore circulation. During severe floods, however, the river plume has exerted some control over coastal circulation patterns (Shillington *et al.* 2006). In the absence of strong winds the buoyant discharge plume from the 1988 Orange-Senqu River flood formed an eddy with a diameter of 42km, and a 10 to 15km band of coastally-trapped shallow, warm, low-salinity water which travelled up to 200km southwards of the mouth (Shillington *et al.* 2006). When south-easterly wind intensified, however, the discharge plume moved north with a deflection to the left caused by the Coriolis Force (Shillington *et al.* 2006). In terms of run-off, this flood was the largest historic flood on record (24.3km^3) (Rogers and Rau 2006), but was by no means exceptional, its return period was estimated to be a 1 in 10 to 15 year event (Swart *et al.* 1990).

4.2 Impacts on marine sediments

The mass of sediment discharged by the Orange-Senqu River is estimated to be around 17 million tons per year (Bremner *et al.* 1990). While this may be small in comparison to the world's leader, the Ganges-Brahmaputra which discharges in the order of 1,670 million tons per year, it still represents a significant volume of sediment entering the Benguela Current System each year. Present day discharges of sediment from the Orange-Senqu system are considerably lower than those recorded prior to the 1960s but of a similar magnitude to those reported for geological time scales (Table 2). A concomitant change has also occurred in the texture of the suspended sediment load carried by the river, which has changed from silt-dominance in pre-1970 material, to clay dominance since this time (Bremner *et al.* 1990). Both of these effects have been attributed to agricultural malpractices in the parts of the catchment (Northeastern Cape in South Africa) in this early period (Rooseboom and Mass 1974), and the fact that easily erodible topsoil was stripped from the Upper Orange catchment during the early 1930s, and the rapid increase in the number and size of dams that were constructed in the catchment in the early 1970s (Bremner *et al.* 1990). These changes are mirrored in the changes in the suspended sediment concentrations measured in flood waters in March 1988 (7.4mg/l) compared with similar sized floods in April 1961 (17.4mg/l), March 1965 (15.5mg/l) and November 1955 (14.5mg/l) (Bremner *et al.* 1990). Historically, the bulk of this sediment carried by was reportedly derived from the upper portion of the catchment from whence most of the runoff is also derived (Rooseboom and Mass 1974, Rooseboom 1974, 1975, 1978, Rooseboom and Harmse 1979), whereas this has now shifted to the lower catchment, below the major impoundments on the system. Bremner *et al.* (1990), list bank erosion and river bed scour, derived from the river channel downstream of the major dams situated near the Orange-Vaal confluence, as the main sources of sediment in the river in the 1988 floods. Large amounts of sediment were also removed from the estuary as well, with vertical scour of at least eight metres deep being recorded at the bridge (Swart *et al.* 1990), and lateral erosion of the salt marsh of about 400m (Bremner *et al.* 1990). The total volume of sediment discharged during the 1988 flood was estimated at 64.2 million tons, very similar to the mean annual sediment discharge of 60.4 million tons measured at Prieska/Upington (close to the mouth) between 1930 and 1969 (Bremner *et al.* 1990).

Table 2. Variation in sediment discharge rates of the Orange-Senqu River (after Bremner et al. 1990)

Period	Information source	Sediment discharge rate (in million tons per year)
Geological time		
Late Cretaceous	Dingle and Hendey (1984)	24
Palaeogene	Dingle and Hendey (1984)	4.5
Neogene	Dingle and Hendey (1984)	0.8
Historical time		
?	Lisitizin (1972)	153
Pre-1921	Perry (1988)	119
1929-1934	Rooseboom and Mass (1974)	89
1934-1943	Rooseboom and Mass (1974)	56
1943-1952	Rooseboom and Mass (1974)	52
1952-1960	Rooseboom and Mass (1974)	46
1960-1969	Rooseboom and Mass (1974)	34
1980's	Rooseboom (pers. comm) cited in Bremner *et al.* (1990)	<17

Once they arrive in the sea, sediments from the Orange-Senqu River are deposited in a submarine delta, and are dispersed north and south wards of the river mouth by wave action, longshore drift and subsurface currents. The submarine delta off the mouth of the river extends approximately 26 km seaward of the Orange-Senqu Mouth and 112km laterally (Rogers and Rau 2006). Littoral drift, driven by the south-westerly swells, moves most of the coarse material (sand and gravel) equatorward of the river mouth, i.e. into Namibia waters (Rogers 1977), while the weak poleward undercurrent (De Decker 1970, Nelson 1989) carries silt and clay south of the mouth, i.e. into South African waters (Rogers and Bremner 1991)

The section of the continental shelf opposite the Orange-Senqu River is termed the "Orange Shelf", and is the widest part of the Namaqualand shelf. It was formed by high sedimentation rates off the Orange-Senqu River in the Cretaceous period (Rogers and Rau 2006). It is up to 100km wide and 200m deep. Most of the terrigenous sediments off the west coast of southern Africa are in fact derived from the Orange-Senqu River, with smaller contributions coming from other rivers in the region (Olifants and Swartlynjies) (Rogers and Bremner 1991). Some of the material on the shelf is comprised of marine biogenic carbonates that are transported northward by longshore drift (De Decker 1988, Rogers and Rau 2006). Much of the fine silt and clay carried south by the inshore undercurrent, accumulates along a mudbelt south of the river mouth (Bremner *et al.* 1990; Compton and Wiltshire 2009). The mudbelt extends approximately 500km southward from the Orange-Senqu River mouth to St Helena Bay and lies at a depth of 40 to 130m (Rogers and Rau 2006). It is at its thickest (35m) at the mouth of the Orange-Senqu River (De Decker 1986).. Mean particle size of the sediments in the mudbelt decreases southward due to the reduced influence of the river and the ability of the poleward undercurrent to transport only very fine materials (Rogers and Rau 2006). The marine biogenic component in the sediments, by contrast, increases southward of the mouth, indicating that there is a significant marine influence on the inner shelf, and that the Namaqualand mudbelt is not primarily derived from the southward transport of terrigenous sediment as was previously thought (Rogers and Rau 2006).

4.3 Impacts on marine water chemistry

Water in the main stem of the Orange-Senqu is reportedly generally of good quality with low levels of nutrients, except in localised areas, where the river runs through small towns where waste water treatment plants discharge poor quality sewage effluent into the river, for example along the Caledon, a major tributary of the Senqu, and in the Upington area in South Africa (ORASECOM 2008). Data on inorganic nitrogen and phosphate concentration near the mouth of the river and in the estuary presented by Taljaard *et al.* (2003) concur with these observations. They suggest that the amount of nitrogen and phosphate carried down by the river under the Present Day conditions (N mostly less than 500μg/l and P mostly less than 60μg/l) are little different from those in the Reference Condition (around 250μg/l for N and 5μg/l for P). These concentrations are similar to those reported for surface waters in the Benguela upwelling region where nutrient concentrations are naturally high (100 to 400μg/l for N and 40 to 90μg/l for P) (Chapman and Shannon 1985, Brown and Hutchings 1987, Brown 1992). As such, the river cannot be considered a major source of nutrient for the marine environment, nor is it likely the nutrient input from the Orange-Senqu River plays a significant role in the overall productivity of the marine ecosystem.

Transport of pollutants by the Orange-Senqu River to the sea is also low as described earlier. While concentrations of trace metals in the water entering the estuary are above guideline limits specified for the BCLME region (BCLME 2006), once these contaminants enter the marine environment they are likely to be rapidly diluted and are unlikely to pose a major risk to marine biota. Similarly, Vosloo and Bouwman (2005) report that concentrations of Toxic Equivalent Factors (TEQs) in the river are low near the mouth (0.23ng/kg), well below the action level determined for the USA.

4.4 Impacts on marine biota

Marine ecosystems off the Orange-Senqu Estuary are situated near the centre of the Namaqua bioregion, a cool-temperate bioregion that extends from Sylvia Hill, north of Lüderitz in Namibia, to Cape Columbine in South Africa (Lombard *et al.* 2004). This bioregion is characterised by strong wave action, intensive upwelling, nutrient rich water, high levels of primary production both on the shore (algae) and offshore (phytoplankton), high filter feeder and grazer biomass (zooplankton, molluscs, and fish), large populations of higher predators (marine mammals and birds), and a number of major commercial fisheries. The influence of the Orange-Senqu River on these communities is most likely small and localised though, due to rapid dilution and distribution of material discharged from the river.

It has been already been highlighted, for example, that nutrients output from the river is unlikely to influence primary production in the offshore marine environment to any great extent. The influence of outputs from the river on phytoplankton communities appears to be restricted to a handful of diatom species that appear more abundance off the mouth of the Orange-Senqu River and the. Kuenene River (Holzwarth *et al.* 2007). These authors speculate that this may be due to reduced salinity in the surface waters and/or other river-specific influences (e.g. nutrient, trace metals and sediment inputs).

There are some clear impacts from the river on offshore benthic invertebrate fauna, though. Oxygen levels in the sediments of the Orange-Senqu River Delta (> 2mg/l O_2) are considered to be sufficient to support benthic fauna (Rogers and Rau 2006), but high sedimentation rates in this area, estimated at 3.70mm/year (Meadows *et al.* 1997), seemingly inhibit the development of such communities. Levels of bioturbation in these sediments are very low, with laminations in the sediment providing a relatively undisturbed record of historical flood events (Mabote *et al.* 1997). Elsewhere on the shelf, where sedimentation rates are lower, infaunal burrowing activity is sufficient to destroy these laminations (Mabote *et al.* 1997, Meadows *et al.* 1997, Meadows *et al.* 2002, Rogers and Rau 2006). High sedimentation rates in the Orange-Senqu River Delta also contribute to low organic matter content in this area (Rogers 1977, Mabote *et al.* 1997). Faecal pellets in sediments increase in the mudbelt south of the Orange-Senqu River Delta (where they are rare) to off the Olifants River (200km to the south) where over 90% of the sediment is composed of faecal pellets (Birch 1975, Rogers and Bremner 1991). A corresponding increase in abundance of polychaete worms has been noted along this trajectory (Christie 1975).

The Benguela Current supports a number of major offshore commercial fisheries including demersal (bottom) trawl and longline fisheries that focus primarily on hake, midwater trawl fisheries that focus on horse mackerel, purse seine fisheries focussing on sardine and anchovy, pelagic longline fisheries focussing on tuna, swordfish and sharks (Crawford *et al.* 1987, Griffiths *et al.* 2004). Closer inshore there is also an important commercial fishery for rock lobster, and smaller operations targeting sole and linefish (snoek). The area off the Orange-Senqu River mouth is not particularly important for any of these fisheries, except the west coast sole *(Austroglossis microlepis)*, presumably owing to low biomass of the other target species in this area. The area off the Orange-Senqu Mouth may, however, be important as a nursery and/or spawning ground for some species. Two stocks of A. microlepis exist in South African and Namibia waters, a southern population centred on the Orange-Senqu mouth and a northern population opposite the Skeleton Coast (Crawford *et al.* 1987). As is the case with many other sole species (Le Clus *et al.* 1994), this one seems to favour areas of fine muddy sediment such as is found of the mouth of the Orange-Senqu River. Monkfish *(Lophius spp.)*, one of the most valuable bycatch species in the bottom trawl fisheries in the Benguela Current, also reportedly spawns off the Orange-Senqu River mouth (Hampton *et al.* 1999, Hampton 2003). Presumably, changes in sediment discharge from the river must have had some impact on these two species, although it is not clear whether this has been positive or negative and whether it will be possible to isolate these effects in the face of many decades of intense exploitation.

The distribution of deep water hake *(Merluccius paradoxus)* the dominant species in the demersal trawl fishery in both South Africa and Namibia, spans the whole of Namibia and the South African west coast. The bulk (65-75%) of the stock is located in South African waters. Spawning seems to be confined to the area south of Cape Town (Strømme *et al.* 2004, 2005a, b). Eggs, larvae and juveniles are carried northwards up the west coast but remain south of the Orange-Senqu River until they reach at least 10 cm in length. Thereafter, the small fish begin to move off the shelf into deeper water, spreading north and south, with a considerable portion moving northwards across or along the edge of the Orange shelf up into Namibian waters. Sediment originating from the Orange-Senqu River that is distributed on the shelf presumably influences the distribution or movement of fish in the nursery area south of the river to some extent. It is not clear how important this is though. Hydrographic features on the Orange shelf areas are reportedly highly dynamic, with varying origin of the water masses, and may temporarily form a barrier to the movement of fish on the shelf (Strømme *et al.* 2004). The role of the Orange-Senqu River in this is also not clear, but probably minimal.

One of the major nursery grounds for pelagic fish in the Benguela (sardine and anchovy) is located on the continental shelf south of the Orange-Senqu Mouth (Hutchings *et al.* 2009). These species spawn on the southern part of the west coast and on the Agulhas Bank (south of the subcontinent). Eggs and larvae are transported in a strong shelf-edge jet up the west coast at which point the pre-recruits move inshore towards the nursery grounds. The influence of the Orange-Senqu River on these processes is probably minimal though. Significant stocks of adult sardine and anchovy are reported to occur within 30 nautical miles off the Orange-Senqu Mouth, but these are not exploited for logistic reasons (CSIR 1994, BCLME 2004).

Rock lobster occurs in commercially exploitable densities along a 900km length of coastline either side of the Orange-Senqu River, from about 25°S in Namibia to Cape Town in the south (Crawford *et al.* 1987). The area immediately south of the river is not considered a good fishing ground for this species, and supports only a small portion of the South African stock. Less than 1.1% of the Total Allowable Catch (TAC) for South Africa has been allocated in this area in recent years (BCLME 2004). By contrast, the main commercial fishing area for rock lobster in Namibia is located just north of the Orange-Senqu River (BCLME 2004). Rock lobster stocks in both countries are severely depressed at the moment, reportedly due to overfishing (Griffiths *et al.* 2004). This most likely has little nothing to do with the Orange-Senqu River.

Colonies of breeding seabirds in the vicinity of the Orange-Senqu River mouth, located mostly in Namibia, are currently in decline. African Penguins, for example, have reportedly dropped from over 40,000 breeding pairs in 1956 to fewer than 1,000 pairs in 2003, while Cape Gannets have dropped from 0.47 birds/ha in 1956 to 0.02 birds/ha in 1996 (BCLME 2004). This was thought to be due to food scarcity, which resulted in poor recruitment to colonies, although some young birds have emigrated to other colonies to the north and south. The food shortage was reportedly caused by the collapse of Namibian sardine and anchovy stocks, and a decreased abundance of gobies in Namibia, caused by the Benguela Nino of 1994/95 (BCLME 2004). These changes most likely also contributed significantly to reduction in abundance of piscivorous bird populations on the Orange-Senqu Estuary (cormorants and terns), and are not related to the condition of the river or estuary itself at all.

The influence of the Orange-Senqu River on nearshore marine biota is likely to be greater than for the offshore environment, especially in the surf zone which is often described as closed system (McLachlan 1981). Taljaard *et al.* (2003) are of the view that the export of nutrients, sediment and detritus to this area is undoubtedly important. They suggest that nutrients from the river serve to stimulate phytoplankton and zooplankton production in the nearshore marine environment, and ultimately, the larval, juvenile and adult fish that depend on this food source. Detritus may be broken down into useful nutrients, serve as a substrate for micro-flora and fauna or be consumed directly by detritivorous fish and invertebrates. Sediment export replenishes the nearshore habitats that are continuously eroded by oceanic currents and also provides a refuge for many fish by increasing turbidity. Turbidity, in turn, will serve to increase the catchability of many species, especially the larger individuals that move into the turbid environment in search of concentrated prey. The freshwater plume centred on the mouth of the estuary will provide cues for the migration of estuarine-dependent juvenile and adult fish into and out of the estuary. The strength of these cues will ultimately dictate how many individuals of these species recruit into the marine fisheries.

Historical changes in the amount and seasonality of freshwater runoff to the estuary and ultimately to the sea would almost certainly have influenced the community composition and abundance of fish and invertebrate communities surrounding the mouth of the estuary. The seasonality of freshwater flows reaching the estuary, and hence the sea, have effectively been reversed with winter flows are often higher now than those in the historical high flow summer period (Taljaard *et al.*

2003), and presumably must be having some impact on those species that rely on seasonal cues for entering or exiting the estuary.

The influence of episodic events such as the 1988 floods extend further from the mouth, and in the latter instance led to mass mortalities of intertidal organisms up to 140km south of the mouth (Branch *et al.* 1990). Limpets, mussels, octopus, chitons, urchins, red bait, barnacles, reef worms and almost all rock lobster and kelp were eliminated from the rocky shores within a 10km radius of the mouth as a direct result of the flood. The causes of mass mortalities were reasoned to be due to lowered salinity, increased turbidity which reduced light penetration, and deposition of silt and organic matter which resulted in depletion of oxygen level in the water column (Branch *et al.* 1990). Following the floods, previously denuded rocky shores became dominated by opportunistic foliar algae (Branch *et al.* 1990).

5. Socio-economic implications of changes

The area around the Orange-Senqu Estuary is very sparsely population and access to the coast and estuary is controlled by diamond mining concession holders Namdeb (Pty) Ltd in Namiba and Alexcor Ltd in South Africa (Richterveld Municipality 2009, Slov *et al.* 2009). The town of Oranjemundis situated on the northern bank of the estuary and has a population of 3,659 (2009). The town is owned by the mining company and access is restricted to employees of Namdeb and their relatives, and only persons with pre-application of 1 month are allowed in. Alexander Bay, with a population of 1,453, is also a privately owned mining town on the south bank of the estuary, and was until recently, inaccessible to anyone not working on or directly associated with Alexcor Ltd. The town is no longer a high-security area and permits are no longer required to access the town. Access to the Orange-Senqu Estuary from the south bank is now also permitted, but as few people are aware of this fact, so tourism in this area is almost non-existent. South of Alexander Bay, the nearest town is Port Nolloth, with a population of 8,652 persons, where mining, fishing and mariculture are listed as the main economic activities (Richterveld Municipality 2009). Fish processing establishments in both Port Nolloth and Luderitz are reported to be struggling due to poor catches. Diamond resources in the area are also now all but exhausted and both Namdeb and Alexcor are scaling down their operation dramatically. Aligned with this, is the process of converting the town of Oranjemund into a formally proclaimed municipality, scheduled for completion in November 2010. Tourism, although low key at present, is a growing industry and looked towards as a future alternative to mining and fishing.

In summary, the direct socio-economic benefits from the estuary are currently very limited to recreational use of the area by residents and visitors to Alexander Bay and Oranjemund, who use the area for passive recreation (walking, camping, picnicking) and recreational angling. Biophysical changes to the estuary have almost certainly had some impact on use, but in the greater scheme of things this will have been negligible. However, in future, with the downscaling in mining activity and reduction in commercial fish catches, it is expected that emphasis will shift towards ecotourism as the major economic activity in the region. In line with this the estuary has been included in the recently established Sperregebiet National Park in Namibia and the Ai-Ais Richtersveld Transfrontier Park that spans Namibia and South Africa. A corresponding growth in the importance and use can thus also be expected.

6. Prioritised impacts and likely causes

Of the twenty-three common GEF trans-boundary issues recognised internationally, those emerging as priority issues in this study include modification of stream flow and modification of ecosystems. Impacts of the issues on the Benguela Current Large Marine Ecosystem, mediated through anthropogenic impacts on the Orange-Senqu River, seem to be mostly confined to the estuary, and inshore coastal environment in the immediate vicinity of the estuary, although deposition of sediment on the continental shelf may have more wide reaching effects.

Historically the Orange-Senqu estuary was a temporarily open/closed estuary, closing briefly in the winter low flow periods and/or as a result of wave action building up the sand bar at the mouth. Under present day conditions, however, hydro power releases during the winter months and massive abstraction of water from the catchment in summer have modified the natural flow regime of the river to such an extent that the estuary mouth seldom, if ever, closes. This in turn, prevents water from building up in the system and flooding the adjacent salt marsh areas. Moreover, mouth closure, when it does occur, is now more likely to occur in summer than winter. Floods that would historically have reset the system in summer and inundated the saltmarshes and floodplain, have also been greatly reduced. Localised anthropogenic impacts such as the construction of roads, dykes, slimes dams near the mouth, have further degraded the estuary and associated ecosystems.

Changes in the volumes and seasonality of freshwater reaching the nearshore coastal environment surrounding the estuary, along inputs of nutrients, sediment and detritus, have most likely influenced both abiotic (e.g. sediment transport, erosion and nutrient cycling) and biotic processes (e.g. recruitment) in this area. Further offshore, impacts are changes in river dynamics are probably restricted to deposition of sediment of the shelf which in turn may have affected abundance, distribution and recruitment success of some commercially important fish species and their prey to a limited extent.

Current use of and dependence on available resources in the estuary and adjacent marine environment are low at present, and socio-economic impacts of historic changes in the ecological functioning and health of this environment are likely to be low as well.

In cognisance of the identified issues but also the anticipated developments, a comprehensive, overarching rehabilitation and management plan for the Orange-Senqu Estuary is required. The need for developing such a plan was identified as a priority at the stakeholder workshop. It was recommended that the proposed plan be compiled in consultation with key government and private sector stakeholders in Nambia and South Africa and should seek to address priority issues, in particular those which led to the placing of the estuary on the Montreux Record. Cooperation between government ministries from both countries will be required at a high level to ensure maximum synergy between any management interventions that are introduced.

References

Acocks, J.P.H., 1953. Veld Types of South Africa. Memoirs of the Botanical Survey of South Africa, vol. 57, third ed. Department of Agriculture, Pretoria, South Africa, 146pp.Agrer. 1999. Lesotho National Livestock Development Study. Phase I Report Part I. Main Report. 163pp.

Anderson, M.D., Kolberg, H., Corné Anderson, P., Dini, J. and A. Abrahams 2003. Waterbird populations at the Orange River mouth from 1980-2001: a reassessment of its Ramsar status. Ostrich. 74: 159-172

Anon. 2002. Orange River Mouth Transboundary Ramsar Site (ORMTRS). Conservation Area Management Plan. Northern Cape Directorate Environment and Conservation (Kimberley) and Ministry of Environment and Tourism (Windhoek). 3rd Draft. February 2002.

BCLME 2004. Report on the Proceedings of the BENEFIT/BCLME Lüderitz Upwelling Cell Orange River Cone (LUCORC) Workshop, Cape Town, 28-29 July 2004.

BCLME 2006. The development of a common set of water and sediment quality guidelines for the coastal zone of BCLME, South Africa.CSIR/NRE/ECO/2006/0011/C. CSIR. CSIR Report.

BCLME SAP (Benguela Current Large Marine Ecosystem Strategic Action Plan). 1999. Strategic Action Plan for the Integrated Management and Sustainable Development and Protection of the Benguela Current Large Marine Ecosystem. Windhoek: UNDP (United Nations Development Programme).

BCLME TDA. 1999. Benguela Current Large Marine Ecosystem Programme (BCLME) Transboundary Diagnostic Analysis (TDA). Windhoek: UNDP.

Beeftink W.G. 1979. The structure of salt marsh communities in relation to environmental disturbances. In: Jefferies R.L., Davy A.J., editors. Ecological processes in coastal environments. Oxford: Blackwell.

Benade, C. 1988. Episodic flood events in the Orange River System – an ecological perspective. Proc. Conf. Floods in Perspective, Pretoria, Paper 3.1: 1-12.

Birch, G.F. 1975. Sediemnts on the continental shelf margin off the west coast of South Africa. Bulletin of the Joint Geological Survey/University of Cape Town Marine Geoscience Unit 6, 142 pp.

Bornman, T. G. 2002. Freshwater requirements of supratidal and floodplain salt marsh on the West Coast, South Africa. PhD Thesis, University of Port Elizabeth, Port Elizabeth, South Africa. 243 pp.

Bornman, T.G. and J.B. Adams 2010. Response of a hypersaline salt marsh to a large flood and rainfall event along the west coast of southern Africa. Estuarine, Coastal and Shelf Science 87: 378–386

Bornman, T.G., Adams J.B. and C. Bezuidenhout 2004. Adaptations of salt marsh to semi-arid environemtns and management implications for the Orange River mouth. Transactions of the Royal Society of South Africa 59: 85-91.Bornman, T.G. and J.B. Adams 2010. Response of a hypersaline salt marsh to a large flood and rainfall event along the west coast of southern Africa. Estuarine, Coastal and Shelf Science. 87: 378-386

Branch, G.M., Eekhout, S. and A.L. Bosman, 1990. Short-term effects of the 1988 Orange River floods on the intertidal rocky-shore communities of the open coast. Transactions of the Royal Society of South Africa 47: 331-354.

Branch, G.M. and Griffiths, C. 1988. The Benguela ecosystems. Part V. The coastal zone. Oceanography and Marine Biology Annual Review 26: 396-486.

Bremner, J.M., Rogers, J. and A. De Wet 1990 Sedimentological aspects of the 1988 Orange River Floods. Transactions of the Royal Society of South Africa. 47: 217-294

Brown, A.C. 1959. The Ecology of South African estuaries. Part IX: Notes on the estuary of the Orange River. Transactions of the Royal Society of South Africa 35: 463-473.

Brown, C.A., Ewart-Smith, J., Conrad, J. and Rossouw, N. 2006: The development of the water resource classification system (WRCS). Volume 2. Ecological, hydrological and water quality guidelines for the 7-step classification procedure. Department of Water Affairs and Forestry, Pretoria, 136pp.

Brown, P. C. 1992. Spatial and seasonal variation in chlorophyll distribution in the upper 30 m of the photic zone in the southern Benguela/Agulhas ecosystem. In: Payne, A. I. L., Brink, K. H., Mann, K. H. and Hilborn, R. (Eds). Benguela Trophic Functioning. South African Journal of Marine Science 12: 515-525.

Brown, P. C. and L. Hutchings 1987. The development and decline of phytoplankton blooms in the southern Benguela upwelling system. I. Drogue movements, hydrography and bloom development. In: Payne, A.I.L., Gulland, J.A. and Brink, K. H. (Eds) The Benguela and Comparable Ecosystems. South African Journal of Marine Science 5: 357-391.

Brundrit GB. 1995. Trends in southern Africa sea level: statistical analysis and interpretation. South African Journal of Marine Science 16: 9–17.

Burns, MER. 1989. The vegetation of the Orange River mouth. Unpublished Paper. Orange River environmental workshop, Oranjemund.

Chao,S.Y. and W.C. Boicourt 1986. Onset of an estuarine plume Journal Physical Oceanography 16: 2137-2149.

Chapman, P. and L.V. Shannon 1985. The Benguela ecosystem Part ll. Chemistry and related processes. Oceanography and Marine Biology: an Annual Review 23: 183-251.

Christie, N.D. 1975. Relationship between sediment texture, species richness and volume of sediment sampled by a grab. Marine Biology 30: 89-96.

Clark, B.M. 2006. Climate change: A looming challenge for fisheries management in southern Africa. Marine Policy 30: 84–95.

Compton, J.S. and J.G. Wilshire 2009. Terrigenous sediment export from the western margin of South Africa on glacial to interglacial cycles. Marine Geology 266: 212-222.

Cooper, J.A.G., Wright, C.I. and T.R. Mason 1999. Geomorphology and Sedimentology of South African Estuaries. In: Estuaries of South Africa, (Eds.) Allanson, B.R. and D. Baird. Cambridge University Press, Cambridge, pp. 5-25.

Cowan, G.I. 1995. South Africa and the RAMSAR Convention. In: Cowan, G.I. (Ed.) Wetlands of South Africa. South African Wetland Conservation Programme Series. Department of Environmental AFfairs and Tourism, Pretoria, 292 pp.

Crawford, R. J. M., L. V. Shannon and D.E. Pollock 1987. The Benguela ecosystem. Part IV. The major fish and invertebrate resources. Oceanography and Marine Biology: An Annual Review 25: 353-505.

CSIR. 1984. Preliminary chemical studies in four Cape estuaries. CSIR Report T/SEA 8307. Stellenbosch.

CSIR, 1985. Freshwater requirements of the Orange River Estuary. CSIR Report C/Sea 8533, Stellenbosch.

CSIR, 1988. Basic physical geography/hydro data for estuaries of the Western Cape (CW1-32). NRIO Data Report D8802. Stellenbosch.

CSIR. 1991. Environmental rehabilitation: Orange River Saltmarshes. CSIR Report EMA - C 91165 CSIR Stellenbosch.

CSIR, 1994. Alexcor environmental management programme. CSIR Contract Report EMAS-C94037, Stellenbosch.

Day, J.H. 1981. Summaries of current knowledge of 43 estuaries in southern Africa. In: Estuarine ecology with particular reference to southern Africa. Pp. 251-330. Day, J.H. (Ed.). A.A. Balkema, Cape Town.

De Decker, A.H.B. 1970. Notes on an oxygen depleted subsurface current off the west coast of South Africa. Investl. Rep. Div. Sea Fish. S. Afr. 84: 1-24.

De Decker, R.H. 1988. Cruise Report: T B Davie514, May 24 to June 1, 1988. A survey to investigate the distribution of Orange River flood sediment. Unpubl. Rep. Geol. Surv. S. AFr. 9 pp.

Department of Water Affairs and Forestry (DWAF) 1999. Water resource protection and assessment policy implementation process. Volume 5: Resource directed measures for protection of water resources: estuarine ecosystems component. Report No. N\31\99. Pretoria.

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

Dollar, E.S.J., Brown, C.A., Turpie, J.K., Joubert, A.R., Nicolson, C.R. and Manyaka, S. 2006: The development of the Water Resource Classification System (WRCS). Volume 1. Overview and 7-step classification procedure. Department of Water Affairs and Forestry, Pretoria, 70pp.

Earle, A., D. Malzbender, A. Turton, and E. Manzungu. 2005. A Preliminary Basin Profile of the Orange/Senqu River. AWIRU, University of Pretoria, South Africa, ISBN: 1-86854-618-7. 44 pp.

Hollingworth, B. 2007. Strengthening river basin organisations (RBOs) in the SADC Region – Programme Document Final – SADC-Infrastructure and Services Directorate – Water Division – Project CB-4 of the RSAP2, p. 53.

Gan, J., Li, L., Wang, D. and X. Guo, 2009. Intersction of a river plume with coastal upwelling in the northeastern South China Sea. Continental Shelf Research. 29: 728-740

Gamito, S. 2008. Water Framework Directive: Defining the Ecological Quality Status in Transitional and Coastal Waters. In: (Gŏnenç et al.) Sustainable Use and Development of Watersheds NATO Science for Peace and Security Series 3, 323-335.

Griffiths, C. L., L. van Sittert, P. B. Best, A. C. Brown, B.M Clark, P. A. Cook, R. J. M. Crawford, J. H. M. David, B. R. Davies, M. H. Griffiths, K. Hutchings, A. Jerardino, N. Kruger, S. Lamberth, R. Leslie, R. Melville-Smith, R. Tarr and C. D. van der Lingen, 2004. Impacts of human activities on marine animal life in the Benguela – An historical overview. Oceanogr. Mar. Biol. Ann. Rev. 42: 303-392.

Hampton, I. 2003. Chapter 5: Harvesting the Sea. In: Namibia's Marine Environment (Molloy, F. and Reinikainen Eds.) Directorate of Environmental Affairs of the Ministry of the Environment and Tourism, Namibia.

Hampton, I., Boyer, D.C., Penney, A.J., Pereira, A.F. and M. Sardinha 1999. Integrated Overview of Fisheries of the Benguela Current Region. BCLME Thematic Report 1. For the Second Regional

Workshop on the Benguela Current Large Marine Ecosystem. 12-16 April 1999, Windhoek, Namibia.

Harrison, T. D. 1997. A preliminary survey of coastal river systems on the South African west coast, Orange River - Groot Berg, with particular reference to the fish fauna. Transactions of the Royal Society of South Africa 52(2): 277-321.

Holzwarth, U., Esper, O. and Zonneveld, K. 2007. Distribution of oranic-walled dinoflagellate cysts in shelf surface sediments of the Benguela upwelling system in relationship to environmental conditions. Marine Micropaleontology. 64: 91-119

Hughes, W.S. and Balling, R. C. 1996. Urban influnces on Southern African temperature trends. International Journal of Climatology, 16, 935-940.

Hulme, M. (ed.) 1996. Climate change and southern Africa: an exploration of some potential impacts and implications for the SADC region. Reoprt commissioned by WWF international and co-ordinated by the Climate Research Unit, UEA,Norwich,UK

Hutchings, L., van der Lingen, C.D., Shannon, L.J., Crawford, R.J.M., Verheye, H.M.S., Bartholomae, C.H., van der Plas, A.K., Louw, D., Kreiner, A., Ostrowski, M., Fidel, Q., Barlow, R.G., Lamont, T., Coetzee, J., Shillington, F., Veitch, J., Currie, J.C. and Monteiro, P.M.S. 2009. The Benguela Current: An ecosystem of four components. Progress in Oceanography. 83: 15-32

IPCC, 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Kiker, GA. 1999. South African County Study on Climate Change Synthesis Report for the Vulnerability and Adaptation Assessment Section (DRAFT). School of Bioresources Engineering and Environmental Hydrology University of Natal

Klein RJT, Nicholls RJ. 1999. Assessment of coastal vulnerability to climate change.
Ambio; 28: 182–7.

Kriel, J.P. 1972. The role of the Hendrik Verwoed Dam in the Orange River Project. The Civil Engineer in South Africa Feb 1972: 51-61.

le Clus, F. H., H.F-K. Melo, Y.C. and A J. Boyd, 1994. The impact of the extent and locality of mud patches on the density and geographic distribution of juvenile agulhas sole, Austroglossus pectoralis (Soleidae). South African Journal of Marine Science 14: 19-36.

Lisitizin, A.P. 1972. Sedimentation in the World Ocean. Spec. Publ. Soc. Econ. Pal. Min. 17: 1-218.

Lombard, A.T., Strauss, T. , Harris, J., Sink, K., Attwood, C. and Hutchings, L. 2004. South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 4: Marine Component. Pretoria: South African National Biodiversity Institute.

Mabote, ME. Rogers, J. and E. Meadows 1997. Sedimentology of terrigenous mud from the Orange River Delta and the inner shelf off Namaqualand, South Africa. South African Geographical Journal 79: 108-114.

Malzbender, D, Earle, A., 2007: The Impact and Implications of the Adoption of the 1997 UN Watercourse Convention for Countries in Southern Africa. Study commissioned by WWF International – Global Freshwater Programme. African Centre for Water Research, Cape Town, South Africa.

McLachlan, A. 1981. Exposed sandy beaches as semi-closed ecosystems. Marine Environmental Research 4: 59-63.

McLusky, D.S., Elliott M. 2007. Transitional waters: A new approach, semantics or just muddying the waters?. Estuarine, Coastal and Shelf Science 71 359-363

Meadows, M.E., Dingle, R.V., Rogers J. and E.G. Mills 1997. Radiocarbon chronology of Namaqualand mudbelt sediments: problems and prospects. South African Journal of Science 93: 321-327.

Meadows, M.E., Rogers J., Lee-Thorpe, J.A., Bateman, M.D. and R.V. Dingle 2002. Holocene geochronology of a continental shelf mudbelt off southwestern Africa. The Holocene 12: 59-67.

Morant, P D and O'Callaghan, M. 1990. Some observations on the impact of the March 1988 flood on the biota of the Orange River Mouth. Transactions of the Royal Society of South Africa 47: 295-305.

Nelson, G. 1987. Low-frequency currents along the west coast of South Africa. Abstr. 6th Nat. Oceanogr. Symp. Stellenbosch, S. Afr. 252: C-29.

Nicholls R.J., Hoozemans F.M.J., Marchand M. 1999. Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. Global Environmental Change;9:69–87.

O'Callaghan, M. 1984. Some management recommendations for the Orange River near Alexander Bay. Unpublished Report. Submitted to State Alluvial Diggings, Alexander Bay.

ORASECOM 2008. Orange-Senqu River Basin Preliminary Transboundary Diagnostic Assessment.

O'Toole, M.J., Shannon, L.V., Debarros Neto, V. and Malan, D.E. 2001. Integrated Management of the Benguela Current Region: A Framework for Future Development. In: Science and Integrated Coastal Management (eds) B. von Bodungen and R.K. Turner, Dahlem University Press. Pp. 229-251.

Perry, J. 1988. Basic physical oceanography/hydro data for 'estuaries' of the Western Cape (CW 1-32). Data Rep. N.R.I.O., C.S.I.R. D8802: 1-6.

Raal, P. 1996. The vegetation of the Orange River Mouth. In: *A. Venter and M van Veelen*. Refinement of the instream flow requirements of the Orange River and Orange River Mouth. Department of Water Affairs and Forestry, Pretoria.

Richtersveld Municipality 2009. The Richtersveld Municipality Integrated Development Plan Review - 2009. 73 pp.

Rogers, J. 1977. Sedimentation on the continental margin off the Orange River and Namib Desert. Bull. Jt Geol. Surv./Univ. Cape Town Mar. Geosc. Unit 7: 1-212.

Rogers, J. and J.M. Bremner 1991. The Benguela Current Ecosystem. Part VII. Marine geological aspects. Oceanography and Marine Biology: An Annual Review 29: 1-85.

Rogers, J. and A.J. Rau. 2006. Surficial sediments of the wave dominated Orange River Delta and the adjacent continental margin off south-western Africa. African Journal of Marine Science 28: 511-524.

Rooseboom, A. 1974. Meting en analise van sedimentvoer in riviere. Tech. Rep. Dept Water Affairs S. Afr., 58: 1-43.

Rooseboom, A. 1975. Sedimentproduksiekaart vair Suid-Afrika. Tech. Rep. Dept Water Affairs S. Afr. 61:1-13

Rooseboom, A. 1978. Sedimentvloei in Suider-Afrikaanse reviere. Water S. Africa 4: 14-17.

Rooseboom, A. and N.F. Maas. 1974. Sedimentafvoergegewens vir die Oranje, Tugela- en Pongola-riviere. Tech. Rep. Dept Water Affairs S. Afr. 59: 1-48.

Rooseboom, A. and H.J. Von M. Harmse. 1979, Changes in the sediment load of the Orange River during the period 1929-1969. Sci. Publ. Int. Assoc. Hydrol. 128: 459-470.

Ryan P.G. and Cooper J. 1985. Waders (Charadrii) and other coastal birds of the Northwestern Cape Province, South Africa. Bontebok 4: 1–8.

Sakko, A. 1999. Biodiversity of Marine Habitats. In: Biological Diversity in Namibia – a country study. (Bernard, P. Ed) Windhoek: Namibian National Biodiversity Task Force. At 189-221.

Schumann, E. Largier, J. and J. Slinger 1999. Estuarine hydrodynamics. . In: Estuaries of South Africa, (Eds.) Allanson, B.R. and D. Baird. Cambridge University Press, Cambridge, pp. 27-52.

Seaman, M.T. and J.G. Van As 1998. The environmental status of the Orange River mouth as reflected by the fish community. Water Research Commission Report No 505/1/98, 73 pp.

Shannon, L.V. 1985. The Benguela ecosystem Part I. Evolution of the Benguela, physical features and processes. Oceanography and Marine Biology: An Annual Review 23: 105–182.

Shannon, L.V. and M.J. O'Toole 1998. Integrated Overview of the Oceanography and Environmental Variability of the Benguela Current Region. BCLME Thematic Report 2. For the Second Regional Workshop on the Benguela Current Large Marine Ecosystem. 12-16 April 1999, Windhoek, Namibia. BCLME Tematic Report 1. For the Second Regional Workshop on the Benguela Current Large Marine Ecosystem. 12-16 April 1999, Windhoek, Namibia.

Shaw, G.A., Adams, J.B. and Bornman, T.G. 2008. Sediment characteristics and vegetation dynamics as indicators for the potential rehabilitation of an estuary salt marsh on the arid west coast of South Africa. Journal of Arid Environments. 72: 1097-1109

Shillington, F. A., Reason, C.J.C., Duncombe Rae, C.M. Florenchie P. and P. Penven 2006. Large Scale Physical Variability of the Benguela Current Large Marine Ecosystem (BCLME). In: V. Shannon, G. Hempel, P. Malanotte-Rizzoli, C. Moloney and J. Woods (Eds.) Large Marine Ecosystems, Vol. 14, pp. 47-68. Elsevier, Amsterdam.

Skov, H., Bloch, R., Stuer-Lauridsen, F. and D. Uushona. 2009. Strategic Environmental Assessment (SEA) for the coastal areas of the Karas and Hardap Regions. Unpublished report prepared for NACOMA, Windhoek. 84 pp.

Strømme, T. Lipinski, M., Ostrowski, M. and O. Alvheim. 2004. BCLME Survey No. 1. A Transboundary Study with Emphasis on Deep Water Hake in the Lüderitz-Orange River Cone Area. Cruise reports "Dr. Fridtjof Nansen" No 5/2004, 19 April-2 May 2004. Institute of Marine Research, Bergen, Norway, and Marine and Coastal Management, Cape Town, South Africa. 47 pp.

Strømme, T. Lipinski, M., Ostrowski, M. and O. Alvheim. 2005. BCLME Survey No. 2. Transboundary Survey between Namibia and South Africa with Focus on Shared Stocks of Hake. Cruise reports "Dr. Fridtjof Nansen" No 2/2005, 4 February-9 March 2005. Institute of Marine Research, Bergen, Norway, and Marine and Coastal Management, Cape Town, South Africa. 82 pp.

Strømme, T. Kainge, P., Lipinski, M., Ostrowski, M., Stenevik, E.-K. and O. Alvheim. 2005. BCLME Survey No. 3. Transboundary Survey between Namibia and South Africa with Focus on Spawning and the Early Life History of Hakes. Cruise reports "Dr. Fridtjof Nansen" No 10/2005, 26 September-17 October 2005. Institute of Marine Research, Bergen, Norway, National Marine Information and Research Centre Swakopmund, Namibia, and Marine and Coastal Management, Cape Town, South Africa. 67 pp.

Swart, D.H., Crowley, J.B., Moller, J.P. and A.De Wet 1990. Nature and behaviour of the flood at the river mouth. Transactions of the Royal Society of South Africa. 47: 217-245

Taljaard, S., van Niekerk, L., Huizinga, P., Theron, A.K., Adams, J.B., Wooldridge, T., Lamberth, S.J. and M. Anderson 2003. Determination of the preliminary Ecology Reserve on a rapid level for the Orange River Estuary. Department of Water Affairs and Forestry, South Africa and Department of Water Affairs, Nambia, 112 pp.

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

United Nations. 1983. United Nations Convention on the Law of the Sea 1982. New York: United Nations.

Van Niekerk, L. van Neto, D.S. Boyd A.J. and H. Holtzhausen 2008. BCLME Project BEHP/BAC/03/04 - Baseline Surveying of Species and Biodiversity in Estuarine Habitats. Report prepared for the Benguela Current Large Marine Ecosystem Programme (BCLME), 151 pp.

Vosloo, R. and H. Bouwman 2005. Survey of certain persistent organic pollutants in major South African waters. Water Research Commission, Pretoria. WRC Report No. 1213/1/05

*Warburton, M. and Schulze, R.E. 2005*a. Detection of Trends over Time in Hydrological Drivers and Responses over Southern Africa. In: Schulze, R.E. (Ed) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Water Research Commission, Pretoria, RSA, WRC Report 1430/1/05. Chapter 17, 297-318.

Warburton, M. and Schulze, R.E. 2005b. Historical Precipitation Trends over Southern Africa: A Hydrology Perspective. In: Schulze, R.E. (Ed) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Water Research Commission, Pretoria, RSA, WRC Report 1430/1/05. Chapter 19, 325-338.

Williams, A.J. 1990. Orange River Mouth Wetland South Africa: Information sheet for the site designated to the List of Wetlands of international importance in terms of the Convention on Wetlands of International Importance especially as waterfowl habitat. South African Wetands Conservation Programme.