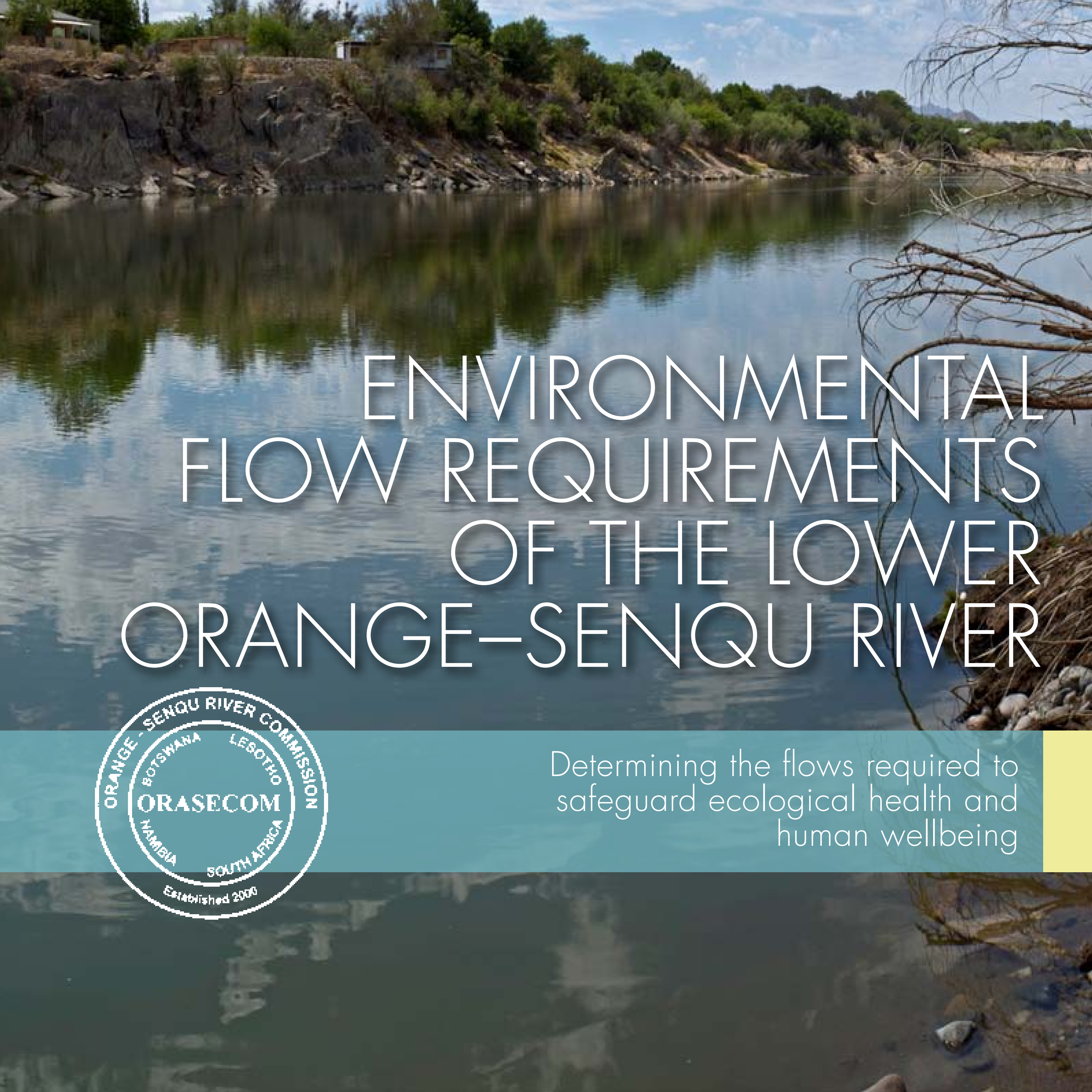

# ENVIRONMENTAL FLOW REQUIREMENTS OF THE LOWER ORANGE–SENQU RIVER

ORANGE - SENQU RIVER COMMISSION
BOTSWANA LESOTHO
ORASECOM
NAMIBIA SOUTH AFRICA
Established 2000

Determining the flows required to safeguard ecological health and human wellbeing

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# ENVIRONMENTAL FLOW REQUIREMENTS OF THE LOWER ORANGE–SENQU RIVER

Determining the flows required to safeguard ecological health and human wellbeing

# FOREWORD

Meeting high demands for water resources has reduced the amount of water reaching the mouth of the Orange–Senqu River to less than half of its average annual natural runoff. The natural pattern of flow has been altered, the frequency and size of floods reduced and the frequency of low flows has been changed. These changes in flow regime affect the ecosystems associated with the river – not least in its arid lower reaches – and potentially the long-term sustainability of the river's water resources. To help determine the flows required to maintain the integrity of these ecosystems, a number of assessments have been carried out along various sections of the basin's river system.

Water demands continue to increase. More dams are planned to help meet these demands, including two in the lower reaches of the river basin – the Vioolsdrift on the lower Orange River and the Neckartal on the ephemeral Fish River. The Orange–Senqu River Commission's (ORASECOM's) UNDP–GEF-funded Orange–Senqu Strategic Action Programme undertook a research project in 2012–2013 along the lower Orange and Fish rivers and at the ecologically sensitive and important estuary (a Ramsar site) to determine the ecological states of these sections of the river and the environmental flow regime required to improve them. This project has assisted the Orange–Senqu River basin states (Botswana, Lesotho, Namibia and South Africa), via ORASECOM, to fulfil their commitment to address threats to the water resources they share. The intention is that through cooperation between the basin states, synchronised catchment releases will ensure appropriately timed flows of enough water, of sufficiently good quality, to sustain the ecosystem of the Orange–Senqu River basin and the needs of its human population.

This booklet is based on the material produced by the environmental flow assessment research project and other related documents and studies. It provides a summary of the process and findings in an attractive and accessible format that is intended to provide a handy reference for technical personnel and policy-makers, and enhance understanding of this complex subject. It also provides recommendations for policy and programme action.

Lenka Thamae
Executive Secretary
ORASECOM

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 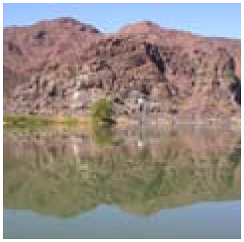   



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# THE ORANGE–SENQU RIVER BASIN

The Orange–Senqu River basin is the largest in southern Africa south of the Zambezi, with an area of almost a million square kilometres. The catchment encompasses the whole of Lesotho and parts of Botswana, Namibia and South Africa, and is inhabited by more than 14 million people.

The river rises in the highlands of Lesotho as the Senqu River before crossing the border into South Africa, where its name changes to the Orange River. It is joined by a number of tributaries, including the Caledon, Vaal and Fish, before reaching the Atlantic Ocean on the subcontinent's west coast, some 2,300 kilometres from its source.

During the course of its journey to the sea, much of the river's water is abstracted, diverted or stored for human needs, with the result that the quantity reaching the mouth is about 40% of its natural volume. Dams, transfer schemes and weirs also alter flow patterns, and may therefore affect water quality, temperature, sediment transport, and plant and animal life – and ultimately the people who depend on the river.

The four countries in the basin are committed to a collaborative approach in addressing threats to their shared water resources, and established the Orange–Senqu River Commission (ORASECOM) to facilitate this. ORASECOM provides a forum for consultation and coordination between the member states to promote integrated water resources management, aimed at developing water resources for maximal socio-economic welfare without compromising long-term environmental sustainability.

One of the main aspects of this will be to ensure that the flow of water in the riverine ecosystem allows it to continue to function in a predetermined ecological condition and provide for the people in the basin. This water is known as the environmental flow.

Environmental flows have been described as the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems, as well as human livelihoods and wellbeing that depend on these ecosystems.


## ORANGE–SENQU RIVER COMMISSION

The Orange–Senqu River Commission – ORASECOM – was established by the goverments of Botswana, Lesotho, Namibia and South Africa to promote equitable and sustainable development and management of the resources of the Orange–Senqu River. This joint commitment was sealed in November 2000 with the signing of the 'Agreement on the Establishment of the Orange–Senqu River Commission', which conforms to best international practices regarding the joint management of shared rivers. The ORASECOM Council, consisting of delegations from each country, is supported by a Secretariat and various 'Task Teams' that manage projects.

## Assessing environmental flows

The first assessment of environmental flows in the Orange–Senqu River basin was based on a workshop convened by the Orange River Environmental Task Group in August 1990, focusing on the environmental flow requirements of the Orange River between Vanderkloof Dam (then known as the PK le Roux Dam) and the mouth. Since then, environmental flow assessments have been conducted for various parts of the basin, but they vary in terms of their basic approach and the level of detail at which they were done.

International methods of assessing environmental flows were found to be unsuitable for use in southern Africa, so the Building Block Methodology – or BBM – was developed in the early 1990s. It was so-named because it aims to identify the blocks of a river's natural flow regime that are most significant, and build these into a skeleton of the natural flow regime.

The first building block is the low-flow, or baseflow, component, which defines the degree to which the river flows year-round under conditions of normal rainfall, as well as the timing of wet and dry seasons. Subsequent building blocks add higher flows that are considered to be essential in performing a required ecological or geomorphological function, including small to medium-sized floods in the wet season. Large floods, although extremely important from a geomorphological perspective, are not included as they cannot be managed through dam releases.

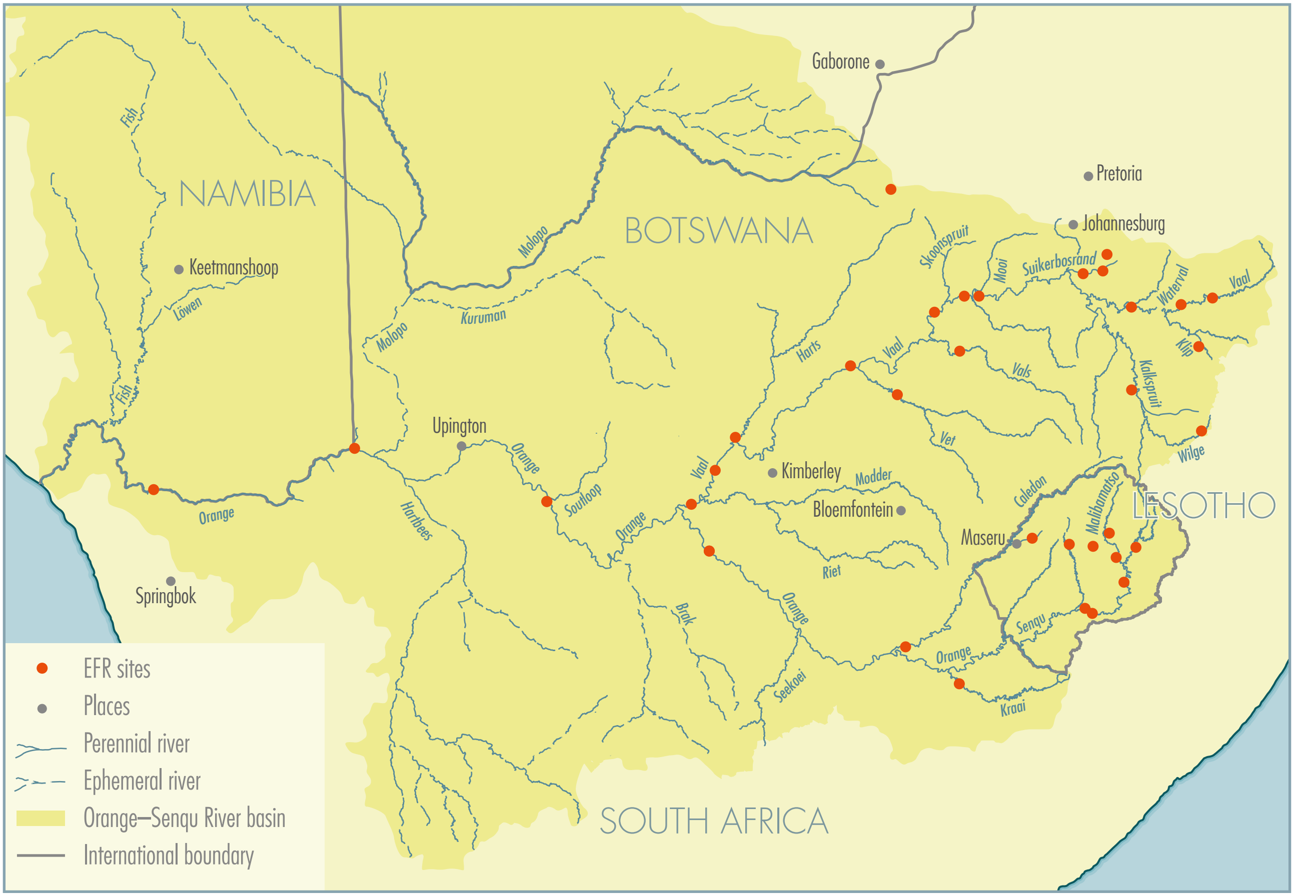
Subsequently, BBM gave rise to two new methods. The first was called DRIFT, an acronym for Downstream Response to Imposed Flow Transformations. The method uses a scenario-based approach, in which potential future flow regimes are evaluated and the ecological consequences predicted. The second, the Habitat Flow Stressor Response (HFSR) method, likewise consists of a process to determine a flow regime that could result in a range of ecological states and can be used to evaluate scenarios.

DRIFT and HFSR are similar in terms of the information they require, and broad-level evaluations suggest that they produce comparable outputs in terms of the predicted impacts associated with changes in flow.

Both DRIFT and HFSR are used for environmental flow assessments conducted at a detailed level, which entails field work and systematic assessments at study sites. There are also desktop models that can be used for more rapid assessments. These exclude field work and use available information to provide low-confidence estimates of environmental flow requirements.

In the case of estuaries, a separate method for determining environmental flow requirements has been developed. This adheres to the same general process applied to rivers, and uses a scenario-based approach.

Environmental flow assessments conducted in the Orange–Senqu River basin prior to the current study are indicated on the map. The ecological consequences of such flow regimes are evaluated during environmental flow assessments.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Springbok
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Löwen
Molopo
Kuruman
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Vaal
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Mooi
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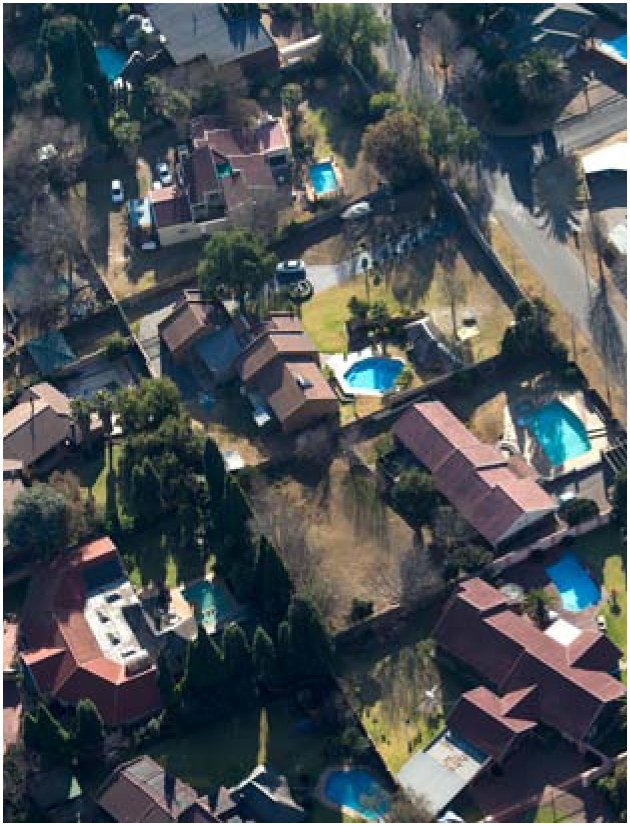
Orange–Senqu River basin
International boundary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## Implementing environmental flows

Although numerous environmental flow assessments have been conducted in the Orange–Senqu River basin, only those for the Senqu sub-basin in Lesotho are currently being actively implemented and monitored.

One of the main challenges in implementing environmental flows is the level of integration required between technical, legal, administrative and political processes, and the private and government sectors. This becomes progressively more important and difficult with increasing development of the basin.

In basins where the demand on water resources is high relative to natural supply, decisions on the volume and distribution of water allocated to environmental flows often necessitate complex technical studies. These explore numerous scenarios, require difficult trade-offs and involve extensive public participation, both during the technical work and for legislating the outcomes. Onerous policing and monitoring regimes are needed to ensure compliance. They also require interventions that depend on people changing their perceptions and behaviour. This means they need broad governmental and societal support, coupled with a programme of technical assistance and cross-disciplinary capacity-building.


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Environmental flows from the Katse Dam (top right) in Lesotho are actively implemented and monitored, but pressure on water resources for industrial, agricultural and domestic needs poses a challenge to effective implementation in many other parts of the basin.





## Environmental flows in the lower Orange River

Environmental flow assessments are undertaken at specific sites, called EFR sites, selected within management resource units (MRUs). The environmental flow requirements determined at each EFR site are representative of the flow requirements of the MRU.

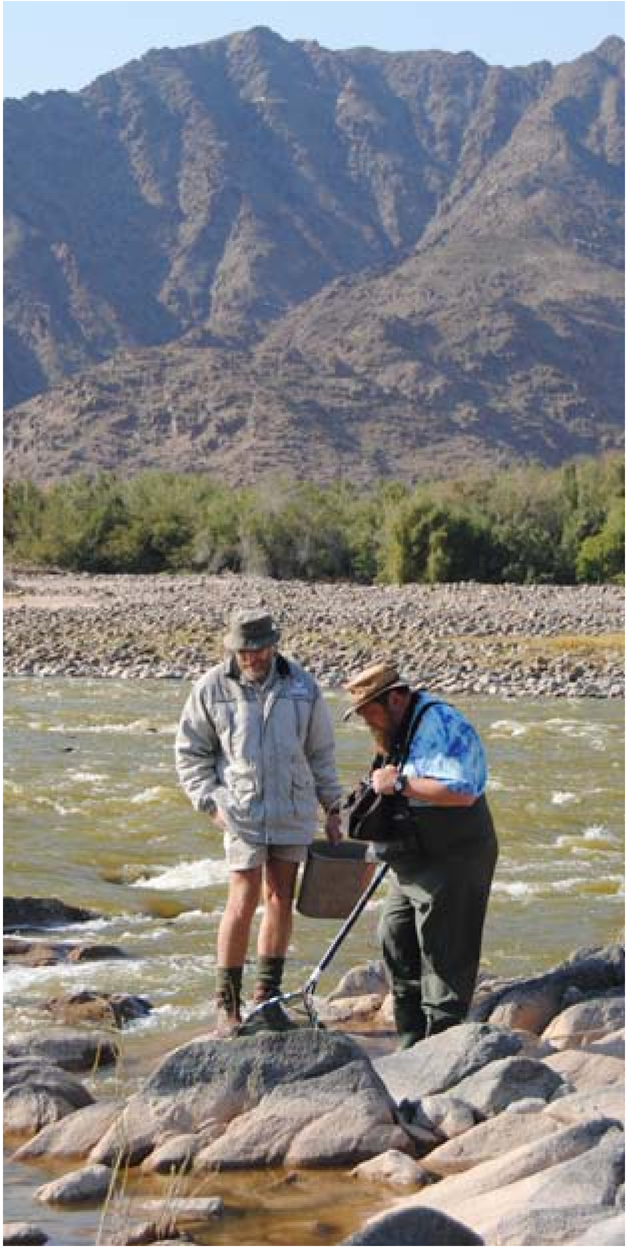
In 2009, with funding from the German Agency for International Cooperation, GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), ORASECOM commissioned a study on the environmental flow requirements at four sites in the Orange River downstream of Vanderkloof Dam and four on the Caledon, Kraai and upper Molopo rivers.

Given that the most downstream EFR site was at Vioolsdrift, the study area excluded the river reach of the lower Orange River between the Fish River confluence and the mouth. This part of the catchment is extremely arid, with rainfall averaging less than 50 millimetres per year, so the mouth and estuary are highly dependent on the upper parts of the system for freshwater inputs. An additional environmental flow assessment was therefore conducted in 2012–2013 as part of the UNDP–GEF Orange–Senqu Strategic Action Programme. This focused on the Orange River downstream of the Fish River confluence and the estuary, but also included the Fish River and the nearshore marine environment.

The MRU for the lower Orange River was the river reach between the Fish River confluence and the estuary. The EFR site for this MRU was named EFR 05 and was situated about six kilometres upstream of Sendelingsdrift, within the /Ai-/Ais–Richtersveld Transfrontier Park. A baseline survey of physico-chemical and biological features was conducted at the site in June 2012 as part of the environmental flow assessment.

The estuary MRU extended from the Sir Ernest Oppenheimer Bridge – the approximate limit of tidal influence – to the mouth, some 11 kilometres downstream. It also included the banks up to the five-metre contour. The entire area, totalling approximately 2,700 hectares, comprised the EFR site. The baseline survey for the study took place in November 2012.


The environmental flow assessment conducted for the lower Orange River at site EFR 04 near Vioolsdrift in 2009 did not include the river downstream of the Fish River confluence. The more recent study therefore focused on site EFR 05 (left) near Sendelingsdrift and the Orange River estuary.



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## Methods and outputs

A team of subject specialists conducted the environmental flow assessment on the lower Orange River and estuary using findings from the baseline surveys, available data from previous surveys and ongoing monitoring, and their expert knowledge of features that could be expected at the site.

The first step was to apply the ecological classification process for each environmental flow assessment (EFR) site, which includes the following tasks:

- Determine the present ecological state (PES) by evaluating the health of the various biophysical components against their likely reference condition – the pristine, natural state. The causes of change are identified, and a PES is allocated within a range of ecological categories from A (near natural) to F (critically modified).
- Define the ecological importance, as well as the socio-cultural importance, by considering a range of criteria and providing an importance rating ranging from low to very high.
- Based on the importance rating, derive a recommended ecological category (REC) to maintain the PES (if importance is low or moderate) or improve the PES (if the importance is high or very high).

The next step is either to set environmental flow requirements for different ecological categories, and/or to evaluate different scenarios and predict the change from the PES. A scenario is a combination of developments and management interventions – or drivers – that are possible in the future and usually linked to a likely timeframe. Typical examples of drivers are construction of new dams, increased water use due to new activities, and dam releases to meet environmental flow requirements.

Baseline surveys were conducted on the lower Orange River (left) and estuary (above right) for the environmental flow assessment.

Based on information collated during the study, a flow requirement can be set, recommendations regarding scenarios can be made and an optimisation process followed with the aim of minimising impacts on the ecology, the ecosystem services and the yield of the system.

A monitoring programme is also designed, incorporating ecological specifications and thresholds of potential concern. Ecological specifications allow predictions made during the study to be tested, while thresholds of potential concern are effectively 'red flags', prompting investigation into the cause of severe change and the need for corrective management action.

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Categories used in the ecological classification process

| Ecological category | PES score (%) | Description of the site |
|---|---|---|
| A | 90–100 | Unmodified, natural. Still in the reference condition. |
| B | 80–90 | Slightly modified from the reference condition. A small change in natural habitats and biota has taken place, but the ecosystem functions are essentially unchanged. |
| C | 60–80 | Moderately modified from the reference condition. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged. |
| D | 40–60 | Largely modified from the reference condition. A large loss of natural habitat, biota and basic ecosystem functions has occurred. |
| E | 20–40 | Seriously modified from the reference condition. The loss of natural habitat, biota and basic ecosystem functions is extensive. |
| F | 0–20 | Critically or extremely modified from the reference condition. The system has been critically modified with an almost complete loss of natural habitat and biota. In the worst instances, basic ecosystem functions have been destroyed and the changes are irreversible. |

The ecological categories used to classify the components at the EFR sites range between A and F, but some components may straddle the boundary of two categories, for example, B/C or C/D.

## Scenarios

Eight scenarios were identified for the environmental flow assessment on the lower Orange River and estuary. The scenarios comprised different combinations of the following development drivers, but implementation of some of these is not envisaged for the next 25 years.

### Orange River drivers

The **Metolong Dam** currently under construction on the south Phuthiatsana River in Lesotho will have a storage capacity of 63.7 million cubic metres. It forms part of the Metolong Dam and Water Supply Programme, which will supply treated water for domestic and industrial use to Maseru and neighbouring towns from September 2014.

**Tandjieskoppe** Green Scheme Project in the Karas Region of Namibia is an area of approximately 1,000 hectares near Noordoewer on the Orange River that has been earmarked for irrigation farming as an agricultural diversification, job-creation and socio-economic upliftment scheme.

**Acid mine drainage** (AMD) emanating from South Africa's abandoned gold and coal mines is increasing the salt loads of the Vaal River system. It is assumed that AMD will be successfully treated by 2020.

The environmental flow assessment funded by the GIZ and completed in 2010 determined the environmental flow requirements (EFRs) at eight sites in the Orange–Senqu River basin. Some of the scenarios assume that these **EFRs will be released** from dams.

'**Optimised releases from dams**' refers to water released for hydropower generation and irrigation. It is assumed that hydropower generation at Vanderkloof Dam will in future be limited to generation through water released for downstream use or water that would otherwise flow over the spillway. Improved operation of dams for irrigation releases is also anticipated.

The construction of the **Polihali Dam** is part of Phase 2 of the Lesotho Highlands Water Project (LHWP), which was launched in March 2014 and is expected to be completed by 2022. The dam will be built just downstream of the confluence of the Khubelu and Senqu rivers in Lesotho, and will have a storage capacity of 2,200 million cubic metres. It will further augment water supply to the Vaal sub-basin in South Africa, while providing Lesotho with infrastructure and hydroelectric power.

Construction of either a small **Vioolsdrift Balancing Dam** or larger **Vioolsdrift Dam** is being investigated as a flow-regulating structure to supply possible irrigation projects or shortfalls to existing irrigators due to development upstream. The dam would be situated near the Vioolsdrift–Noordoewer border post between South Africa and Namibia.

The **Boskraai Dam** has been proposed as a means of harnessing the water resource potential of the Upper Orange Water Management Area. This would be a large dam on the farm Bosberg at the confluence of the Orange and Kraai rivers near Aliwal North.

### Fish River drivers

The **Neckartal Dam** is being constructed on the Fish River near Snyfontein, some 25 kilometres north of Seeheim and 40 kilometres west of Keetmanshoop in Namibia. The dam will have a storage volume of approximately 857 million cubic metres and will provide water for irrigation of 5,000 hectares of land. Its impact on the flow regime of the lower Fish River – and hence the lower Orange River – will depend on the environmental flow releases made from the dam.

The Naute Dam on the Löwen River – a tributary of the Fish River in Namibia – has a storage capacity of 83.6 million cubic metres. It provides the water supply for Keetmanshoop and for an irrigation scheme downstream of the dam comprising 270 hectares of dates, grapes, pomegranates, prickly pears and pecan nuts. It is anticipated that there will be an **increase in Naute Dam irrigation** in the short term.

| Scenario | Orange River drivers | Fish River drivers |
|---|---|---|
| Scenario 1 | Modelled present-day current releases and use included. | |
| Scenario 2 | Metolong Dam, Tandjieskoppe, acid mine drainage (AMD) treated. | Neckartal Dam. Increase in Naute Dam irrigation. |
| Scenario 3 | Metolong Dam, Tandjieskoppe, AMD treated. | Neckartal Dam with EFR release. Increase in Naute Dam irrigation. |
| Scenario 4 | Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released. Optimised releases from dams. | Neckartal Dam with EFR release. Increase in Naute Dam irrigation. |
| Scenario 5 | Metolong Dam, Tandjieskoppe, AMD treated, 2010 EFR flows released, Polihali Dam, Vioolsdrift Balancing Dam (small). Optimised releases from dams. | Neckartal Dam with EFR release. Increase in Naute Dam irrigation. |
| Scenario 6 | Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams. | Neckartal Dam. Increase in Naute Dam irrigation. |
| Scenario 7 | Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, large Vioolsdrift Dam (no EFR), Boskraai Dam. Optimised releases from dams. | Neckartal Dam with EFR release. Increase in Naute Dam irrigation. |
| Scenario 8 | Metolong Dam, Tandjieskoppe, AMD treated, Polihali Dam, large Vioolsdrift Dam (EFR 04 released), Boskraai Dam. Optimised releases from dams. | Neckartal Dam with EFR release. Increase in Naute Dam irrigation. |



Naute Dam

# THE LOWER ORANGE RIVER

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On the final stretch of its journey to the Atlantic Ocean, the Orange River flows through the harsh environment of the Namib Desert. Few people live along the river, apart from subsistence stock-farmers who spend the summer months here with their herds of goats and sheep. The main commercial land uses downstream of the Fish River confluence are mining and ecotourism, but at Aussenkehr some 50 kilometres upstream 2,000 hectares of riverside land are under irrigation for grape production.

In its natural, pristine state – the reference condition – the lower Orange River would have had a mean annual runoff (MAR) of an estimated 11,373 million cubic metres. Today, the MAR is only 4,641 million cubic metres due to water abstraction higher up the catchment for industrial, agricultural and domestic use, and evaporative losses from dams. The dampening of high flows by dams means that small floods no longer occur, while the frequency and intensity of larger floods has been reduced significantly.

In addition, water releases from dams for irrigation schemes downstream, as well as for hydropower generation at the Gariep and Vanderkloof dams, have resulted in elevated flows in the river during low-flow periods and some reversal of seasonal flows. Water quality has also declined, because effluent discharges, runoff from agricultural land and other pollution sources cause elevated nutrient loads and salinity, and higher concentrations of some metal contaminants.

Opposite: The lower Orange River flows through a rugged landscape where few people live, but its waters irrigate 2,000 hectares of table-grape vineyards at Aussenkehr and sustain herds of goats and sheep belonging to subsistence stock-farmers.

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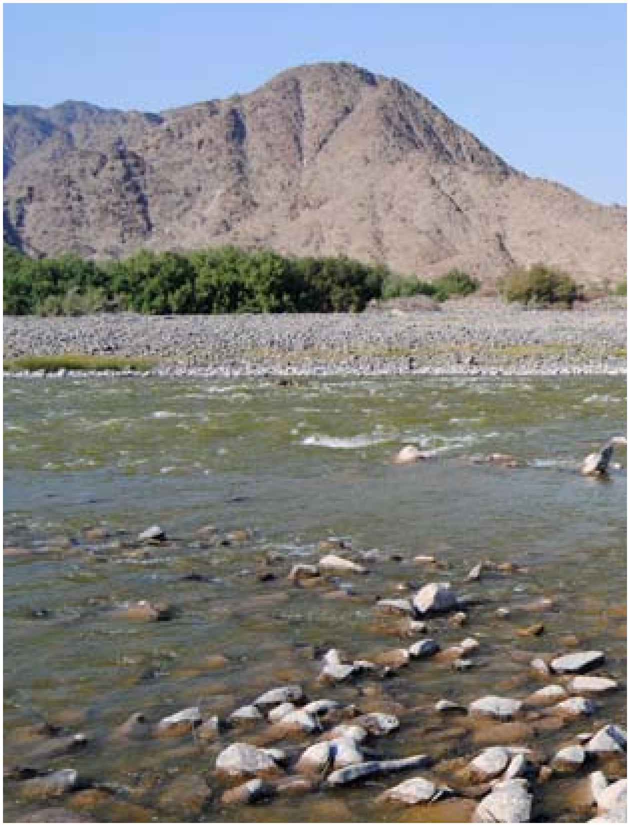

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## Habitat

Changes in flow and water quality have affected both instream and riparian habitat of the lower Orange River, and the animals that depend on it. The study site on the lower Orange River, EFR 05, lies in a river reach where channels activated during high flows become quiet backwaters and isolated pools once the waters recede. The reduction in small and moderate flood events means that these channels and pools cannot be sustained, while the lower frequency of large floods prevents regular scouring of sediment from the main channel and its banks.

Under reference conditions, the river reach would have included deep open-water areas, extensive sandbanks, large stretches of exposed shoreline, few reed beds and grassy edges, a continuous riparian corridor of woody thicket, and floodplains with temporary wetland areas. In the present ecological state, the more stable flows and lower frequency of scouring, together with an increased nutrient load, has allowed reed beds to expand and colonise new areas, reducing the extent of sandbanks and exposed shoreline. Infestation by alien *Prosopis* trees has further reduced sandbank habitat, and has also transformed the riparian corridor, where it has not been degraded by livestock trampling and grazing. Wetlands have virtually disappeared because floodplains are rarely inundated, and the river's pools have become shallower as a result of siltation.

The channel bed at the study site consists of large cobbles, but fine silt deposits occur in quiet backwaters and pools.

## Invertebrates

Macro-invertebrates such as insects, crustaceans, worms and molluscs are commonly used as indicators of the ecological health of river systems. Although there is little information on the species diversity and abundance of aquatic macro-invertebrates in the lower Orange River before the major dams in the catchment were built in the 1970s, 30 taxa used in river health scoring systems are expected to have occurred at site EFR 05, with filter feeders being most abundant. Only 21 of these 30 taxa were recorded during the survey in June 2012, and filter feeders were noticeably rare, but this was attributed to the scouring and turbidity resulting from high flows from the Fish River at the end of March.

The elevation of low flows in the dry season caused by dam releases – to generate hydropower and supply irrigation schemes and other downstream users – is considered to be the most important factor affecting the macro-invertebrate community, although other changes have probably played a role too. For example, historical flow data from the Boegoeberg Dam – built in the 1930s some 760 kilometres upstream of the study site – reveal that the driest month prior to the construction of the Gariep and Vanderkloof dams was September, with the first spring freshet usually occurring in November. After impoundment there was no winter dry period and no consistent spring freshet.

The increased nutrient load in the river may have altered food supplies and habitat, and has resulted in periodic blooms of potentially toxic blue-green algae (cyanobacteria) associated with significant reductions in macro-invertebrate abundance elsewhere in the system. Elevated salinity levels caused by irrigation return flows, and competition from invasive alien species such as the snail *Physa acuta*, are additional factors potentially contributing to the macro-invertebrate community's modified state.

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The invertebrate fauna of the lower Orange River includes mayfly larvae and freshwater shrimp.

## Fish

Any changes in macro-invertebrate abundance and species composition may have a knock-on effect for fish that feed on them, but the fish assemblage has also been impacted directly by changes in water quantity and quality, or plant-based food supplies and habitat. Fish species have different tolerance levels to changes in their environment, and different preferences in terms of velocity–depth regimes (i.e. slow–deep, slow–shallow, fast–deep or fast–shallow water) and type of cover, such as overhanging vegetation, aquatic plants, undercut banks or the water column itself.

Fish are also negatively impacted by increased competition and predation from invasive alien species, and at least four such fish species that would not occur naturally in the lower Orange River are found here – the carp *Cyprinus carpio*, the largemouth bass *Micropterus salmoides*, the Mozambique tilapia *Oreochromis mossambicus* and the redbreast tilapia *Tilapia rendalli*.

During the field survey in June 2012, 11 of the 12 indigenous fish species that could be expected to have occurred under reference conditions were recorded at the lower Orange River study site, EFR 05. These were the smallmouth yellowfish *Labeobarbus aeneus*, largemouth yellowfish *Labeobarbus kimberleyensis*, Namaquab barb *Barbus hospes*, threespot barb *Barbus trimaculatus*, straightfin barb *Barbus paludinosus*, river sardine *Mesobola brevianalis*, Orange River mudfish *Labeo capensis*, African sharptooth catfish *Clarias gariepinus*, rock catfish *Austroglanis sclateri*, southern mouthbrooder *Pseudocrenilabrus philander* and banded tilapia *Tilapia sparrmanii*. The moggel *Labeo umbratus*, which was probably scarce even under reference conditions, was not found but is still expected to occur within the river reach. Mozambique tilapia was the only alien fish recorded.

The Orange River mudfish was the most abundant and common fish in the samples, followed by the smallmouth yellowfish and river sardine. Although some species were estimated to have a slightly lower frequency of occurrence than under reference conditions, overall the fish assemblage was considered to be in a largely natural to slightly modified state.

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Above: The Orange River mudfish was the most abundant and common fish in samples from the study site.

Left, clockwise from top left: River sardine, southern mouthbrooder, African sharptooth catfish and Mozambique tilapia – the only alien fish recorded – were also found at the site.

## Other riverine animals

A variety of other animals living in the harsh, arid environment through which the lower Orange River flows are dependent on the river course for food, water and shelter. Some use it as a breeding ground or migration corridor at certain times of the year only, while others may visit when their temporary wetlands dry up during the dry season, or when high flows fill shallow pans on the floodplain.

Under reference conditions, 37 riverine animal species – comprising two mammals, 33 birds and two frogs – are expected to have occurred at the lower Orange River study site, EFR 05, and the adjacent river reach. These were associated with the following habitats:

- sluggish instream channel and pool habitats (ten species),
- backwater pool habitats (five species),
- exposed shoreline – shallow edge habitats (14 species),
- floodplain habitats (one species),
- reed-bed habitats (five species),
- grassy bank habitats (one species),
- wooded bank habitats (one species).

This diversity of species is unchanged today, with no species having been lost from the system. However, abundance of the more sensitive species can be expected to have changed in response to more consistent flows, and the resulting altered food supplies and reduced variability in riverine habitat.

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The marbled rubber frog, Namaqua dove, African red-eyed bulbul and Cape clawless otter are some of the animals expected to frequent the river reach close to the study site.

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## Ecological importance and sensitivity

After determining the present ecological state of the lower Orange River, the study team carried out the second task in the ecological classification process and assessed the ecological importance and sensitivity of site EFR 05 against a range of criteria. They found it to be high on the basis of instream and riparian species that are either rare and endangered or unique; the river course's importance as a migration corridor for various species; and the site's location within the /Ai-/Ais–Richtersveld Transfrontier Park.

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The camel-thorn tree, Orange River white-eye, black stork and smallmouth yellowfish are among the rare and endangered or unique species that contribute to the study site's ecological importance and sensitivity.

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## /AI-/AIS–RICHTERSVELD TRANSFRONTIER PARK

The /Ai-/Ais–Richtersveld Transfrontier Park was formally established on 1 August 2003 with the signing of an international treaty by President Sam Nujoma of Namibia and President Thabo Mbeki of South Africa, making it southern Africa's third 'peace park' after the Kgalagadi Transfrontier Park and Great Limpopo Transfrontier Park.

The park covers more than 6,000 square kilometres and incorporates the /Ai-/Ais Hot Springs protected area in Namibia and the Richtersveld National Park in South Africa, proclaimed in 1968 and 1991 respectively. The former makes up more than two-thirds of the park and – apart from the thermal springs (/Ai-/Ais means 'burning water' in the Nama language) – includes the Huns Mountains and the spectacular Fish River Canyon. The canyon, some 160 kilometres long and more than 500 metres deep in places, is considered second in size only to the Grand Canyon in North America. Abutting this northern section of the transfrontier park are the privately owned Canyon Nature Park and Gondwana Cañon Park.

The Richtersveld National Park has the distinction of being South Africa's first fully contractual national park, as the land is owned by the Richtersveld community and jointly managed with South African National Parks (SANParks). The area is of great cultural importance, as it contains a number of significant archaeological sites and is also one of the last places in southern Africa where nomadic pastoralism – the traditional lifestyle of the Nama people – is still practised. Proclamation of the park has helped preserve the Nama language as well as traditional knowledge of medicinal plants. South of the Richtersveld National Park is the Richtersveld Community Conservancy, which was declared the core zone of the Richtersveld Cultural and Botanical Landscape World Heritage Site in 2007.

The transfrontier park straddles the Nama Karoo and Succulent Karoo biomes, the latter recognised as a global biodiversity hotspot as it supports the richest succulent flora in the world, including the iconic quiver tree or 'kokerboom' (top) and the 'halfmens' (below). Approximately 30% of the plant species found in the park are endemic to the area, occurring nowhere else in the world.

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## Present ecological state

The study team assigned an ecological category to the river's various biophysical components under the present ecological state (PES), reflecting the change in health compared to the reference condition. The ecological categories of the biological components were then integrated to determine the ecological status (EcoStatus) of the lower Orange River at the study site, EFR 05. The EcoStatus under the present ecological state was found to be at the B/C boundary – slightly to moderately modified from the reference condition.

The change from reference conditions has been caused primarily by flow-related impacts. These include a general increase in low flows and a reduction in small and medium floods owing to the Vanderkloof Dam and other dams in the catchment. Dry-season baseflows are elevated, especially during drought periods, while wet-season baseflows are reduced. Nutrient concentrations and salinity are high due to irrigation return flows.

The EcoStatus has also been influenced by impacts that are not related to flow. The 'non-flow' impacts include grazing and browsing pressure from livestock, mainly goats, and the effects of alien plants, fish and macro-invertebrates.

© Steve Crerar

Water releases from the Vanderkloof Dam result in elevated baseflows during the dry season, while the the frequency and magnitude of small and medium floods are reduced due to the dam's storage capacity.

## Recommended ecological category

The recommended ecological category (REC) was then determined, taking into account the high ecological importance and sensitivity, the potential for restoration and the ability to attain it. The REC for the lower Orange River site was set as a B EcoStatus, and each component was adjusted accordingly.

Achieving the REC would require reinstatement of droughts – with lower flows than present during the dry season – and higher baseflows during the wet season. Although these mitigation measures would not improve water quality or flood-dependent aspects of geomorphology, they would result in an overall improvement in river health.

These recommendations are compatible with those made for site EFR 04 near Vioolsdrift, approximately 165 kilometres upstream, in the environmental flow study undertaken in 2010.

**Ecological classification of site EFR 05 on the lower Orange River**

| Components | PES | REC |
|---|---|---|
| Hydrology | C | C |
| Physico-chemical | C | C |
| Geomorphology | B/C | B |
| Fish | B/C | B |
| Macro-invertebrates | B/C | B |
| **Instream** | **B/C** | **B** |
| Riparian vegetation | B/C | B |
| Riverine fauna | B | B |
| **EcoStatus** | **B/C** | **B** |
| **Ecological importance and sensitivity** | **High** | |

## Environmental flow requirements

The flow requirements at site EFR 05 on the lower Orange River were determined using the Habitat Flow Stressor Response method, which involves the following steps:

- Stress indices are set for fish and macro-invertebrates, describing the consequences of flow reduction on the habitat of particular indicator species and their response to that change.
- The stress indices are then used to convert natural and present-day flow time series to a stress time series, which is, in turn, converted to a stress duration table for the highest and lowest flow months. This indicates the degree to which stress has changed from the reference condition to the present due to changes in flow.
- Stress requirements are determined for fish and macro-invertebrates in both wet and dry seasons and for the different ecological states – present (PES) and recommended (REC) – and then converted to flow. A range of flood classes are set, describing the peak flow, duration, month and number of events for the required flood regime.
- The low and high flows are combined and an environmental flow requirement rule table is provided as a final output. This gives the recommended environmental flows – volume and duration – for each month of the year.

The environmental flow requirements for the lower Orange River site EFR 05 can be summarised as a percentage of the natural and present-day mean annual runoff (MAR).

Although the mean annual runoff of the lower Orange River is now only 40% of the natural volume, improving the river's ecological condition nevertheless requires periodic drought conditions.

### Flow requirements to maintain the PES and to achieve the REC

| Hydrology | Unit of measure | PES | REC |
|---|---|---|---|
| Natural mean annual runoff (nMAR) | $Mm^3$ | 11,373 | 11,373 |
| Maintenance low flows | % of nMAR | 6.35 | 10.15 |
| Drought low flows | % of nMAR | 0.96 | 1.32 |
| High flows | % of nMAR | 4.51 | 4.51 |
| Long-term mean | % of nMAR | 10.85 | 14.66 |
| **Present-day mean annual runoff (pMAR)** | **$Mm^3$** | **4,641** | **4,641** |
| **Maintenance low flows** | **% of pMAR** | **15.54** | **24.87** |
| **Drought low flows** | **% of pMAR** | **2.4** | **3.2** |
| **High flows** | **% of pMAR** | **11.1** | **11.1** |
| **Long-term mean** | **% of pMAR** | **27** | **36** |

$Mm^3$ = million cubic metres
PES = present ecological state (Category B/C, slightly to moderately modified)
REC = recommended ecological category (Category B, slightly modified)

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## Scenario assessment

The consequences of different scenarios (see pages 14–15) on the river's ecological state were assessed. Four scenarios were considered, but were combined into two – Scenario 2&3 and Scenario 6&7 – on the basis of their similarity.

Scenario 2&3 maintained the present ecological state (PES) for all components, but did not achieve the recommended ecological category (REC). Scenario 6&7 did not meet the PES or the REC. It caused a decline in health in the instream components and resulted in a D EcoStatus (largely modified from the reference condition).

Scenarios 4 and 5, and possibly Scenario 8, should improve river health, as they all include an environmental flow release that would provide the low-flow requirements. However, they do not address the unnaturally high flows during the dry season or the decreased frequency of floods due to dams in the catchment. The altered flood regime, in particular, will be exacerbated by scenarios that include more large dams.

Biophysical responses to some scenarios at site EFR 05 on the lower Orange River

| Components | PES | REC | Scenario 2&3 | Scenario 6&7 |
|---|---|---|---|---|
| Physico-chemical | C | C | C | D/E |
| Geomorphology | B/C | B | B/C | C/D |
| Fish | B/C | B | B/C | D/E |
| Macro-invertebrates | B/C | B | B/C | D/E |
| **Instream** | **B/C** | **B** | **B/C** | **D/E** |
| Riparian vegetation | B/C | B | B/C | C/D |
| Riverine fauna | B | B | B | D |
| **EcoStatus** | **B/C** | **B** | **B/C** | **D** |



The Orange River snakes across the coastal plain towards its final destination, the Atlantic Ocean.

# THE FISH RIVER

The Fish River, which rises to the south-west of Windhoek and flows some 635 kilometres to its confluence with the lower Orange River, would only have contributed about 5% of the mean annual runoff of the lower Orange River under reference conditions. Today, the landscape through which it flows is still relatively undeveloped and sparsely populated, but the Fish River is a vitally important water resource for the people of the region, while also supporting diverse aquatic and riparian ecosystems.

Two major dams – the mainstream Hardap Dam close to the town of Mariental and the smaller Naute Dam on the Löwen River tributary near Keetmanshoop – supply water to their respective towns and for irrigated agriculture in the vicinity. A third – the Neckartal Dam – is under construction on the Fish River near Keetmanshoop. This will be the largest dam in Namibia, and will provide irrigation water for 5,000 hectares of land.

In order to evaluate the effect of these dams on ecological health, the environmental flow assessment included a Fish River component. However, the standard methods used to determine environmental flow requirements in southern Africa are applicable to perennial and seasonal rivers. The Fish River is an ephemeral system, flowing only after good rains, so the methods needed to be adapted. This entailed evaluating the implications of different flow regimes on the ecological state downstream of the Neckartal Dam site, and then recommending an optimised flow regime that could be used as an operating rule for releases from the dam.



Left: The Hardap Dam on the Fish River supplies water to Mariental and the Hardap Irrigation Scheme.

Opposite: The Fish River Canyon is one of Namibia's main tourist attractions.

The ecological classification process was conducted for three sites on the Fish River:

- EFR Fish 1, 250 kilometres downstream of the Hardap Dam and 70 kilometres upstream of the proposed site for the Neckartal Dam,
- EFR Fish 2, 25 kilometres downstream of the proposed site for the Neckartal Dam and immediately downstream of the Seeheim Gauge,
- EFR Fish /Ai-/Ais, 175 kilometres downstream of the confluence with the Löwen River and immediately downstream of /Ai-/Ais Hot Springs Spa Resort.

At all three sites the ecological importance and sensitivity was considered high due to the presence of Red Data species; the importance of the riparian vegetation and pools as a refuge and critical habitat; and – in the lower Fish River – the conservation value of the /Ai-/Ais–Richtersveld Transfrontier Park.

The present ecological state (PES) ranged from a B/C (slightly to moderately modified) to a C (moderately modified) ecological category at the three sites. The major causes of change from the reference condition were identified as the altered flow regime due to Hardap Dam, water quality problems, and – outside conservation areas – overgrazing by goats.

A range of environmental flow release options, representing 0%, 10%, 20%, 30%, 40% and 50% of the inflow to the Nectartal Dam, was evaluated for study sites EFR Fish 2 and EFR Fish /Ai-/Ais, as these sites lie downstream of the dam. At EFR Fish 2, release options 40% and 50% were found to maintain the PES, while at EFR Fish /Ai-/Ais only the latter would do so.

The ecological recommendation would therefore be to implement the 50% release option as the environmental flow requirement. However, this would have a significant impact on the yield of the Neckartal Dam, so an optimised release option that would minimise the impacts on both the yield and the ecological status of the river downstream of the dam was investigated. Release option 30% would have significantly less impact on yield, so would be preferable from a water resources perspective, and also would have a minimal impact on the ecological state at certain times of the year.

The 'compromise solution' entails releasing 40% of the inflow while the Neckartal Dam is more than 60% full, decreasing to 30% of the inflow should the dam storage drop below this level. It was recommended that specific operating rules based on this optimised release option should be developed for the Neckartal Dam.

© James MacKenzie

Pools provide critical habitat for fish and other aquatic life when the ephemeral Fish River dries up after the rainy season, and are an important source of water for terrestrial wildlife. People living nearby also use the pools for their domestic needs, as well as for small-scale crop irrigation, livestock watering, fishing and swimming.


The environmental flow assessment for the Fish River in Namibia considered three sites downstream of Hardap Dam.

# THE ORANGE RIVER ESTUARY

The Orange River flows into the sea via a large estuary situated between the towns of Oranjemund in Namibia and Alexander Bay in South Africa. The proximity of these towns, and the mining industry they service, has caused some disturbance to the estuarine environment. For example, dykes and levees were constructed along the banks to protect agricultural fields and a golf course from flooding, cutting off channels on the floodplain that were then used as sewage ponds. A causeway built to provide road access to the mouth area negatively impacted the saltmarsh, and dust from mining activities caused further damage. Nevertheless, it is the change in river flow that has had the most marked effect on the Orange River estuary.

The mean annual runoff reaching the estuary has been reduced by almost 60% from the natural state, or reference condition, but the baseflows have increased significantly because of dam releases. This means that flow rarely abates enough for the mouth to close, whereas closure used to occur every few years for days or weeks at a time. Despite the almost permanently open mouth state, the estuary is still a river-dominated system, so seawater and marine sediment influx is usually limited to the lower section of the estuary. At spring tide, however, tidal variation in water level of a few centimetres can be detected at the Sir Ernest Oppenheimer Bridge, 11 kilometres upstream of the mouth.

The effect of river regulation by storage dams on floods has also had a major impact on the estuary. Large floods play an important role in 'resetting' estuarine habitat by flushing out accumulated sediment and removing small islands, but these events occur less frequently now. Small floods, which shape the braided channel system in the estuary's upper reaches, have been altered the most. The natural one-in-two-year floods now only occur every eight years on average and have been reduced in magnitude by an estimated 85%. As a result of the altered flood regime, islands are becoming increasingly vegetated and hence more resistant to erosion, while the channels between them are more stable and less likely to meander.

The Orange River estuary has been degraded by development on its floodplain, as well as by changes to the river's flow regime.

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## Habitat

The channels in the upper reaches of the estuary are lined by reeds and sedges, primarily *Phragmites australis* and *Schoenoplectus scirpoides*. It is likely that this habitat type has increased slightly since the reference condition in response to altered flows and increased sedimentation, as well as elevated nutrient loads from the catchment. Reeds and sedges cannot survive in the more saline areas near the mouth, so islands and banks in the lower reaches of the estuary are dominated by saltmarsh plants. These are mostly supratidal species that are only occasionally swept by high spring tides or storm seas, or inundated by floodwaters.

Aquatic plants – or macrophytes – that are rooted and submerged have probably never been well-represented in the estuary owing to the high flows and the silt load, which increases turbidity of the water and reduces the light available for photosynthesis. In quiet backwaters, macroalgae such as *Ulva* and *Cladophora* are able to take advantage of elevated nutrient concentrations, whether from external sources or localised recycling, to form short-lived blooms. The subsequent decomposition of these accumulations typically depletes oxygen in the water, causing physiological stress or death of fish and invertebrates. Macroalgal abundance is thought to have increased significantly since the reference condition owing to higher nutrient concentrations in river water as well as the influx of nutrient-rich seawater through the estuary's open mouth.

The nutrient enrichment, or eutrophication, of the estuary is also evident from the high microalgal biomass. The planktonic microalgae – or phytoplankton – would have had a much lower cell density in the reference condition and been dominated by diatoms, but chlorophytes and flagellates have probably increased to a similar density now. The large biomass of benthic microalgae is evident from the very high chlorophyll content of subtidal and intertidal surface sediments, and the community composition is representative of polluted or eutrophic environments.

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Areas of sheltered, shallow water in the intertidal saltmarsh provide foraging and roosting habitat for a variety of birds. Along the banks of quiet backwater channels, macroalgae may bloom in response to elevated nutrients and temperatures.

© Andre Theron

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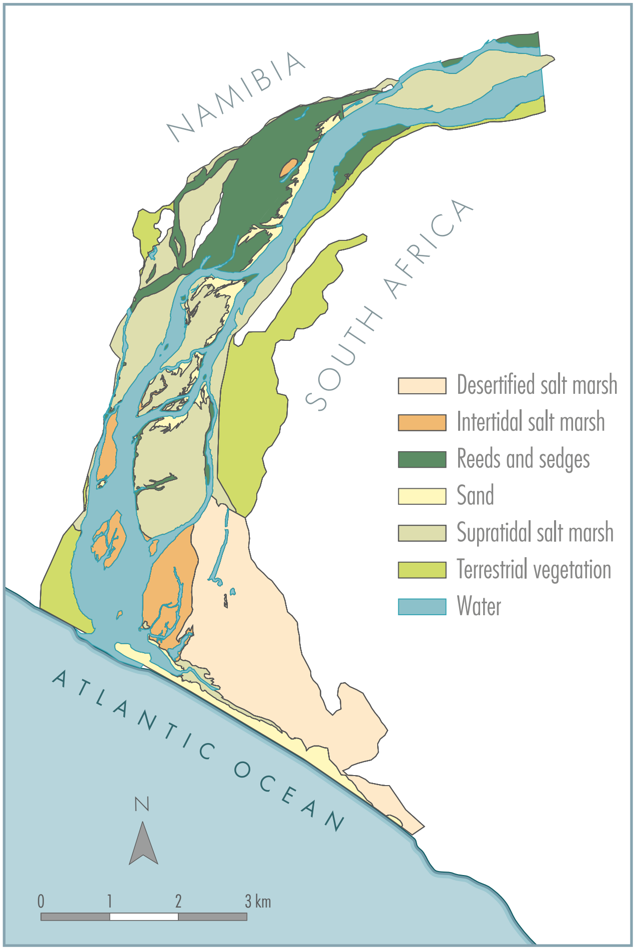


Reeds line the channels in the upper reaches of the estuary, but are replaced by saltmarsh plants in the more saline areas near the mouth.

© Steve Lamberth

© Steve Lamberth

**The degradation of the Orange River estuary dates back to the 1920s, when diamond mining began in the area. The recent southward migration of the estuary mouth has exposed the wreckage of old earth-moving equipment, which was dumped in the sand berm to stabilise the mouth position and protect the diamond-processing plant and other infrastructure from erosion damage.**

## A CHRONICLE OF DECLINE

Under reference conditions, supratidal saltmarsh covered a large area on the south bank of the estuary. By the mid 1990s, almost all of the saltmarsh – consisting primarily of the glasswort *Sarcocornia pillansii* – had died off, and the area became desertified and barren.

The history of degradation dates back to 1929, when diamond mining began here and attempts were made to keep the mouth open. Subsequently, artificial breaching of the mouth was undertaken alternately on the northern and southern sides of the estuary by the mining companies for many years. The aim was to reduce the impact of floods and maintain the quality of water supply from the alluvial aquifer, but the practice also prevented vital backflooding of the saltmarsh during mouth closure.

River regulation following the commissioning of the Gariep and Vanderkloof dams in the 1970s resulted in higher baseflows, which reduced the frequency of mouth closure. It also altered the flood regime, with small floods that periodically bathed the saltmarsh in freshwater being most affected. In the same period, the penetration of floodwaters and tidal flows into the saltmarsh was blocked by flood-protection levees and a causeway constructed by the mining companies. In the 1980s, seepage and dust from slimes dams used to store mining wastewater accelerated the decline of the saltmarsh, and the 1988 Orange River flood caused further damage through scouring and sediment deposition.

The first attempt at rehabilitation took place in 1997, when a section of the causeway near the mouth was removed to allow tidal inundation of the saltmarsh, but poor drainage resulted in pools of standing water that slowly evaporated, causing hypersaline conditions to persist. In 2005, Working for Wetlands began implementing a plan to improve inflow and outflow, and breached the causeway in three places. However, additional breaches and restoration of old channels on the floodplain were considered necessary to flush accumulated salts from the soil and groundwater to allow the saltmarsh to recover. This work was delayed pending the removal of sewage oxidation ponds in the old channels, which was completed in early 2013.

An environmental impact assessment has now been conducted for the removal of the entire causeway and levee along the south bank, paving the way for rehabilitation efforts to continue. Among the other interventions needed are the development of a mouth management protocol for artificial breaching of the estuary, since prolonged inundation following mouth closure would cause die-back of the saltmarsh, and removal of invasive alien vegetation, such as rooikrans (*Acacia cyclops*).

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**The old causeway was breached to promote recovery of the desertified saltmarsh, but it will soon be removed entirely as part of the rehabilitation effort.**

## Invertebrates

Few invertebrate species can tolerate the highly variable conditions in the Orange River estuary. High flows bring very turbid, silt-laden water from the catchment, while low flows are associated with tidal fluctuations in salinity and temperature when the mouth is open. The strong river flow and tidal currents mean that the residence time of water in the estuary is only a few days at most, and small invertebrates are under constant threat of being flushed out to sea. Zooplankton in the water column are most affected and are poorly represented, but hyperbenthic species such as mysids, which live just above the substrate, are able to maintain populations in the estuary, particularly in deeper areas. Benthic invertebrates residing on or in the bottom sediments are most abundant, although only two species – a filter-feeding and a predatory polychaete – occur in any numbers.

Under reference conditions, the higher frequency of floods meant that an open river mouth state prevailed for much of the time, and salinity values probably remained too low for a typical estuarine invertebrate community to become established.

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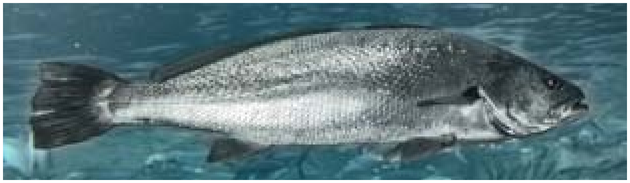

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Right: Invertebrates are poorly represented in the Orange River estuary, partly because strong flows through the mouth flush them out to sea, but marine fish such as kob and elf use these flows as cues to enter the estuary.

Opposite: The southern mullet or harder is the dominant fish in the estuary.

## Fish

While only the hardiest invertebrates can survive in the estuary, most fish species that occur here are adapted to take advantage of both high- and low-flow conditions. Of the 36 species that have been recorded, 31% are partially or completely dependent on estuaries for their survival, 47% are freshwater species with varying degrees of salinity tolerance and the remaining 22% are marine species that occasionally venture into estuaries. High flows and floods may provide cues for marine fish to enter the estuary, while estuarine and freshwater fish typically move upstream or onto the inundated floodplain. Nowadays, obstructions such as the dykes and causeway restrict access to these refuge areas, so fish are more at risk of being flushed out to sea, possibly at slightly lower flows. However, during flood events most can survive in the discharge plume in the vicinity of the mouth.

The southern mullet or harder *Liza richardsonii*, which feeds on benthic microalgae and detritus, is the dominant fish species in the estuary, contributing more than 90% of the fish biomass. Most other fish species in the estuary consume either plankton or other fish, with the fish-eating elf *Pomatomus saltatrix*, silver kob *Argyrosomus inodorus* and leervis *Lichia amia* making up most of the biomass after harder. Patches of *Ulva* in the lower reaches provide habitat for pipefish *Syngnathus temminckii*, klipvis *Clinus superciliosus* and the gobies *Caffrogobius nudiceps* and *C. saldanha*, while Mozambique tilapia *Oreochromis mossambicus*, banded tilapia *Tilapia sparrmanii*, three *Barbus* species and river sardine *Mesobola brevianalis* feed on or amongst the filamentous algae in the freshwater backwaters.

Under reference conditions the fish assemblage would have resembled the present-day one, with the same four species dominant, although these fish are far less abundant now as they are heavily exploited through recreational angling and illegal gillnetting. The total catch from the estuary is estimated at 5–10 tonnes per annum, but abundance has also been affected by countrywide overexploitation.

Historically, fish species composition and abundance probably varied seasonally in response to high flows in summer, low flows in winter and the resulting physico-chemical changes in the estuary. Altered flows have likely confused behavioural cues for recruitment or emigration, although changes to hydropower releases in recent years have partially restored the winter low-flow period. Reduced inundation of the saltmarsh probably resulted in the loss of fish habitat and foraging area, but much of the intertidal component has recovered since the removal of sections of the causeway.

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## Birds

Bird counts have been conducted at the Orange River estuary some 30 times since 1980, and the number of species recorded has remained relatively stable, ranging from 41 to 64 and averaging 52. However, bird numbers have decreased dramatically, from more than 20,000 birds recorded in summer counts in 1980 and 1985, to an average of 6,891 for six summer counts over the period 2000–2005. This can be attributed primarily to the considerable fall in numbers of terns, cormorants and waders at the estuary.

There are various viewpoints on the reason for the decline, which may be due to external factors rather than conditions at the estuary. In the case of terns and cormorants, both of which used to roost and breed at the estuary in large numbers, it is possible that changes in the abundance or availability of their fish prey inhibited successful breeding or caused the seabirds to relocate. Disease outbreaks, oil spills and disturbance at breeding sites are thought to have contributed to a general decline in the Cape cormorant population in southern Africa. However, some experts believe that terns and cormorants have decreased at the Orange River estuary as a result of increased levels of disturbance from humans and cattle, as well as a reduction in suitable roosting and breeding sites owing to changes in mouth architecture.

Wader populations have declined globally, but the degradation of the saltmarsh – and hence the loss of intertidal and shallow water habitat – is suspected to have played a role in the drop in their numbers at the estuary. Nevertheless, many other species that use saltmarsh habitat for foraging, such as lesser flamingo and curlew sandpiper, have not declined significantly. This may be because tidal flows through the permanently open mouth maintain extensive areas of intertidal mudflats, which are valuable foraging areas. Benthic-feeding waders were the dominant bird group at the estuary during the site survey in November 2012, closely followed by gulls and terns.

Given that comprehensive bird counts at the Orange River estuary only began after all the major dam developments in the catchment had been completed, there is no reliable information on birdlife in the reference condition. Furthermore, the causeway was built in the 1960s, so bird numbers recorded in the 1980s may have already been affected by the loss of saltmarsh.

© Johan van Rensburg

Clockwise from top left: Sandwich terns, chestnut-banded plovers, Cape cormorants, greater flamingoes and (right) white-backed pelicans are among the most abundant birds at the estuary.

## Present ecological state

For the purposes of the environmental flow assessment, the various physico-chemical and biological components of the Orange River estuary were assigned a health score by the subject specialists. The score reflects the health of that component as a percentage of the pristine natural state, or reference condition. The individual health scores were then weighted and averaged to determine the overall estuary health score.

The Orange River estuary was found to have an overall health score of 51 relative to the reference condition (which would have a health score of 100). This translates to a present ecological status of D, representing a largely modified system.

The degradation can be attributed to the following factors:

- significant freshwater flow modification through loss of floods and increased baseflows;
- lack of estuary mouth closure and the resulting backflooding of saltmarshes with fresher water;
- road infrastructure in the form of the causeway across the saltmarsh and old bridge crossings;
- nutrient input from the catchment downstream of Vioolsdrift;
- gillnetting of indigenous fish species and angling pressure in the vicinity of the estuary mouth;
- infrastructure on the banks, such as the levees that prevent backflooding;
- mining activities, including dust generation and industrial wastewater disposal;
- sewage effluent disposal.

The extent to which changes in estuary health are due to human activities such as habitat destruction, disturbance, pollution and overexploitation was assessed. These 'non-flow' impacts have played a significant role in the degradation of the Orange River estuary, but flow-related impacts are the main cause.

Addressing the quantity and quality of freshwater flows to the estuary was therefore identified as the highest priority for management action, particularly the increase in baseflows, which is hindering mouth closure, as well as elevated nutrient levels due to poor agricultural practices downstream of Vioolsdrift. Of the non-flow impacts, the causeway crossing the saltmarshes, the levees on the banks and gillnetting in the estuary were found to be the most important factors influencing the health of the system.

### Present ecological state for the Orange River estuary

| Variable | Weight | Health score (%) |
|---|---|---|
| Hydrology | 25 | 44 |
| Hydrodynamics and mouth condition | 25 | 70 |
| Water quality | 25 | 53 |
| Physical habitat alteration | 25 | 78 |
| ***Habitat health score*** | | ***61*** |
| Microalgae | 20 | 40 |
| Macrophytes | 20 | 50 |
| Invertebrates | 20 | 45 |
| Fish | 20 | 50 |
| Birds | 20 | 23 |
| ***Biotic health score*** | | ***42*** |
| **Estuary health score** | | **51** |
| **Present ecological status** | | **D** |

© Trygve Cooper

Angling pressure and mining activities have contributed to the degradation of the Orange River estuary.

© UNOPS/Greg Marinovich

## Estuary importance

Estuary importance reflects the value of an estuary in maintaining ecological diversity and estuarine functioning on a broader scale. The criteria used for ranking estuary importance differ slightly from those used to determine ecological importance and sensitivity in riverine environmental flow assessments. Individual scores for the estuary's size, the rarity of its type within the biogeographic zone, its habitat diversity, biodiversity importance and functional importance are aggregated to arrive at the final estuary importance score.

The functional importance reflects the ecological services the estuary provides to the adjacent freshwater and marine environments.

### Estimation of the functional importance of the estuary

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

The estuary is important as a nursery area for juvenile marine fish, as a movement corridor for freshwater and estuarine fish that breed in the sea, and as a waypoint and temporary refuge for fish migrating along the coast.

The functional importance was deemed to be very high because sediment from the Orange River catchment supplies beaches to the north of the mouth and provides habitat for flatfish in the nearshore marine environment.

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

### Importance rating for the estuary

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

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The estuary is used as a migratory stopover by a variety of coastal birds. It is also important in the supply of sediment to the marine environment, particularly during floods.

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The estuary's intertidal saltmarsh is composed of a mosaic of brackish species.

## Recommended ecological category

The next step in the process of determining the estuary's environmental flow requirements is to set the recommended ecological category (REC). This is based upon the present ecological status (PES), as well as the estuary's importance and protection status.

The PES determines the minimum REC, and the degree to which the REC needs to be elevated above the PES depends on the level of importance and level of protection, or desired protection, of the estuary.

### Estuary protection status and importance, and the basis for assigning a REC

| Protection status and importance | REC | Policy basis |
|---|---|---|
| Protected area: existing or desired | A or BAS | Protected and desired protected areas should be restored to and maintained in the best possible state of health |
| Highly important | PES + 1, minimum B | Highly important estuaries should be Category A or B |
| Important | PES + 1, minimum C | Important estuaries should be Category A, B or C |
| Of low to average importance | PES, minimum D | Estuaries of low to average importance can remain in Category D |

BAS = best attainable state

The Orange River estuary has a PES of D, and is rated as highly important. It is also a designated Ramsar site, the Namibian component of which forms part of the Tsau//Khaeb (Sperrgebiet) National Park, and it has been identified as a desired protected area in the *South African Biodiversity Plan for the 2011 National Biodiversity Assessment*.

The REC for the estuary is therefore Category A or its best attainable state, which is estimated as Category C.

# RAMSAR WETLAND OF INTERNATIONAL IMPORTANCE

The Convention on Wetlands of International Importance, better known as the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

The South African component of the Orange River estuary was designated a wetland of international importance under the Convention in 1991. The Namibian component was added to the Ramsar site in 1995, following Namibia's ratification of the Convention. In the same year, however, South Africa requested the listing of its site on the Montreux Record – a register of Ramsar wetlands where significant ecological changes have occurred as a result of human interference. The listing was motivated by a dramatic decline in bird numbers and the severely degraded state of the saltmarsh on the South African side of the estuary.

The Orange River estuary no longer fulfils one of the criteria under which it was originally designated a Ramsar site, relating to wetlands that regularly support more than 20,000 water birds. However, it still meets the remaining criteria, in that it is an example of a rare or unusual wetland type in its biogeographical region and supports an appreciable assemblage of rare or endangered species, as well as more than one per cent of the global or southern African populations of a water bird species. New criteria for designating Ramsar wetlands have been introduced over the years, and the Orange River estuary meets some of these too.

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## Scenario assessment

As part of the environmental flow assessment, the six main scenarios identified (see pages 14–15) were evaluated to assess the implications of flow alteration on estuary health. This allowed the determination of the 'recommended environmental flow requirement', which is the flow scenario representing the highest change in river inflow that will maintain the estuary in the recommended ecological category, in this case Category C.

The study found that the estuary's health would deteriorate slightly under Scenarios 2, 3 and 5, but remain in Category D, its present ecological status. Scenarios 6 and 7 would cause a significant decline in health to Category F.

Scenario 4, which allows a decrease in baseflows, would only improve the estuary to Category C/D. However, by also addressing 'non-flow' impacts – the anthropogenic influences – further improvement could be attained. Scenario 4A revealed that removing the causeway, lowering fishing effort and achieving a 50% reduction in nutrient levels could raise the estuary's health to Category C.

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Combining Scenario 5BR with a decrease in baseflows and some rehabilitation measures would result in the estuary remaining in Category C/D.

Since none of the scenarios would meet the recommended ecological category of C based solely on river inflow, the recommended environmental flow requirement is Scenario 4 in conjunction with the following remedial measures:

- Decreasing the winter baseflows sufficiently to allow for mouth closure, and hence backflooding of the saltmarshes with brackish water to reduce soil salinities.
- Controlling the fishing effort on both the South African and Namibian sides of the estuary through increased compliance and law enforcement, as well as alignment of fishing regulations such as size and bag limits.
- Removing the remnant causeway across the saltmarshes to improve circulation during high flow and flood events, which will also increase circulation in the lower saltmarsh areas.
- Decreasing nutrient input from the catchment downstream of Vioolsdrift, through improved agricultural practices.
- Controlling wind-blown dust and wastewater from mining activities.

Remedial measures necessary to improve the health of the estuary include (left) controlling wind-blown dust from mining activities and (opposite) removing the remnant causeway across the saltmarshes.

Estuary health score and corresponding ecological category under different scenarios

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

Scenarios are explained on pages 14–15.
* Scenario 4A = Scenario 4 and addressing local, anthropogenic influences
** Scenario 5BR = Scenario 5 with a decrease in baseflows and some local rehabilitation

# ESTUARY MANAGEMENT PLAN

The environmental flow assessment team recommended that the remedial measures relating to 'non-flow' impacts, as well as potential flooding and water quality issues stemming from increased mouth closure, should be addressed as part of the estuary management plan.

The 'Strategic Management Plan for the Orange River Mouth Ramsar Site' has been developed through a collaborative process involving regional institutional structures, government agencies, local communities and other key stakeholders in South Africa and Namibia. The process began with the compilation of a situation assessment report, which contains a detailed description of the site based on existing information, and an initial evaluation of threats and issues that need to be addressed during the strategic planning phase.

At the outset of the strategic planning phase, a vision and mission for the future management of the estuary were developed during stakeholder workshops.

**Vision**

A healthy trans-boundary Ramsar site providing opportunities for all

**Mission**

To restore, manage and maintain the estuary in order to enhance the ecological values that qualify the Orange River estuary as a Ramsar site whilst providing opportunities through sustainable socio-economic initiatives

Additional issues and challenges requiring management attention were also identified during the stakeholder workshops. All issues were grouped into three thematic areas – institutional, ecological and socio-economic – and allocated a priority rating.

A strategic goal with a number of strategic objectives was developed for each thematic area. The key issues and strategic objectives were then converted into a series of management objectives, which will, in turn, guide actions needed to improve management of the estuary. Action plans were drawn up with details on specific activities, outcomes, responsibilities, timing and an indicative budget.

The management plan will be continually reviewed and refined according to an adaptive management approach, in which lessons learnt during implementation are used to improve management practices.

| Thematic area | Strategic goal | Strategic objectives |
|---|---|---|
| Institutional | 1. To establish viable arrangements that promote collaboration and accountability between all relevant stakeholders | 1.1. To improve the formal conservation status and associated protection and management of the Orange River mouth Ramsar site |
| | | 1.2. To develop institutional arrangements to support the implementation of well-coordinated actions towards improved management and wise use of the Orange River mouth Ramsar site |
| | | 1.3. To ensure appropriate communication and collaboration with local communities, stakeholders and regional initiatives |
| | | 1.4. To ensure that Ramsar obligations are addressed and communicated to the Ramsar Secretariat |
| Ecological | 2. To ensure ecological restoration, management and maintenance of the Orange River mouth Ramsar site so as to maximise its functional integrity (C+ ecological category) | 2.1. To ensure that catchment management activities do not undermine local conservation efforts |
| | | 2.2. To implement directed management interventions to ensure recovery of the degraded saltmarsh area |
| | | 2.3. To actively promote research and ongoing monitoring to inform management activities |
| | | 2.4. To ensure that recreational resource use and other activities are adequately controlled in line with conservation objectives |
| | | 2.5. To ensure that estuarine and associated wetland habitats are managed in such a way that the ecological functioning and habitat value of these areas are maintained or enhanced |
| Socio-economic | 3. To provide nature-based recreation and ecotourism, sustainable resource use and stimulate local social and economic benefits | 3.1. To promote local benefication by growing and actively marketing a range of nature-based recreation and tourism products |
| | | 3.2. To promote environmental education and awareness |
| | | 3.3. To ensure that use both within and around the Ramsar site is controlled and managed in line with other strategic objectives |

# THE NEARSHORE ENVIRONMENT

The environmental flow assessment also explored the interactions between the river and the nearshore marine environment to assess the effect of changes in flow.

The outflow from the river forms a plume of sediment-laden freshwater outside the estuary mouth, reducing salinity and increasing turbidity of the surrounding sea. The size and shape of the plume varies with the volume of river flow and wind conditions, but may extend 100 kilometres or more during major flood events.

The plume provides cues for the migration of estuarine-dependent juvenile and adult fish into and out of the estuary, while some commercially important offshore species, including the anchovy *Engraulis capensis*, use the plume itself as a nursery area. Coastal fish may use both the plume and the estuary as a refuge from cold, upwelled water or even from potentially fatal low-oxygen events in the sea. The high turbidity provides protection from predators for some fish species, while allowing others to increase their success in catching prey. In addition, much of the sediment in the plume settles out on a delta that provides soft-substrate habitat for bottom-dwelling flatfish such as sole and skates. Some sediment is carried further afield, where it replenishes nearshore habitats or is moved ashore as a sand supply for beaches.

Rivers are also a significant source of the mineral silica, which originates from weathered rock. Diatoms in the phytoplankton community take up dissolved reactive silicate as a building material for their hard cell walls, or frustules. Nutrients from the catchment are also brought down by the river and may enhance phytoplankton production in the vicinity of the mouth, providing food for zooplankton. The plankton communities, as well as detritus, are, in turn, a source of food for certain invertebrates and fish.

During floods the Orange River spews a plume of sediment-laden freshwater into the Atlantic Ocean.

The reduction of mean annual runoff in the Orange River since the reference condition, together with changes in flood regimes, seasonal flow variation and mouth closure events, would almost certainly have influenced the community composition and abundance of fish and invertebrate communities in the nearshore environment adjacent to the estuary mouth. It must presumably also have had some impact on species that rely on seasonal cues for entering or exiting the estuary.

Furthermore, it has been hypothesised that the reduction in sediment export to the sea, due to the construction of the major dams in the catchment during the 1970s, prevented the recovery of the southern stock of west coast sole *Austroglossus microlepis*, which collapsed due to overfishing in the 1960s.

The specialist team assessed inflows of freshwater, sediment, turbidity and dissolved reactive silicate to the nearshore marine environment under six future scenarios (see pages 14–15), and found that Scenarios 2 to 5 are unlikely to cause any discernible change from the present state. However, Scenarios 6 and 7 could have a severe impact in terms of flow and export of sediment to the sea, since they both entail the construction of a large dam at Vioolsdrift. The dam's relatively close proximity to the sea would further reduce the sediment load in the lower Orange River, and hence the sediment contribution to the nearshore marine environment.



The area around the mouth of the estuary is extremely dynamic. Floods flush sandbanks and much of the berm into the sea and stormy seas bring sand back onshore and inside the mouth.

© Tom Bornman

# ECOSYSTEM SERVICES

Ecosystem services supplied by rivers, wetlands and estuaries include attributes that provide aesthetic, recreational, cultural and spiritual value; goods such as fish and raw materials; and ecosystem functions that save costs, such as water quality amelioration or the provision of nursery areas for exploited fish species.

The environmental flow assessment included an evaluation of such benefits to people living in the vicinity of the rivers and estuary, and beyond.

The lower parts of the Orange–Senqu River basin – being highly arid – have very low population densities, so the numbers of people benefiting directly from ecosystem services are much lower than for the upper parts of the basin. However, poor communities living close to the Fish River, and people of Nama descent along the lower Orange River, are dependent on the river for recreational and subsistence fishing, hunting, harvesting of reeds for handicrafts or hut construction, gathering of firewood for cooking and warmth, and grazing and browsing of livestock.

Livestock farmers in the region experience an ecosystem 'dis-service' in the form of blackfly *Simulium* species, which breed in rivers. The fly's biting and blood-feeding habits make it a major agricultural pest, causing livestock to stop grazing and lose condition, with consequent production and economic losses. The construction of dams and irrigation canals has not only increased the areas suitable for blackfly breeding, but also altered the flow regime in their favour, as elevated winter low flows provide more habitat for eggs and larvae to survive during the dry season. Flow manipulation by reducing dam releases can be used to control blackfly numbers and reduce outbreaks of the pest.

Ecosystem services provided by the lower parts of the Orange–Senqu River basin include the recreational value derived from canoeing on the Orange River and hiking in the Fish River canyon. However, livestock farmers in the area are negatively impacted by blackfly, an agricultural pest that breeds in rivers. The larvae attach themselves to rocks and filter food particles from the water.

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## Scenario assessment

The potential impacts on the supply of ecosystem services, and the value or benefits derived from them, were assessed for the various scenarios.

For the Fish River, only release option 40% and 50% were considered to have sufficiently low negative impacts to be acceptable (see page 30). The impacts of Scenario 6 were considered severe and unacceptable for both the lower Orange River and the estuary.

Reeds harvested from the Fish River are used to make mats and other products.

© Carole Roberts

| Values, goods and services | FISH RIVER | | | | | | LOWER ORANGE RIVER | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Release option | | | | | | Scenario | | |
| | Description | 0% | 20% | 30% | 40% | 50% | Description | 2–5 & 8 | 6 | 7 |
| Harvested resources | Fish, reeds, riparian foods, medicines | | | | | | Important for limited number of people | | | |
| Grazing | Important in dry periods | | | | | | Important for limited number of people | | | |
| Recreation | Swimming, picnicking | | | | | | Important for limited number of people | | | |
| Nature-based tourism | Associated with /Ai-/Ais Hot Springs, Fish River Canyon and conservancies | | | | | | Associated with Orange River and transfrontier park | | | |
| Water quality amelioration | Pollution (irrigation return flows, wastewater from settlements) | | | | | | Upstream pollutants | | | |
| Pest control | Control of blackfly larvae | | | | | | Control of blackfly | | | |

- Orange: Overall negative impact with a substantial or moderate implication for either the significance or the magnitude of ecosystem services
- Yellow: Overall negative impact with a minor implication for either the significance or the magnitude of ecosystem services
- Light green: Status quo maintained or an overall positive impact with a minor implication for either the significance or the magnitude of ecosystem services
- Green: Overall positive impact with a substantial or moderate implication for either the significance or the magnitude of ecosystem services.

### ORANGE RIVER ESTUARY

| | | Scenario | | | | |
|---|---|---|---|---|---|---|
| **Values, goods and services** | **Description** | **2 & 3** | **4** | **5** | **6** | **4A*** |
| Harvested resources | Negligible value | Green | Light green | Green | Orange | Green |
| Grazing | Small herd supported | Green | Light green | Green | Green | Green |
| Recreation | Moderate value | Light green | Green | Light green | Yellow | Green |
| Nature-based tourism | Small value in the order of <ZAR1 million | Green | Green | Light green | Orange | Green |
| Water quality amelioration | Negligible value | Green | Green | Light green | Orange | Green |
| Export of nutrients | Small, localised value in inshore environments | Green | Green | Light green | Orange | Green |
| Export of sediments | Low value due to human influence | Green | Green | Light green | Orange | Green |
| Nursery function | Contributes about ZAR7.5 million to the value of South Africa's Western Cape fisheries | Light green | Green | Light green | Yellow | Green |

Note: ZAR1 = USD0.10 at 2010 rates
* Scenario 4 with anthropogenic impacts addressed

# FINAL RECOMMENDATION

The scenario assessment for the lower Orange River indicated that Scenario 4 or 5 would be most likely to meet the recommended ecological category (REC) for the river reach. The estuary component of the study suggested that only Scenario 4 in conjunction with certain remedial measures would achieve the REC. However, Scenario 4 excluded both the Polihali Dam and the Vioolsdrift Balancing Dam as future options.

In order to avoid compromising the yield of the Orange River system, an optimised scenario – Scenario 9 – was developed. It represents a deviation of Scenario 5, which includes the Polihali and Vioolsdrift Balancing dams and meets the environmental flow requirements at the lower Orange River site EFR 05 and hence maintains the present ecological status (PES). Achieving the REC would depend on whether flows emulating floods could be released from dams in the lower catchment to mitigate the effect of dams further upstream.

Scenario 9 includes dam operating rules that reduce flows to less than two cubic metres per second for one to two months in winter between two and four times each decade. This would allow for closure of the estuary mouth and backflooding of the saltmarshes, ensuring that the estuary would remain in Category C/D. Implementing the remedial measures to address 'non-flow impacts' too would allow the REC of C to be achieved. The ecological benefits associated with Category C include:

- a more natural mouth state, with closure occurring every few years;
- improved water quality and hence less reed and microalgae growth;
- reversal of the saltmarsh decline;
- increased diversity and abundance of invertebrates and fish in the estuary.

Since Scenario 9 includes the optimised release option from Neckartal Dam, it would maintain the Fish River PES, and would also have a negligible impact on ecosystem services provided by the lower Orange River and estuary. A small reduction in nearshore marine ecosystem services, such as sediment and nutrient supply to the sea, can be expected if this scenario is achieved through a large dam near the estuary.

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Opposite: The optimised scenario, which allows for closure of the estuary mouth and backflooding of the saltmarshes, takes into account the potential construction of a small dam at Vioolsdrift. Right: Additional measures to improve water quality will be needed to limit the growth of reeds and algae.

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# NEXT STEPS

It is anticipated that the recommendations emanating from the environmental flow assessment will be considered as part of a consultative process to agree on a basin-wide environmental flow regime. This has been identified as a priority project within the Strategic Action Programme for the Orange–Senqu River basin, which provides a framework for jointly addressing transboundary problems of concern to the member states.

The proposed project will entail harmonising information on hydrology and ecosystems for various parts of the basin to ensure that the findings of existing environmental flow assessments are comparable, and integrating this information with the necessary legal and administrative provisions. A suite of basin-wide development scenarios will then be developed for presentation to the four member states, and an environmental flow regime jointly agreed upon. The states will be supported in setting up the systems required for effective implementation, which include compliance monitoring and assessment of the regime's efficacy in maintaining target ecosystem conditions. An adaptive management programme will be implemented so that the regime can be adjusted as necessary.

Furthermore, impacts on the Orange River estuary that are not flow-related will be addressed through a project focusing on management interventions that improve the condition of the saltmarshes, enhance the estuary's nursery function to improve the stock status of overexploited fish species, and improve the water quality of the inflowing river by reducing the nutrient input downstream of Vioolsdrift. These interventions have also been incorporated into the Strategic Management Plan for the Orange River mouth Ramsar site, which will be implemented by Namibia and South Africa.

In addition to these priority projects identified in the Strategic Action Programme, ORASECOM is in the process of developing an Integrated Water Resources Management Plan for the Orange–Senqu River basin, with a ten-year planning horizon. One of its central objectives is to ensure the optimised, sustainable management of the basin's water resources. Implementation of environmental flow assessments will be fundamental to meeting this objective.

Future work will include the development of a basin-wide environmental flow regime, and the implementation of management interventions that improve the health of the estuary.

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# FURTHER READING


Brown, C, 2013. Basin-wide environmental flow regime in the Orange–Senqu River basin. Technical Report 45 of the UNDP–GEF Orange–Senqu Strategic Action Programme.

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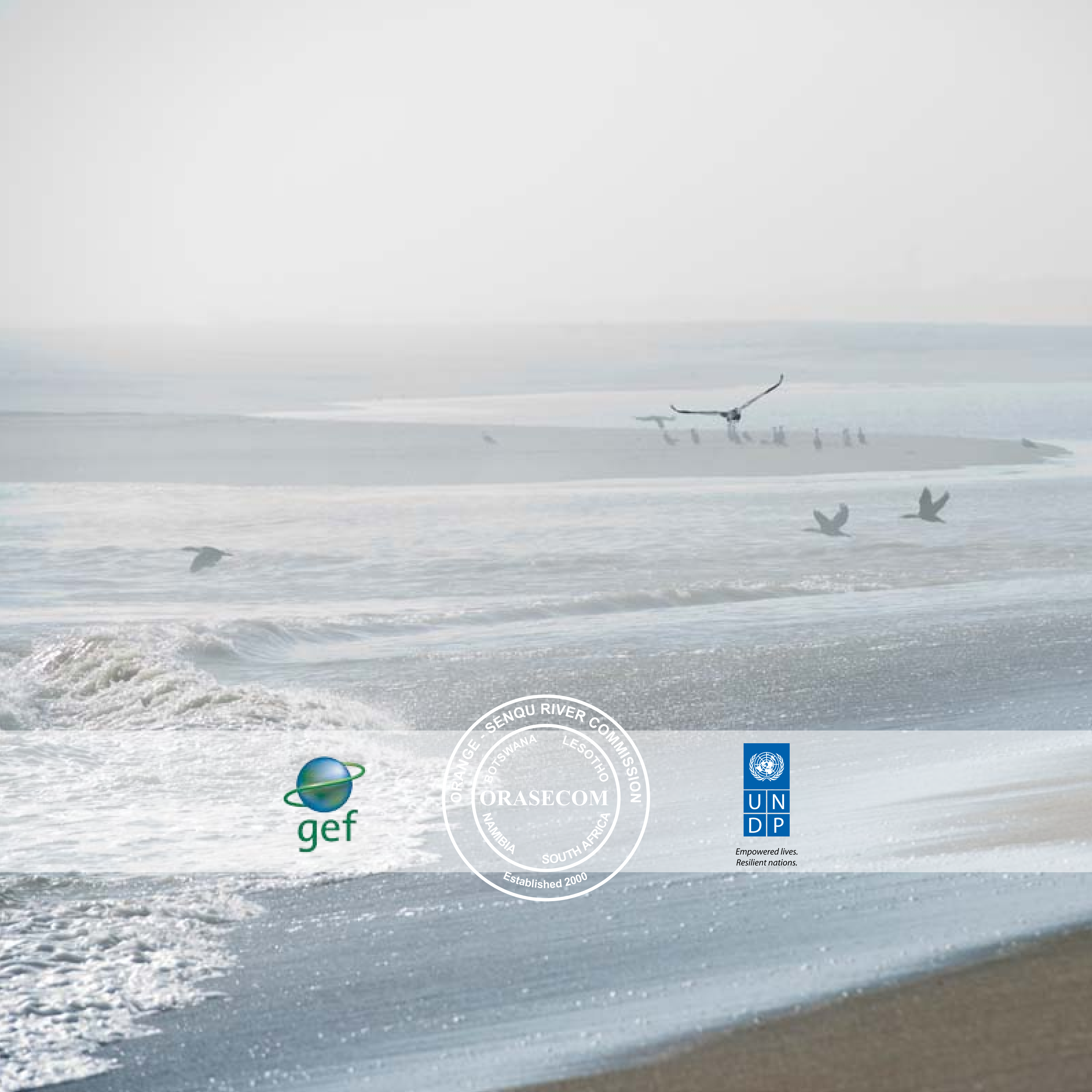
All reports from the environmental flow requirement study of the UNDP–GEF Orange–Senqu Strategic Action Programme can be downloaded from the following link:
http://wis.orasecom.org/environmental-flow-requirements-of-the-fish-river-and-the-orange-senqu-river-mouth/


gef
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