APPENDIX B

ABIOTIC (PHYSICAL DYNAMICS AND WATER QUALITY) SPECIALIST REPORT

Orange Estuary Abiotic Specialist Report: Hydrodynamics, Water Quality and Sediment Dynamics

REPORT COMPILED BY:	***PREPARED FOR:***
L van Niekerk ***P Huizinga*** ***S Taljaard*** ***AK Theron***	***LOR Consultants***
CSIR ***P.O Box 320*** ***Stellenbosch*** ***7599***	***Ninham Shand (South) Pty Ltd*** ***81 Church Street*** ***Cape Town*** ***8001***

August 2003

CSIR REPORT ENV-S-C 2003-114

TABLE OF CONTENTS

TABLES

FIGURES

1. BACKGROUND

1.1 CATCHMENT

The Orange River System is one of Southern Africa' s largest river systems, with a catchment exceeding one million km^2. Approximately 65 % of the catchment is arid to semi-arid in nature, where the mean annual precipitation is only 50 mm and the mean annual potential evaporation is more than 3 000 mm/yr. The low rainfall means that the ecological functioning of the mouth and estuary is completely dependent on the water from the river itself and the underlying alluvial aquifer.

The Orange River System became highly regulated with the construction of 23 major dams within its catchment between 1884 and 1978 (Table 1). It is also connected to other river systems for water import and export via six interbasin water transfer schemes. One of these schemes, the Lesotho Highlands Water Project may, for example, transports approximately 2 000 million m^3 of water from the Orange River headwaters to the Vaal Dam Catchment when the scheme is fully operational. Such a large transfer of water from the upper reaches of the Orange River has a significant influence on the water availability further downstream.

Table 1: Major impoundments on the Orange River System (Bremner et al., 1990)

Name	***Year***	***River***	***Full Capacity ($X10^6$ m^3)***	***Full surface area (Ha)***
Van Wyksvlei	*1884*	*Van Wyksvlei*	*145*	*3 276*
Smartt Syndicate	*1912*	*Ongers*	*100*	*3 089*
Vaalharts	*1936*	*Vaal*	*63*	*Not given*
Vaal	*1938*	*Vaal*	*2 536*	*29 269*
Kalkfontein	*1938*	*Riet*	*324*	*5 139*
Erfennis	*1960*	*Grootvet*	*211*	*3 308*
Allemanskraal	*1960*	*Sand*	*176*	*2 697*
Krugersdrif	*1970*	*Modder*	*77*	*1 807*
Bloemhof	*1970*	*Vaal*	*1 269*	*22 821*
Gariep (Hendrik Verwoerd)	*1972*	*Orange*	*5 670*	*36 488*
Welbedagt	*1973*	*Caledon*	*40*	*Not given*
Vanderkloof (PK le Roux)	*1977*	*Orange*	*3 236*	*13 867*
Sterkfontein	*1977*	*Wilge*	*2 617*	*5 073*
Groot Draai	*1978*	*Vaal*	*359*	*Not given*
Total			***16 823***	

1.2 LAND-USE

About 12% of the catchment is under agriculture consisting mainly of temporary dryland agriculture, subsistence farming and some temporary irrigated agriculture. Approximately 4% of the catchment is degraded (mostly bushland, grassland, and shrubland). Some dongas and sheet erosion was also present. Roughly 83% of the catchment is natural comprising of shrubland, grassland, and bushland, with some waterbodies (impoundments).

Urban development accounts for about 1% of the catchment land-cover. This comprises residential development, mines and quarries, smallholdings, and commercial and industrial development. Covering most of South Africa and all of Lesotho, the catchment includes the major cities of Bloemfontein, Johannesburg, Kimberly, Klerksdorp, Maseru, Potchefstroom, Vereeniging, and Welkom (DEAT 2001).

1.3 ORANGE RIVER ESTUARY

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

The estuary of the Orange River consists of a delta type river mouth, comprising a channel system between sand banks, a tidal basin, the river mouth and the salt marsh on the south bank. A map of the estuary is shown in Figure 1. Previous freshwater requirement studies indicated that the Orange River mouth system extends from the mouth as far as the Ernest Oppenheimer Bridge, approximately 9,5 km upstream (DWA, 1990). Tidal variations of a few centimetres are observed at springtide at this bridge (Figure 1).

The estuary has been disturbed by human activities such as the agricultural developments at Alexander Bay, the levees protecting these developments, the oxidation pond system near the village of Alexander Bay, the road across the salt marsh to the river mouth on the south bank and the golf course, protected by a dyke on the north bank.

The closest flow gauging station on the river is at Vioolsdrift, approximately 280 km from the mouth, which unfortunately is not very accurate under low flow conditions.

Although the flows have been drastically reduced and regulated, the estuary is still dominated by river flow and the marine water interchange is limited to the lower section of the estuary under normal flow conditions. The wetland habitats in the mouth are described, in order of dominance, as: a river mouth comprising a distributed and braided channel system (located between sand banks covered with pioneer vegetation), a small tidal basin, an (almost) permanently open river mouth and a severely degraded saltmarsh on the south bank of the river mouth (Cowan, 1995).

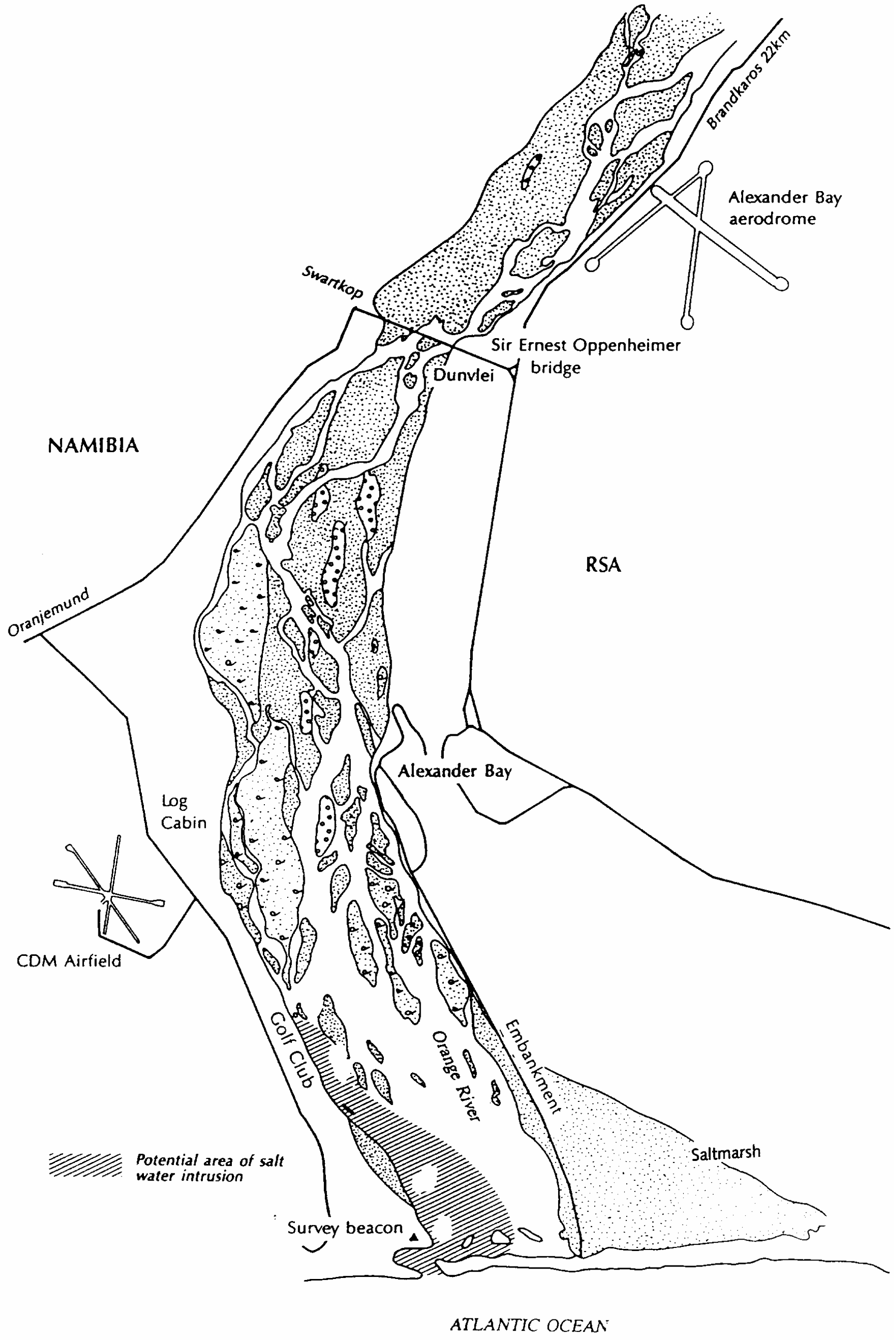


Figure 1. Map of the Orange River Estuary

1.4 CONSERVATION IMPORTANCE

Turpie *et al.* (2002) nationally ranked the Orange River Estuary as the 7th most important system in South African in terms of conservation importance. The prioritisation study calculated conservation importance on the basis of size, habitat, zonal type rarity and biodiversity) importance.

The Orange River Mouth Wetland was designated a Ramsar status, i.e. a wetland of international importance, on 28/06/1991 (Cowan 1995). It is situated at the mouth of the Orange River and has an area of about 2,000 ha (2 298 ha in GIS coverage). The nearest towns are Alexander Bay in the Northern Cape Province, South Africa, and Oranjemund in Namibia. The wetlands are situated between the north and south flood margins of the Orange River, extending from the Sir Ernest Oppenheimer Bridge to the Atlantic Ocean, a distance of about 10 km.

In September 1995 the Ramsar site was placed on the Montreux Record as a result of a belated recognition of the severely degraded state of the salt marsh on the south bank (CSIR, 2001). (The Montreux Record is a list of Ramsar sites around the world that are in a degraded state). This implies that the Orange River mouth may lose its status as a Ramsar site unless the condition of the salt marsh can be restored.

2. PREVIOUS EFR STUDIES

Past studies on the Orange River Mouth concluded that the estuary should meet the following sustainable natural resource utilization goals (DWAF 1996):

- ecological systems and processes, particularly those on which human survival and development depend must be maintained,

- due to the fact that the Orange River Mouth was designated as a Wetland of International Importance in terms of the Ramsar Convention on 28 June 1991, the future flows in the river should be sufficient to ensure that the ecological integrity of the mouth is maintained now and in the future,

- genetic diversity essential for the functioning of ecological processes must be conserved,
- the sustainable and equitable utilization of the natural resources which support communities and industries must be promoted,

- the quality of life of rural communities must be improved by developing opportunities for a sustainable tourism industry in publicly administered protected areas,

- a clean and healthy living environment for the people of the catchment should be created and maintained,

- development must be sustainable and environmentally compatible,

- the integrity of the natural environment must be protected to ensure its sustained ability to produce renewable commodities and to serve as a basis for tourism, and

- the flows in the river should ensure that the requirements for a sustainable biodiversity are met.

3. SIMULATED RUNOFF SCENARIOS

3.1 INTRODUCTION

The hydrology for the bulk of the catchment was obtained from previous studies. Only the hydrology for the Fish River (Namibia) was updated as part of the LORMS. The hydrology for the total Vaal River catchment as well as for the Senqu catchment in Lesotho was recently updated as part of the Vaal River System Analysis Update study (VRSAU). This hydrology covers the period 1920 to 1994 (hydrological years). The hydrology for the incremental catchment downstream of Lesotho (Caledon River included) and upstream of Vanderkloof Dam is relatively old, dating back to a report completed in November 1992. This document, entitled "Upper Orange River Hydrology" was produced as part of the Orange River System Analysis Study carried out in 1991/92. This hydrology covers the period 1929 to 1987. The hydrology for the Lower Orange (Vanderkloof Dam to Orange River Mouth excluding Fish River in Namibia) was obtained from the "Surface Water Resources of South Africa 1990" (WRS90) publication and covers the period 1920 to 1989 (Mr M Maré, WRP).

3.2 LOWER ORANGE RIVER MANAGEMENT STUDY SCENARIOS

The following simulated runoff scenarios (average monthly flows) were generated by WRP, Mr Manie Maré, for the study (Table 2):

Table 2: Summary of the simulated runoff scenarios generated for the Orange River Estuary

FUTURE SCENARIO:	*MAR ($x10^6$ $m^{3)}$*	*% REMAINING*
Reference Condition	*10 833.01*	*100.00*
Present State (with hydropower water releases as up to 2000)	*4 743.46*	*43.79*
Scenario 1: Present State (2005) with out hydropower releases	*4 423.46*	*40.83*
Scenario 2: Vanderkloof lower level storage	*4 296.43*	*39.66*
Scenario 3: Vioolsdrift reregulating dam	*4 082.1*	*37.68*
Scenario 4: Large Vioolsdrift	*3 369.92*	*31.11*
Scenario 5: River Class C	*1 969.50*	*18.18*
Scenario 6: River Class D	*1 558.10*	*14.38*
Scenario 7: Modified River Class D	*4 529.93*	*41.73*
Scenario 8: Modified River class D with Natural losses	*4 345.67*	*40.12*
Scenario 9: River class C with floods	*4 979.99*	*45.97*
Scenario 10: River Class D with floods	*4 758.93*	*43.93*

3.2.1 Reference Condition

All the demands imposed on the Orange River System have been removed from the simulated monthly flows.

3.2.2 Present State (similar to Scenario 1, but with the addition of hydro power releases)

There are three different releases or types of releases that are used to generate hydropower.

1. The normal releases to satisfy all the downstream requirements, including river losses and IFR are released through the turbines to generate hydro-power.
2. *The surplus in the system available each year as determined in May every year can be released from the dams through the turbines any time during the year as required by Eskom. These releases occur most of the time during the winter months.*
3. Based on storage control curves determined for Gariep and Vanderkloof Dams water can be released at maximum flow through the turbines when the storage in the dam is above a specific level in a month. The purpose of this is to reduce spills from the dams to the minimum during periods of high inflow and to route most of the spills through the turbines. This should not affect the IFR much as these high flows will be in phase with natural high flow periods.

The hydropower water releases included in the Present State Scenario are:

UNIT	*OCT*	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*TOTAL*
$X\ 10^6 m^3$	0	0	0	0	0	0	0	50	100	150	20	0	320
m^3/s	0	0	0	0	0	0	0	18.7	38.6	56.0	7.5	0	

3.2.3 Scenario 1: Present (2005)

Purpose: To determine surplus yield available at 2005 development level and to serve as the reference system yield. This yield will be used to compare with the yield from the other scenarios to determine the increase or decrease in yield.

Description: With phase 1 of the LHWP and urban/industrial demands at 2005 development level.

- All the demands imposed on the Orange River System will be at 2005 development level.
- Updated/final existing irrigation demands based on scheduled areas and quota. Effect of return flows will be included in the model.
- The Gariep and Vanderkloof dams are not supported by any upstream dam including Katse and Mohale dam in Lesotho.
- Vaal River System will be modeled separately with 2005 development level spills used as inflow to the Orange River System, just upstream of the confluence of the Vaal and Riet River. For the Vaal system analysis it is assumed that pumping from the Tugela River will continue until Sterkfontein Dam is full.

- Transfer from LHWP to Vaal = 804 million m³/a for the full phase 1 as based on the most recent hydrology that was accepted by both the RSA and Lesotho. The given transfer of 804 million m³/a is based on the 1 in 100 year long-term stochastic firm yield.
- Transfer to the Eastern Cape through the Orange/Fish tunnel based on the updated LORMS demands (627 million m³/a urban & irrigation).
- Orange/Riet transfer various demands will be modeled in detail as part of the system.
- Orange/Douglas transfer, all the demands will be modeled in detail as part of the system.
- Transfer from the Caledon to Modder from Welbedacht Dam as well as the Novo transfer from Knellpoort Dam will be in place and modeled in detail with all the demands in place as part of the system. Current existing operating rule will be used. This is however not necessarily the optimum operating rule.
- Compensation flow from Gariep Dam 16 m³/s.
- Hydropower will be generated in accordance with downstream demands only (no additional releases for hydro power purposes will therefore be made).
- Minimum operating level for Gariep at 1 231.63m. This is equal to the m.o.l. for Orange/Fish tunnel outlet. (DSV = 637.25 million m³ and live storage = 4 705.68 million m³)
- Minimum operating level for Vanderkloof Dam at 1 147.78m. (This is equal to the m.o.l. for releases into Vanderkloof canals (DSV = 1 014.38 million m³ and live storage = 2 172.69 million m³).
- Lower Orange hydrology and spills from the Vaal will be excluded from the base scenario as these flows are currently not taken into account when water is released from Vanderkloof Dam.
- Fish River (Namibia) inflows will not contribute to any of the demands in the Lower Orange River.
- Operational losses will be included as a demand.
- River evaporation losses will be included along the river and abstracted as a demand at the previously defined river reaches.
- Include ORRS environmental demands, river mouth and Instream flow requirements.
- 2045 updated/verified sediment levels will be used in dams

3.2.4 Scenario 2: Vanderkloof lower level storage

Purpose: To determine river flow at Augrabies and at the river mouth.
These results will be used as input to the additional environmental flow task for the LORMS.

Description: As Present day (2005) but with the following changes:

- Lower level storage in Vanderkloof Dam will be utilized and the additional yield abstracted at Vanderkloof Dam (271mcm/a surplus yield). The additional yield will therefore not be released directly into the river to support users downstream.
- The 2005 demands imposed on the system and surplus yield abstracted at Vanderkloof. No additional releases for hydropower.

3.2.5 Scenario 3: Vioolsdrift reregulating dam

Purpose: To determine river flow at Augrabies and at the river mouth.
These results will be used as input to the additional environmental flow task for the LORMS.

Description: As Vanderkloof lower level storage but with the following changes:

- Include a re-regulating dam at Vioolsdrift. The saving in operational losses will be used to support possible future irrigation requirements in the Lower Orange

3.2.6 Scenario 4: Large Vioolsdrift

Purpose: To determine river flow at Augrabies and at the river mouth.
These results will be used as input to the additional environmental flow task for the LORMS.
Description: As Vanderkloof lower level storage but with the following changes:

- Include a Large Dam at Vioolsdrift. The saving in operational losses and additional yield will be used to support possible future irrigation requirements in the Lower Orange (766mcm/a surplus yield) .
- The 2005 demands imposed on the system and surplus yield abstracted at Vioolsdrift as well as the saving in operational losses . No additional releases for hydropower.

3.2.7 Scenario 5: River Class C

Purpose: To determine the impact of a River Class C releases on river and the estuary. The main difference with Scenario 1 is that the ORRS EFR was replaced with desktop Class C EFRs (417mcm/a shortage). The 2005 demands imposed on the system . No additional releases for hydropower. Note that for this scenario only the flow as required by the Desktop class C requirement was provided for each site.

These results will be used as input to the additional environmental flow task for the LORMS. The preliminary environmental flow requirements (provided by Ninhan Shand) were use to generated the simulated monthly flow tables in the WRYM. However, flows in the excess of these requirements occur at these sites from time to time, but is not included in the simulated results.

3.2.8 Scenario 6: River Class D

Purpose: To determine surplus yield available at 2005 development level with updated environmental requirements included and to serve as the reference system yield and to determine the impact of a River Class D releases on river and the estuary. This yield will be used to compare with the yield from the other scenarios to determine the increase or decrease in yield. These results will be used as input to the additional environmental flow task for the LORMS.

Description:

- Desktop Environmental requirements Class D will be used instead of the ORRS environmental requirement. The desktop requirement is not a fixed annual volume but varies from year to year depending on the variation of the natural flow at the site. For the historic analysis period the EFR varied from 758 million m^3/a to 2773 million m^3/a with an average of 1605 million m^3/a.
- Spills from the Vaal plus losses from the Vaal, which flow into the Orange River, will be included in the analysis. The spills will only be used to support the environmental requirements and not the irrigation or urban demands.
- The recently updated environmental releases from the Lesotho Highlands Water Project (LHWP) will be used. The effect of the updated EFR from Lesotho on the transfer rate to the RSA was not available at the time and the transfer rate as given in Reference Scenario1 was used.

3.2.9 Scenario 7: Modified River Class D

This is as River Class D used for yield modeling purposes. The main difference is that the modified River Class D EFR was used at the mouth and Augrabies and not the full class D EFR (14mcm/a surplus yield). The 2005 demands imposed on the system . No additional releases for hydropower.

3.2.10 Scenario 8: Modified River Class D with Natural losses

This is as River Class D used for yield modeling purposes with the only difference that the modified River Class D EFR was used only used at Augrabies and not at the Mouth. It was assumed that the EFR releases at Augrabies as reduced by river evaporation will be sufficient for the mouth (248 mcm/a surplus yield). The 2005 demands imposed on the system . No additional releases for hydropower.

3.2.11 Scenario 9: River Class C with floods

This is as Scenario 5 with the only difference that the total flow at each site were provided that includes the River Desktop Class requirements as well as other flows over and above the Class C EFR due to spills from Vanderkloof the Vaal, Fish river and local inflows.

3.2.12 Scenario 10: River Class D with floods

This is as Scenario 6 with the only difference that the total flow at each site were provided that includes the River Desktop Class requirements as well as other flows over and above the Class D EFR due to spills from Vanderkloof the Vaal, Fish river and local inflows.

Notes on the Simulated Flow Scenarios:

- **Environmental Requirements**: The river mouth is always modeled as a consumptive demand simply due to the fact that the water is not available for users as soon as it enters the ocean. For Reference scenario 1 where the river mouth EFR was the main driver of the EFRs the EFR was regarded as a consumptive demand abstracted at the end of the system.

  For Reference scenario 2 the River EFR is the main driver. These EFRs are non-consumptive demands and are modeled in that manner. For Reference scenarios 2 & 3 the environmental requirement could also utilize the spill flows coming from the Vaal or the incremental Lower Orange River catchment. It was decided to model it this way as the EFRs for scenario 2 & 3 vary significantly from year to year depending on the variation in the natural flow record. It is then just logic that the EFR should use spills when it is available. The ORRS EFR as used in Reference Scenario 1 is a fixed annual value with a different value for each month but no variation from year to year. The total EFR for Reference Scenario 1 is therefore released from Vanderkloof Dam, which corresponds with what is done in practice.

  The system was modeled in such a manner that irrigation and urban/industrial/mining demands along the Orange River were not allowed to abstract any of the water required for the environment. The only consumptive "user" along the river that was allowed to use water reserved for the environment, are the evaporation losses, evapo-transpiration and seepage from the river and riparian vegetation. This use is also referred to as river requirements and is in fact part of the river EFR.

  - **Vaal surplus**: The surplus currently available in the Vaal System sits in the Tugela/Vaal sub-system. With the LHWP transferring water at a constant flow rate into the Vaal System, it is currently not necessary to pump the total available yield from the Tugela/Vaal sub-system to Sterkfontein Dam in the Vaal River catchment. This surplus can be made available to users for consumptive use in the Lower Orange River at the same cost that any new user in the Vaal system would have to pay for the water from the Vaal System. This water must then be pumped from the Tugela into Sterkfontein Dam and from there released into the Vaal River to flow to the Orange through the various major dams. The pumping cost from the Tugela is already included in the standard Vaal tariff. This surplus will however reduce over time due to the growth in the Vaal System demand from 200 million m³ in 2005 to almost zero in 2015. This surplus water can therefore be used in the short-term before a new development is in place in the Orange River.

  - **Water quality in the Lower Vaal**: The Vaal River system is operated to minimize the spills from the Vaal into the Orange River. Releases from Vaalharts Weir are therefore made to only supply the users downstream and not to support the Orange River. Due to the large irrigation schemes in the Lower Vaal a significant volume of return flows from irrigation also enters the river, which results in the deteriorating of the water quality in the Lower Vaal. This is already a significant problem at Douglas where large volumes of water is abstracted for irrigation. To improve the situation water is already transferred from the Orange River at Marksdrift Weir to Douglas Weir. If the surplus in the Vaal is according to scenario 3 used to support the Orange, the water will finally be released from Bloemhof and Vaalharts Weir. These releases will dilute the poor quality water in the Lower Vaal and therefore improve the quality of the available water in the Lower Vaal. Some of these salts and other elements will unfortunately also be washed into the Orange River as result of the support from the Vaal.

- **Operational losses**: The possible saving in operational losses have been determined by means of a separate analysis by using a hydraulic river model. The possible savings and required dam sizes for re-regulating dams at Vioolsdrift and Boegoeberg are given in the description of scenario 3e. It is however possible to consider a large storage dam at any of the two sites and also use it as a re-regulation dam to reduce operational losses. This dam will then have the benefit of increasing the yield due to the additional storage of X m^3 plus the possible saving in operational losses. To be able to obtain this advantage the size of the storage dam should be slightly increased to X plus required storage for a re-regulating dam at that site.

For the purpose of the system analysis and initial costing, the effect of the individual scenarios will first be determined. Depending on the URVs of each, as well as taking into account the practical aspects, a combination of scenarios will be analyzed at a later stage.

3.3 HYDROLOGY EVALUATION

As part of the LORMS the RSA hydrology was reviewed by the Namibian consultants, which concluded the following: *"The general impression is that the work has been carried out thoroughly as far as the data will allow. There is no reason to disagree with the hydrological files being used as input for the system analysis".* The need to update the hydrology for the incremental Orange River Catchment upstream of Vanderkloof Dam as well as for the Orange River downstream of Vanderkloof Dam to the Orange River Mouth (Fish River excluded) was also expressed by them, as this hydrology is already more than a decade old (Mr M Maré, WRP).

A high confidence level can be placed on the hydrology generated as part of the VRSAU study, which includes the Senqu hydrology in Lesotho. Almost 70% of the natural runoff is generated in these catchments, which clearly represents the bulk of the runoff generated in the Orange River catchment. Approximately 23% of the natural flow is generated in the Orange River incremental catchment upstream of Vanderkloof Dam and downstream of Lesotho (Caledon River catchment included). Although this hydrology is old, a relatively high confidence level can be placed on the hydrology.

A medium to low confidence level can be placed on the hydrology downstream of Vanderkloof Dam (excluding the Vaal and Fish rivers). The runoff generated in this catchment however represents only 3% of the total natural runoff. The fact that the accuracy of the hydrology used for this extremely large incremental catchment is not at the required level, will due to the volume of runoff generated, have an insignificant effect on the analysis.

As part of the LORMS a simplified rainfall/runoff modelling was carried out to obtain updated hydrology for the Fish River (Namibia). A detailed rainfall/runoff assessment was therefore not carried out for the Fish River (Namibia), partly due to time constraints, but also due to the fact that the natural runoff from the Fish River catchment only represents approximately 4% of the total Orange River runoff.

Although the bulk of the hydrology can be regarded as reliable, the main problem regarding the accuracy of observed flows, is with regards to flows and specifically low flows measured in the Lower Orange River. Most of the gauging weirs in the Lower Orange River are long weirs, so that the slightest increase in flow depth, results in a significant increase in the flow rate. It is therefore extremely difficult to tell from the observed flows, how much water is flowing in the Lower Orange River and specifically the flow that enters the river mouth. This problem is further complicated by the fact that the bulk of the abstractions are for irrigation purposes for which there is basically no observed data available. A large volume of water is also lost due to evaporation from the river, for which a fairly good indication was obtained of the average river evaporation losses from studies carried out by the WRC. This will however vary depending on the actual weather conditions and flow in the river.

To conclude, the inflows to Gariep and Vanderkloof dams as well as the outflow from the Vaal River catchment entering the Orange River can be used with confidence, the actual observed flows in the Lower Orange River is not at the required level and need to be improved significantly (Mr M Maré, WRP).

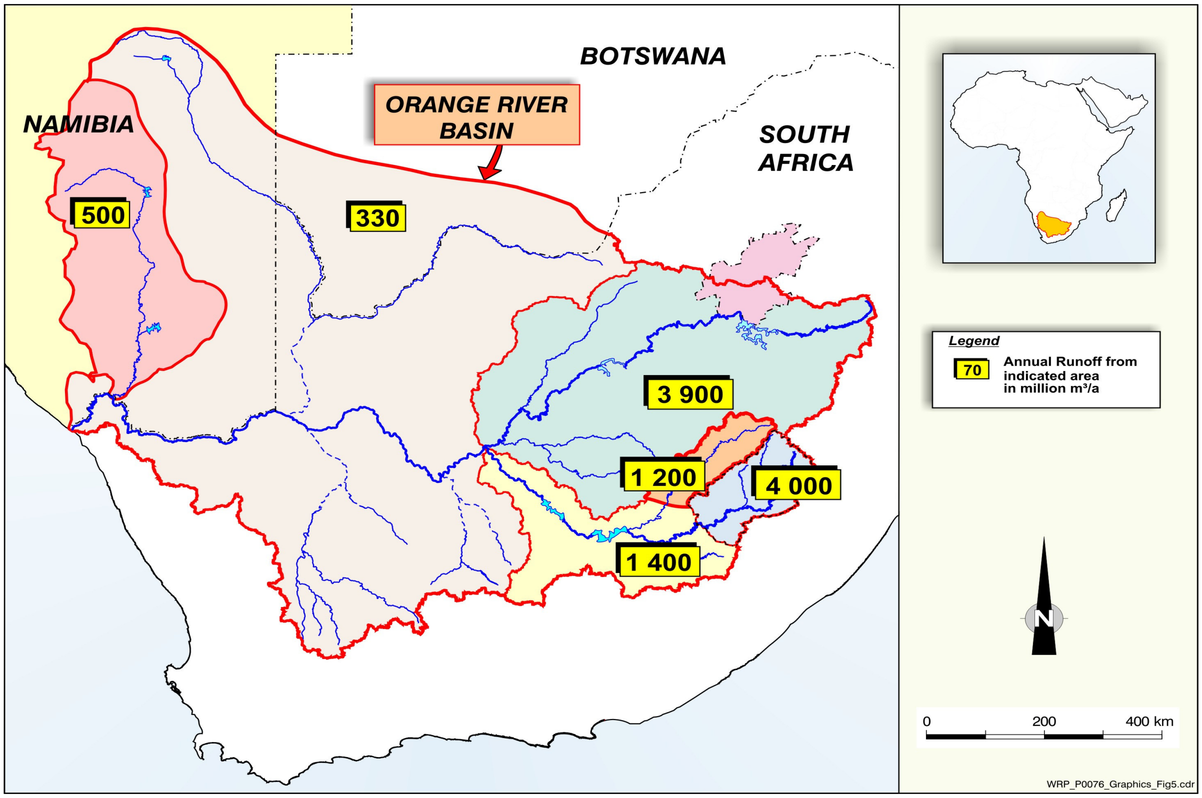


Figure 2. Map indicating natural runoff for Orange River Cathment

3.4 FLOODS

In an attempted to obtain a first impression on changes in the frequency and magnitude of the highest monthly flows in the simulated monthly datasets for the different scenarios, the highest monthly flows for the reference (or natural) conditions are listed and these are compared with the flows in the same months for the other scenarios. For the purpose of this analysis monthly flows of 5 000 x 10^6 m^3 or more are seen as being indicative of flood events under the Reference condition.

It is likely that during a month with such a high average flow a major flood with a much higher peak flow would have occurred. This analysis gives therefore only an indication on the occurrence of major floods under the different scenarios.

Table 3: A comparison of the reduction in average monthly flows (in 106 m3/month) for the different scenarios for the months with the highest monthly flow (> 5000 x 106 m3) as they occurred under reference (or natural) conditions.

Date	**Reference**	**Present State**	**Scenario**									
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Feb 1974	11110.01	6528.27	6528.27	5754.70	5838.26	5052.48	1120.11	903.15	6199.24	6233.27	5918.1	6113.36
Mar 1925	10329.10	9400.24	9400.24	9124.13	9107.73	9197.13	485.31	356.29	9302.13	9295.65	8975.6	9123.54
Feb 1988	9803.26	7694.77	7694.77	6939.96	6999.97	4040.26	1120.11	903.15	7373.22	7716.73	5640.16	5871.83
Jan 1934	8402.93	3045.05	3045.05	3045.05	3031.51	1811.81	374.40	267.89	2996.56	3035.29	2848.81	2848.82
Mar 1976	8115.52	7675.18	7675.18	7662.60	7652.37	7605.35	485.31	356.29	7541.38	7550.77	7734.54	7716.21
Feb 1976	7974.58	7211.70	7211.70	7200.24	7214.81	7162.85	1120.11	903.15	7076.91	7126.36	7250.43	7233.72
Mar 1974	6844.81	6345.52	6345.52	6332.95	6317.94	6273.74	485.31	356.29	6361.56	6343.78	6404.88	6386.55
Jan 1976	6509.95	5383.08	5383.08	5370.50	5371.50	5304.37	374.40	267.89	5337.95	5373.84	5438.07	5419.74
Feb 1955	6473.44	4474.09	4474.09	4343.00	4313.53	3078.57	1120.11	903.15	4495.99	4518.71	3419.18	3913.46
Jan 1974	6383.54	2042.26	2042.26	2042.26	2028.72	1020.76	374.40	267.89	1999.85	2025.42	1852.58	1853.19
Mar 1948	6045.27	1884.37	1884.37	1696.39	1686.21	39.53	485.31	356.29	1792.3	1831.05	1731.18	1731.18
Feb 1975	5654.91	4789.82	4789.82	4765.90	4755.49	4746.83	1120.11	903.15	4908.11	4920.09	4924.76	4908.05
Nov 1936	5562.65	2463.00	2463.00	2463.00	2449.90	1713.56	245.35	202.87	2378.1	2378.1	2268.82	2268.82
Feb 1944	5561.82	5111.24	5111.24	5099.78	5081.14	5013.85	1120.11	903.15	5119.41	5049.41	5150.62	5133.92
Feb 1967	5498.63	3512.91	3512.91	3372.33	3381.11	2977.59	1120.11	903.15	3738.08	3742.48	3779.23	3721.31
Nov 1943	5404.48	4744.97	4744.97	4732.80	4731.88	4684.44	245.35	202.87	4752.95	4547.96	4780.63	4762.89
Feb 1939	5247.66	3470.70	3470.70	3213.84	3197.95	2288.29	1097.25	785.79	3115.91	3182.82	2587.8	2820.71
Apr 1925	5129.42	4799.57	4799.57	4787.40	4781.50	4736.10	315.05	226.02	4756.88	4712.74	4870.56	4852.83
Oct 1957	5084.99	4342.45	4342.45	4329.88	4311.98	4254.99	150.81	131.34	4119.52	4122.69	4403.63	4385.3
Mar 1972	5042.62	1923.56	1923.56	1923.55	1884.52	1317.77	485.31	356.29	2006.99	2017.44	1945.77	1945.77
Average	6808.98	4842.14	4842.14	4710.01	4706.90	4116.01	672.22	522.80	4768.652	4786.23	4596.268	4650.56

Table 4: A comparison of the percentage reduction in average monthly flows for the different scenarios for the months with the highest monthly flow (> 5000 x 10^6 m^3) as they occurred under reference (or natural) conditions.

Date	**Reference**	**Present State**	**Scenario**									
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Feb 1974	100.00	58.76	58.76	51.80	52.55	45.48	10.08	8.13	55.80	56.10	53.27	55.03
Mar 1925	100.00	91.01	91.01	88.33	88.18	89.04	4.70	3.45	90.06	89.99	86.90	88.33
Feb 1988	100.00	78.49	78.49	70.79	71.40	41.21	11.43	9.21	75.21	78.72	57.53	59.90
Jan 1934	100.00	36.24	36.24	36.24	36.08	21.56	4.46	3.19	35.66	36.12	33.90	33.90
Mar 1976	100.00	94.57	94.57	94.42	94.29	93.71	5.98	4.39	92.93	93.04	95.31	95.08
Feb 1976	100.00	90.43	90.43	90.29	90.47	89.82	14.05	11.33	88.74	89.36	90.92	90.71
Mar 1974	100.00	92.71	92.71	92.52	92.30	91.66	7.09	5.21	92.94	92.68	93.57	93.31
Jan 1976	100.00	82.69	82.69	82.50	82.51	81.48	5.75	4.12	82.00	82.55	83.53	83.25
Feb 1955	100.00	69.11	69.11	67.09	66.63	47.56	17.30	13.95	69.45	69.80	52.82	60.45
Jan 1974	100.00	31.99	31.99	31.99	31.78	15.99	5.87	4.20	31.33	31.73	29.02	29.03
Mar 1948	100.00	31.17	31.17	28.06	27.89	0.65	8.03	5.89	29.65	30.29	28.64	28.64

Feb 1975	*100.00*	*84.70*	*84.70*	*84.28*	*84.09*	*83.94*	*19.81*	*15.97*	*86.79*	*87.01*	*87.09*	*86.79*
Nov 1936	*100.00*	*44.28*	*44.28*	*44.28*	*44.04*	*30.80*	*4.41*	*3.65*	*42.75*	*42.75*	*40.79*	*40.79*
Feb 1944	*100.00*	*91.90*	*91.90*	*91.69*	*91.36*	*90.15*	*20.14*	*16.24*	*92.05*	*90.79*	*92.61*	*92.31*
Feb 1967	*100.00*	*63.89*	*63.89*	*61.33*	*61.49*	*54.15*	*20.37*	*16.43*	*67.98*	*68.06*	*68.73*	*67.68*
Nov 1943	*100.00*	*87.80*	*87.80*	*87.57*	*87.55*	*86.68*	*4.54*	*3.75*	*87.94*	*84.15*	*88.46*	*88.13*
Feb 1939	*100.00*	*66.14*	*66.14*	*61.24*	*60.94*	*43.61*	*20.91*	*14.97*	*59.38*	*60.65*	*49.31*	*53.75*
Apr 1925	*100.00*	*93.57*	*93.57*	*93.33*	*93.22*	*92.33*	*6.14*	*4.41*	*92.74*	*91.88*	*94.95*	*94.61*
Oct 1957	*100.00*	*85.40*	*85.40*	*85.15*	*84.80*	*83.68*	*2.97*	*2.58*	*81.01*	*81.08*	*86.60*	*86.24*
Mar 1972	*100.00*	*38.15*	*38.15*	*38.15*	*37.37*	*26.13*	*9.62*	*7.07*	*39.80*	*40.01*	*38.59*	*38.59*
Average	***100.00***	***70.65***	***70.65***	***69.05***	***68.95***	***60.48***	***10.18***	***7.91***	***69.71***	***69.84***	***67.63***	***68.33***

The Following conclusions can be drawn from Tables 3 and 4:

- The highest average monthly flows have been reduced to 71 % of the Reference condition to the Present state.
- There is no difference between the Present state (with hydropower release) and Scenario 1: Present (2005) in terms of changes to the flood regime of the Orange River system.
- Scenario 2 and 3 reduces the highest average monthly flows to about 69% of what it was under the Reference conditions. This is similar to the Present state flood regime and therefore represents no significant change in the estuarine dynamics.
- Scenario 4 reduced the high flows to about 60% of Reference Conditions.
- Scenarios 5 and 6 represent extreme reduction to 10 and 8% respectively of the Reference State.
- Scenario 7 and 8 reduces the highest average monthly flows to about 70% of what it was under the Reference conditions. This is similar to the Present state flood regime and therefore represents no significant change in the estuarine dynamics.
- Scenario 9 and 10 reduces the highest average monthly flows to about 68% of what it was under the Reference conditions. This is slightly less than Present state flood regime and therefore represents no significant change in the estuarine dynamics.

Table 5: A comparison of the reduction in high flow events, represented by monthly flows greater than 5000 x 10^6 m^3) between the Reference Conditions, Present State and various future runoff scenarios.

SCENARIO	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**TOT**
Reference Condition	1	2	0	3	8	5	1	0	0	0	0	0	**20**
Present State (with hydropower release)	0	0	0	1	4	4	0	0	0	0	0	0	**9**
Scenario 1: Present State (2005)	0	0	0	1	4	4	0	0	0	0	0	0	**9**
Scenario 2: Vanderkloof lower level	0	0	0	1	4	4	0	0	0	0	0	0	**9**
Scenario 3: Vioolsdrift reregulating	0	0	0	1	4	4	0	0	0	0	0	0	**9**
Scenario 4: Large Vioolsdrift	0	0	0	1	3	4	0	0	0	0	0	0	**8**
Scenario 5: River Class C	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Scenario 6: River Class D	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Scenario 7: Modified River Class D	0	0	0	1	4	4	0	0	0	0	0	0	9
Scenario 8: Modified River class D with Natural losses	0	0	0	1	4	4	0	0	0	0	0	0	9
Scenario 9: River class C with floods	0	0	0	1	4	4	0	0	0	0	0	0	9
Scenario 10: River Class D with floods	0	0	0	1	4	4	0	0	0	0	0	0	9

The following can be deduced from an analysis of Table 5:

- Noteworthy, is the fact that the majority of high flow months (where monthly flows of 5000 x 10^6 m^3 or more is seen as indicative of flood events) occurred in the late summer, January to March.
- Twenty high flow months occur under the Reference conditions, of which 16 events were simulated for the period January to March, with 4 more occurring in October (1), November (2) and April (1).
- The occurrence of high monthly flows was strongly reduced under the Present state and the various simulated future scenarios. Under the Present state and Scenario 1 to 3 only 9 flood events occur from January to March.
- Under Scenario 4 the occurrence of high monthly flows has been further reduced to 8 months in total for January to March.
- There were no high flow months simulated for Scenarios 5 and 6.
- The occurrence of high monthly flows was strongly reduced under Scenario 7 to 10 (similar to scenarios 1 to 3), only 9 flood events occur from January to March.

Flood hydrographs for different occurrences were not available for the study, but Ninham Shand provided a limited number of flood estimates for Augrabies. The Vioolsdrift measured flow data was not judged to be of a high enough quality for detailed flood analysis. The potential impacts of future development options on the magnitude and occurrence of floods entering the Orange River estuary were assessed through a comparison of the natural flow regime with flow regimes resulting from observed data and Scenario 1: Present (2005).

Table 6 was generated through performing an annual maximum series assessment on the data provided. The monthly naturalised and 2005 data set were disaggregated using observed data from gauging station D7H008. As indicated in Table 6 there is a marked decrease in magnitude of inter-annual floods.

Table 6 : Results of annual maximum series assessment on the naturalised, 2005 and observed data for Augrabies

Daily peak discharge (x 10^6 m^3)	*Reference (Modelled data)*	*Present State (Observed data*)*	*Present (2005) (Modelled data)*
1:2	2832	1871	434
1:5	5369	3299	1380
1:10	6667	4130	2070
1:20	9349	4973	3422

**These data are from D7H008 for 1932 – 2000. This means that analyses of the full data set, such as is required for flood analysis, are confused by the trend of increasing abstraction over the period.*

4. PSYCHICAL DYNAMICS

4.1 RIVER FLOW

The main driving force of all estuaries is the river flow in all its variability entering the estuary.

The catchment of the Orange River is approximately 1 000 000 km^2 (DWA, 1990) and the natural mean annual run-off (MAR) is estimated at 10 833 000 million m^3. It is estimated, that by 1989 the MAR had been reduced to about 50 % of the natural MAR (DWA, 1990) (Figure 3) and at present to about 44%.

4.1.1 *Reduction in variation in river flow*

Besides the significant reduction in river flow, the variability in the Orange River flow has also been strongly reduced because of the major dam development in the catchment (Table 1), and especially because of the regulated releases from these dams. Low (dry season) flows are elevated and flood peaks are much lower or captured by the dams. Some aspects are:

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

An important result is that because of the reduction in variability in river flow the water levels are also far less variable now. This probably has resulted in sandbanks being more permanently exposed and, as a consequence become vegetated.

4.1.2 *Further changes in river flow*

The surplus releases for the generation of hydropower purposes are currently in the process of being significantly reduced from about 320 million m^3 an annum, as was the case up to two or three years ago, to 60 million m^3 an annum at present. The Mohale Dam has also started to impound water and therefore is significantly reducing the surplus flow available in Gariep and Vanderkloof Dams. It is expected that this surplus will be reduced even more in the future, due to the escalation in demands, such as a planned increase in irrigation, imposed on the system (pers comm. Mr M. Maré).

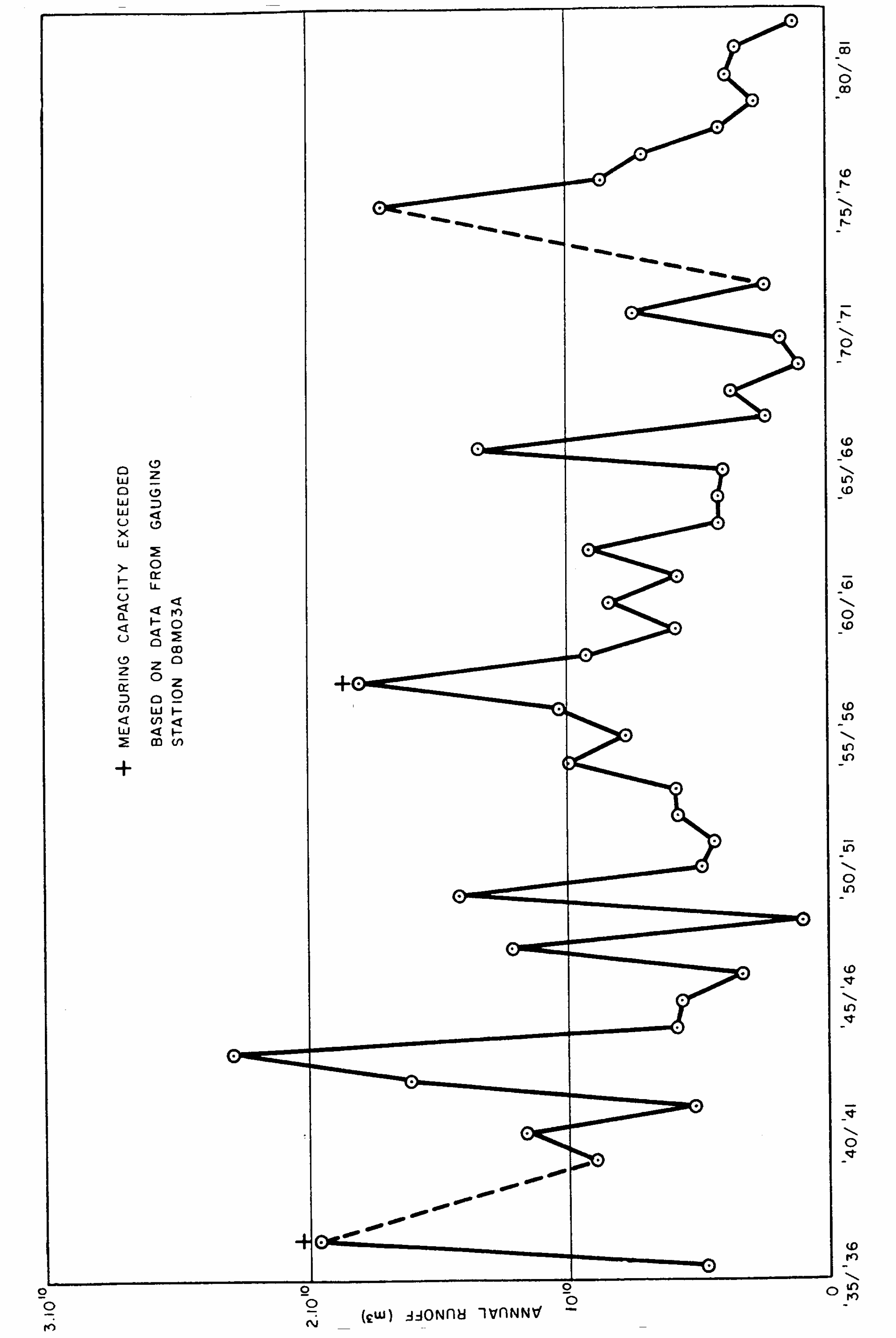


Figure 3. Measured annual run-off between 1935 and 1980

Reduction in river flow will result in a reduction in the size of the mouth of the estuary and can eventually result in mouth closure. The tidal amplitude and the seawater intrusion in the estuary will then also be reduced.

More frequent mouth closures are therefore expected if the river flow becomes too low to keep the mouth open. Reliable data on the river flow required to maintain an open mouth are not available.

4.2 INTERACTION BETWEEN RIVER FLOW AND MOUTH CONDITIONS

As a result of local conditions, considerable differences exist between estuaries in terms of the river flow required to keep an estuary mouth open. The Great Brak Estuary mouth, for example, often stays open if a river flow of 0.5 m^3/s is maintained for a few days over neap tide (CSIR, 1994). However, the mouth of the Umgeni Estuary near Durban closes occasionally at river flows of 7 m^3/s (CSIR, 1990) even at springtide.

Estuary specific data on river flow and mouth closures are therefore required to determine the flows under which the estuary mouth will close and, unfortunately, such data are not available for the Orange River Estuary.

In the following section earlier estimates based on observations of the mouth and the river during 1995, that the river flow required to keep the mouth open could be between 5 and 20 m^3/s (or between 13 x 10^6 and 52 x 10^6 m^3/month). These estimates were based on the evaluation of measured inflow data, estimated demand down stream of Viooldrift and calculations of the water levels and the surface area of the estuary.

4.2.1 Water demand downstream from Vioolsdrift

It should be emphasized that the data from the Vioolsdrift gauging station should be used with caution (?)causation, as the gauging station is about 280 km upstream from the Orange River Estuary, with significant water demand downstream from the station. Table 7 illustrated the estimated total water demand in million cubic meters per month of the various catchment activities (e.g. farming and mining) and river evaporation.

Table 7: Monthly Demand (x10^6 m^3 per annum) (Source: WRP, Mr M Maré)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Ausenkher & Noordoewer	3.33	5.23	6.62	8.91	4.34	1.16	0.68	0.41	0.25	0.31	0.49	0.84	32.57
Vioolsdrift South irrigation	0.77	1.21	1.53	2.06	1.00	0.27	0.16	0.09	0.06	0.07	0.11	0.19	7.53
Alexander Bay Irrigation	1.10	0.64	0.68	1.50	1.15	1.49	1.23	0.23	0.25	0.34	0.58	0.87	10.05
Noordoewer, Aussenkehr Urb.	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.17
Mines Rosh Pinah, Scorpion, Namdeb, Auchas, Daberas	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	6.85
Urban Rosh Pinah, Scorpion, Oranjemund.	0.74	0.78	0.69	1.09	0.78	0.78	0.76	0.60	0.61	0.56	0.67	0.61	8.68
Alexander Bay, Trans Hex & Other Mines	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	7.30
Sub-total (Activities)	**7.14**	**9.06**	**10.71**	**14.76**	**8.47**	**4.89**	**4.01**	**2.52**	**2.36**	**2.47**	**3.04**	**3.70**	**73.14**
River evaporation Reach 6	5.67	6.99	7.60	7.57	5.67	4.54	3.08	2.33	1.67	1.93	2.86	4.29	54.20
River evaporation Reach 7	6.95	8.57	9.32	9.29	6.95	5.57	3.78	2.86	2.06	2.37	3.51	5.27	66.50
Sub-total (Evaporation)	**12.62**	**15.56**	**16.92**	**16.86**	**12.62**	**10.11**	**6.86**	**5.19**	**3.73**	**4.30**	**6.37**	**9.56**	**120.70**
Total	**19.76**	**24.62**	**27.63**	**31.62**	**21.09**	**15.00**	**10.87**	**7.71**	**6.09**	**6.77**	**9.41**	**13.26**	**193.84**

Table 8 converts the monthly water demand (Table 7) into estimated average losses downstream form Vioolsdrift in m^3/s. Potentially there is a significant loss in flow between Vioolsdrift and the head of the estuary, with maximum values of about 10 – 12 m^3/s estimated for November and December.

Table 8: Estimated average monthly demand in m^3/s

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
Sub-total (Activities)	2.67	3.49	4.00	5.51	3.50	1.83	1.55	0.94	0.91	0.92	1.13	1.43	27.31
Sub-total (Evaporation)	4.71	6.00	6.32	6.29	5.22	3.77	2.65	1.94	1.44	1.61	2.38	3.69	45.06
Total	**7.38**	**9.50**	**10.32**	**11.80**	**8.72**	**5.60**	**4.20**	**2.88**	**2.35**	**2.53**	**3.51**	**5.12**	**72.37**

4.2.2 Measured inflow

4.2.2.1 Measured inflow for 1993

In order to quantify the river inflow at which mouth closure for the Orange River Estuary could occur, measured inflow at the Vioolsdrift Gauging station (D8H003) were correlated with the three documented mouth closure events. These were the prolonged mouth closure of spring 1993, and two brief mouth closure events during December 1994 and December 1995, recorded by the permanent water level recorder (D8H012) near Alexander Bay.

Table 9: Measured Daily flows for 1993 at Vioolsdrift Gauging station (D8H003) in m^3/s (flows less than 10 m^3/s are shaded)

MEASURED DAILY FLOWS FOR 1993 AT VIOOLSDRIFT GAUGING STATION (D8H003)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	15.35	20.89	53.54	11.15	12.61	18.68	10.20	10.22	1.17	0.11	2.36	9.57	1
2	18.28	33.80	45.49	9.29	18.39	18.48	8.50	10.42	1.28	0.06	1.55	7.95	2
3	18.53	37.10	36.96	7.32	27.51	16.80	8.15	12.60	1.40	0.05	1.13	6.50	3
4	18.83	30.94	32.48	7.07	25.11	17.32	10.10	12.46	1.53	0.09	0.91	6.20	4
5	18.58	26.27	29.17	8.13	23.01	18.21	10.89	9.63	1.68	0.08	0.90	6.16	5
6	13.53	24.93	47.85	11.55	20.92	19.09	11.17	7.41	1.51	0.12	0.90	9.83	6
7	9.40	22.55	53.31	13.01	20.26	19.84	11.45	6.89	1.28	0.10	1.11	11.47	7
8	6.11	20.01	45.04	14.32	21.38	18.15	11.74	7.12	1.07	0.08	1.49	9.80	8
9	4.34	19.43	38.11	14.29	22.22	15.96	12.03	7.44	0.88	0.06	1.75	8.12	9
10	7.46	21.81	30.68	17.28	24.86	14.81	12.35	7.77	0.72	0.04	1.58	8.64	10
11	8.14	13.84	25.06	17.27	28.41	12.78	13.70	7.94	0.85	0.03	1.77	9.33	11
12	7.86	34.29	21.61	15.02	31.22	10.45	14.45	6.95	0.91	0.02	1.88	10.86	12
13	6.17	53.24	18.55	12.89	31.40	9.15	13.03	5.83	0.95	0.01	1.66	12.64	13
14	5.19	27.87	19.26	10.42	30.63	8.11	11.69	4.88	0.99	0.01	1.33	13.47	14
15	4.07	20.78	19.60	29.58	27.52	7.77	10.43	4.56	1.03	0.00	1.02	11.27	15
16	4.32	18.16	18.54	43.55	26.03	7.82	9.26	4.38	1.07	0.00	0.76	9.12	16
17	4.14	19.56	15.96	34.32	24.96	7.87	8.42	4.20	1.12	0.00	0.52	7.22	17
18	3.75	20.04	14.80	28.36	24.75	7.43	9.41	4.03	1.15	0.00	0.30	5.64	18
19	3.03	20.93	13.70	23.51	25.54	7.08	10.81	4.34	1.16	0.00	0.15	4.89	19
20	2.50	29.39	14.68	18.46	23.62	7.54	11.01	4.49	1.16	0.00	0.05	5.62	20
21	2.14	25.56	18.43	14.55	20.41	7.93	10.44	3.45	1.16	0.00	0.02	7.57	21
22	1.81	24.54	19.88	11.34	18.59	8.33	9.49	3.14	0.92	0.00	0.01	7.64	22
23	1.57	31.81	17.74	9.27	18.51	8.74	8.33	2.86	0.51	0.00	0.04	5.82	23
24	1.51	28.35	16.76	8.22	18.40	8.91	7.38	2.60	0.42	0.00	0.06	4.82	24
25	1.17	25.63	15.13	7.74	18.21	7.93	7.67	2.35	0.42	0.00	0.05	3.87	25
26	0.92	53.09	14.83	9.17	16.49	6.96	8.32	2.12	0.41	7.21	0.04	3.42	26
27	9.55	78.73	15.50	10.90	15.38	6.76	8.32	1.99	0.41	8.04	0.61	3.42	27
28	14.95	65.78	16.34	11.66	15.61	6.71	8.32	1.90	0.40	7.65	4.65	3.53	28
29	16.74		15.64	11.22	16.09	6.82	8.53	1.80	0.39	6.75	7.76	5.11	29
30	21.88		14.97	16.66	18.02	10.77	9.97	1.70	0.29	4.53	9.90	4.60	30
31	19.30		14.07		18.47		10.26	1.48		3.38		3.63	31
Average	**8.747**	**30.33**	**24.96**	**15.25**	**22.08**	**11.44**	**10.19**	**5.449**	**0.941**	**1.239**	**1.542**	**7.347**	
Median	**6.169**	**25.6**	**18.55**	**12.28**	**21.38**	**8.826**	**10.2**	**4.49**	**1.01**	**0.04**	**0.967**	**7.217**	

Unfortunately, there are no measured water level data for the estuary mouth for 1993 indicating at which precise flows the Orange River Estuary closed. But, as demonstrated by the shaded measurements (Table 9), from August to December 1993 flows of 10 m^3/s, or far less, occurred on average for most of the spring and summer. The measured low flows therefore support statements on mouth closure for this period.

Because of irrigation activities and evaporation losses between Vioolsdrift and the Orange River mouth, which are of the order of 5 m^3/s in September to 10m^3/s in December, it is likely that hardly any flow reached the estuary during this period.

4.2.2.2 *Measured inflow for 1994*

Table 10: Measured Daily flows for 1994 at Vioolsdrift Gauging station (D8H003) in m^3/s (flows less than 10 m^3/s are shaded)

MEASURED DAILY FLOWS FOR 1994 AT VIOOLSDRIFT GAUGING STATION (D8H003)													
DAY	*JAN*	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*OCT*	*NOV*	*DEC*	*DAY*
1	2.87	33.95	95.66	45.47	66.70	80.17	223.00	61.54	36.20	33.03	21.14	16.00	1
2	2.57	32.64	96.20	55.74	67.17	80.17	225.80	62.39	44.58	30.69	15.17	15.07	2
3	6.21	33.39	100.20	55.89	67.65	80.17	223.90	63.22	51.24	27.45	12.17	17.82	3
4	14.21	40.82	98.81	51.04	68.13		221.70	57.55	43.36	27.54	11.52	24.29	4
5	15.14	50.95	87.39	51.40	68.60		219.40	58.49	52.84	29.54	13.41	23.42	5
6	12.91	61.69	71.15	50.86	69.09		216.70	59.41	71.88	31.76	21.19	22.48	6
7	20.87	58.48	119.50	42.44	69.52		220.10	57.42	63.83	37.60	20.85	40.15	7
8	41.68	48.20	191.60	44.11	69.58		238.70	60.75	60.35	52.89	16.87	38.23	8
9	38.74	44.13	137.30	58.65	69.58		230.50	65.99	61.36	47.06	18.69	37.15	9
10	23.98	51.31	151.80	57.06	69.58		230.20	66.23	48.29	38.58	32.58	42.32	10
11	19.36	66.50	159.60	55.76	69.58		224.70	81.83	35.61	36.91	31.87	41.30	11
12	59.82	73.41	137.30	63.92	69.58		222.10	80.71	27.84	32.53	31.41	36.60	12
13	44.99	93.48	105.70	56.41	69.58		222.30	64.56	23.12	28.84	33.76	33.53	13
14	58.89	97.94	100.20	43.37	69.69		221.60	54.79	19.32	29.89	32.48	31.92	14
15	61.77	77.82	97.80	37.88	70.52		206.20	61.32	18.51	32.51	27.07	26.77	15
16	48.93	86.78	98.63	49.29	71.50		189.90	56.67	19.08	30.45	20.85	37.99	16
17	41.37	211.70	116.50	46.99	72.49		187.00	48.44	20.53	27.87	15.73	46.81	17
18	39.12	211.10	124.20	43.06	73.49		185.90	44.27	26.58	25.42	12.89	52.42	18
19	38.61	188.70	124.30	41.94	74.49	279.50	184.70	43.95	26.13	23.33	18.77	52.78	19
20	40.46	194.00	118.00	43.43	75.50	284.10	182.60	46.81	21.68	25.72	26.31	42.92	20
21	49.31	176.00	97.57	44.67	76.46	298.40	173.60	41.77	17.20	25.18	26.54	33.25	21
22	53.48	144.00	82.26	51.83	77.05	327.40	169.70	35.81	14.47	21.82	22.83	27.09	22
23	49.87	147.80	74.99	53.74	77.56	313.60	145.90	34.17	12.54	21.21	20.18	39.60	23
24	42.15	202.30	75.50	54.79	78.07	283.60	115.50	37.69	22.96	22.68	18.05	47.86	24
25	60.06	199.10	73.27	55.83	78.58	276.00	93.26	39.46	30.40	22.12	17.55	40.64	25
26	73.19	172.10	70.47	56.89	79.10	274.30	81.68	41.17	31.40	22.32	20.58	29.90	26
27	60.71	136.10	65.92	57.96	79.62	263.90	72.33	43.26	29.57	21.97	25.67	27.62	27
28	50.77	107.90	51.77	60.76	80.09	236.10	64.55	46.00	27.37	18.59	26.17	26.13	28
29	42.69		46.21	65.50	80.17	213.30	62.14	42.24	27.73	16.20	23.43	20.81	29
30	38.74		42.16	66.20	80.17	212.80	60.23	36.50	31.22	24.29	19.65	20.28	30
31	35.95		40.62		80.17		60.70	35.10		27.05		28.82	31
Average	**38.37**	**108.6**	**98.49**	**52.1**	**73.2**	**233.6**	**173.4**	**52.56**	**33.91**	**28.81**	**21.85**	**32.97**	
Median	**41.37**	**90.13**	**97.8**	**52.78**	**71.5**	**274.3**	**189.9**	**54.79**	**28.71**	**27.54**	**20.85**	**33.25**	

The permanent water level recorder (D8H012) installed near Alexander Bay indicates a brief period of mouth closure from 1 to 3 December 1994. Table 10 indicates that a mean measured inflows of about 21 m^3/s were recorded for November 1994, and less than 30 m^3/s for September and October 1993. The measured inflow data indicate that under certain conditions there is a possibility of brief mouth closures at inflows of less than 25 m^3/s.

As discussed earlier, approximately 7 m^3/s may be lost due to irrigation and evaporation during November and about 10 m^3/s in December.

The surface water area of the Orange estuary from the mouth to the bridge was estimated to be about between 2 x 10^6 m^2 and 6 x 10^6 m^2. If a conservative amount of the surrounding flood plain area is included, as is the case under at higher water levels, in this calculation the surface water area can be increased to about 12 x 10^6 m^2.

Through the correlation of the water levels recorded by DWAF in December 1994 and 1995 and the estimated surface area, related flows required to keep the mouth open was calculated (Table 11). These flows are of a similar order as those recoded at the Vioolsdrift Gauging station.

Table 11: Summary of water level increase and river inflow required to maintain an open mouth

Date	Water level increase	Lower flow range In channel area (m^3/s)	Higher flow range Including flood plain (m^3/s)
1 Des 1994	0.23 m	15.4	30.8
2 Des 1994	0.19 m	12.7	25.4
3 Des 1994	0.12 m	8.0	16.0

4.2.2.3 *Measured inflow for 1995*

Table 12: Measured Daily flows for 1995 at Vioolsdrift Gauging station (D8H003) in m^3/s (flows less than 10 m^3/s are shaded)

MEASURED DAILY FLOWS FOR 1995 AT VIOOLSDRIFT GAUGING STATION (D8H003)													
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	30.86	34.27	11.76	44.94	23.43		10.59	27.89	4.05	9.09	8.04	122.10	1
2	30.12	27.92	9.48	41.59	22.58		11.71	24.58	3.43	11.17	7.49	121.10	2
3	23.51	23.35	6.69	35.78	22.58		11.99	21.50	3.13	12.51	5.56	87.07	3
4	18.86	23.32	5.49	56.90	22.58	24.33	11.64	18.60	2.88	11.74	4.21	60.83	4
5	14.79	33.04	4.95	133.60	22.71	25.31	12.97	14.67	2.63	10.78	3.12	43.15	5
6	13.00	34.89	6.08	147.20	24.77	26.28	14.38	14.09	2.45	9.32	3.01	32.83	6
7	15.59	30.87	6.78	121.30	25.41	25.19	13.39	14.55	2.41	8.23	3.67	27.82	7
8	25.21	23.53	6.72	101.70	23.20	23.03	11.64	11.01	2.38	8.26	5.71	32.69	8
9	28.83	17.72	6.55	79.45	20.34	21.24	11.20	7.78	2.32	9.76	6.03	39.58	9
10	22.30	14.71	6.01	66.20	16.42	21.59	11.03	7.47	2.09	11.51	5.58	38.84	10
11	16.85	20.38	6.49	59.78	14.65	22.24	10.87	28.25	1.84	10.51	4.43	29.74	11
12	13.09	21.19	7.02	59.49	12.99	22.45	10.54	30.59	2.10	8.15	3.89	28.45	12
13	11.09	21.11	9.16	57.07	11.76	19.22	10.35	25.76	2.79	7.14	3.81	37.96	13
14	9.95	21.44	9.56	56.38	12.96	15.55	10.88	20.56	3.48	6.26	5.68	43.58	14
15	15.24	20.04	9.98	59.99	14.72	12.69	11.51	16.31	3.26	6.27	9.65	54.55	15
16	15.59	19.35	10.41	59.19	16.70	11.35	12.44	12.59	2.45	6.97	8.26	62.61	16
17	13.49	15.74	10.81	55.69	23.73	10.29	13.44	10.81	2.33	9.56	6.59	63.63	17
18	12.31	12.92	14.17	51.34	25.28	10.96	13.66	9.94	2.16	10.68	5.53	63.06	18
19	12.58	12.37	22.66	42.74	26.84	11.51	12.24	8.08	1.82	9.27	5.49	75.86	19
20	12.09	19.11	20.65	39.52	29.32	11.41	10.85	8.01	1.61	8.38	10.09	94.31	20
21	12.13	19.14	17.58	38.71	29.64	11.31	8.82	7.89	2.12	8.23	13.86	78.12	21
22	24.34	16.51	14.80	37.59	30.17	11.22	7.95	7.78	2.41	8.59	10.83	77.19	22
23	36.11	15.47	12.61	34.73	30.28	10.12	29.33	7.67	3.02	9.00	8.23	69.02	23
24	34.10	12.82	11.35	30.94	27.57	7.77	76.46	7.04	3.33	9.40	5.83	55.08	24
25	34.70	11.35	8.58	24.79	26.08	8.13	63.80	5.42	2.77	8.83	4.63	49.71	25
26	36.65	15.35	12.23	20.96	27.54	13.21	41.47	4.79	3.49	7.54	4.13	47.90	26
27	42.82	19.67	17.37	17.50	28.88	13.46	30.34	4.73	6.27	6.16	8.44	53.35	27
28	52.77	16.20	25.18	15.65	29.06	10.94	23.59	4.73	7.00	5.24	10.13	54.43	28
29	53.54		30.62	16.57		9.29	22.20	4.73	7.59	4.45	8.41	54.74	29
30	49.60		40.57	23.01		8.75	33.69	4.73	8.25	4.08	8.44	58.33	30
31	42.90		46.12				31.45	4.66		6.43		52.35	31
Average	**25**	**20.49**	**13.82**	**54.35**	**22.93**	**15.51**	**19.56**	**12.81**	**3.261**	**8.502**	**6.625**	**58.39**	
Median	**22.3**	**19.51**	**10.41**	**48.14**	**23.58**	**12.69**	**12.24**	**9.936**	**2.702**	**8.587**	**5.767**	**54.55**	

The permanent water level recorder (D8H012) indicates a brief period of mouth closure from 1 to 6 December 1995. Table 12 indicates that mean measured inflows of less than 10 m^3/s were recorded from August to November 1995. Once again it should be noted, that there was only a brief mouth closure event of a few days, recorded on the water level recorder.

The surface water area of the Orange estuary from the mouth to the bridge was estimated to be about between 2 x 10^6 m^2 and 6 x 10^6 m^2. If a conservative amount of the surrounding flood plain area is included, as is the case under at higher water levels, in this calculation the surface water area can be increased to about.

Through the correlation of the water levels recorded by DWAF in December 1994 and 1995 and the estimated surface area (between 6 x 10^6 m^2 and 12 x 10^6 m^2), related flows required to keep the mouth open was calculated in Table 13.

Table 13: Summary of water level increase and river inflow that breached the Orange Estuary in 1995

Date	*Water level increase*	*Lower flow range In channel area (m^3/s)*	*Higher flow range Including flood plain (m^3/s)*
5 Des 1995	*0.51 m*	*34.0*	*68.2*
6 Des 1995	*0.44 m*	*29.4*	*58.8*

Noteworthy is that preceding 1 December 1995, Viooldrift gauging station was recording flows in the order of 10^3 m/s, or less. On 1 December 1995 the gauging station (about 280km upstream from the mouth) recoded a significantly higher flow of about 120 m^3/s. This increased flow caused the breaching of the mouth on 6 December 1995.

4.2.3 Fish River catchment

No data is available for the river inflow for the period 1993 to 1995 for the Fish River which enters the Orange river below the Vioolsdrift gauging station, about 145 km from the estuary, from the Namibian side. For the propose of this analysis, the inflow from the Fish River catchment was therefore not taken into account, as it generally contributes very little to the overall flow reaching the estuary (see Table 14). Simulated monthly runoff data for the Fish River indicate that the river is dry for about 72% of the time, that monthly flows of 10 m^3/s or less occur for 15% of the time and that monthly flows higher than 10 m^3/s occur for only 13% of the time for the simulated 68-year period.

Table 14: Simulated monthly flows (m^3/s) for the Fish River Catchment

	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*
90%ile	*0.00*	*1.21*	*12.80*	*109.47*	*230.80*	*293.49*	*31.72*	*2.42*	*0.14*	*0.00*	*0.00*	*0.00*
80%ile	*0.00*	*0.00*	*0.00*	*12.64*	*66.40*	*103.53*	*15.20*	*0.30*	*0.00*	*0.00*	*0.00*	*0.00*
70%ile	*0.00*	*0.00*	*0.00*	*2.90*	*18.97*	*40.90*	*7.25*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
60%ile	*0.00*	*0.00*	*0.00*	*0.79*	*8.52*	*15.65*	*2.83*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
50%ile	*0.00*	*0.00*	*0.00*	*0.00*	*2.61*	*8.49*	*0.61*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
40%ile	*0.00*	*0.00*	*0.00*	*0.00*	*0.12*	*4.08*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
30%ile	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*1.14*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
20%ile	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
10%ile	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
1%ile	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*

4.2.4 Estimated flow required to keep the Orange River Estuary mouth open

Although the above data implies that the Orange estuary probably only closes at flows of 10 m^3/s or less, low confidence in the measured inflow data (the gauging station can be out by as much as 70% during the low flow period, pers. comm., Mr M. Maré, WRP) requires that a precautionary approached be followed and that mouth closure for the purpose of this study be set at flows of 10 m^3/s.

At higher flows, probably more than 10 m^3/s, the water level will continue to increase till breaching occurs and the mouth will therefore remain closed for a limited period. However, the berm can build up to levels of + 3.0 m MSL in a short time and extensive backflooding would probably take place.

At lower flows, possibly below 10 m^3/s, the water level will initially increase, but could then remain constant or even drop again, based on the balance between the flows and the losses, mainly through seepage and evaporation. The mouth would then remain closed until the river flow starts increasing again. Tidal flows through the mouth will then not occur and seawater will not enter the estuary, except perhaps in a limited way because of overwash by waves at high springtides.

Note:

It is critical that the estimated cut-off flow value for mouth closure be verified through further monitoring in the future, as the hydropower release are becoming more infrequent and the mouth should therefore close or almost close more often.

Based on progress in understanding of the dynamics of temporary open estuary mouths a few additional conclusions can be drawn:

The mouth of the Orange Estuary can close at higher flows, e.g. At 20 – 30m^3/s, but after closure the water level in the estuary will rapidly increase.

This increase will continue until:

- the mouth breaches again when the water level becomes higher than the berm, or
- until the losses through seepage through the berm and evaporation are less than the river flow. In which case the water level will stay constant or can even decrease again.

4.3 ADDITIONAL MECHANISMS THAT INFLUENCE MOUTH DYNAMICS

The important aspects related to the dynamics of the mouth are:

- Open and closed mouth conditions
- The position of the mouth along the berm

4.3.1 Open and closed mouth conditions

Mouth closure causing back flooding will have a beneficial effect on the salt marshes near the mouth, because the area will be flooded with fresher water. The forces influencing mouth conditions are therefore described in greater detail.

One of the most important influences of river flow on an estuary is that on the condition of the mouth. It is the main force keeping an estuary mouth open. Mouth closures will occur if the flow is reduced below certain levels. These flow levels are different for each estuary and are also dependent on other influences such as the wave action at the mouth.

In addition to river inflow the dynamics of an estuary mouth are also determined by the following factors:

- Wave action, driving the sediment dynamics, is the main force causing closure of the mouth.
- Tidal flow is often an important additional force in maintaining an open mouth. However, this becomes less relevant at smaller estuaries such as the Orange Estuary where tidal flows are reduced.

4.3.2 The effect of wave action on the mouth

In the past longshore sediment transport, generated by waves approaching the coastline obliquely, was considered to be the main force causing closure of an estuary mouth. According to resent information the "net" longshore sediment transport to the north at the Orange River mouth is estimated of the order of 100 000 million m^3 per annum, which is much lower than earlier estimates of 750 000 m^3 per annum (CSIR, 2003). Recent studies, such as those on the Great Brak Estuary (CSIR, 1994a), have shown that the major effect of the waves can be more direct. Higher waves cause more turbulence and therefore bring more sediment in suspension than lower waves. This sand is transported on the incoming tide into the estuary mouth and settles out when the wave action subsides and the current velocities become smaller. This also occurs when the breaker line of the waves is parallel to the coastline and the longshore transport is zero. The higher the waves, the more sediment will be in suspension and at flood tide will move into the mouth and the stronger the closing force will be. High waves occur more in winter and less often in summer. It is, therefore, more difficult to maintain open mouth conditions in winter compared to summer.

River flows and tidal flows can prevent or reduce this process, but mouth closure will occur if these flows become too low.

4.3.3 The effects of tidal flows

Tidal flow is a factor additional to river flow in keeping an estuary mouth open. At larger estuaries, such as that of the Krom in the eastern Cape, it can be the only factor. In smaller estuaries, such as that of the Orange River Estuary it only plays a minor role.

The **mean tidal range** at the mouth of the Orange River is approximately 0.4 m and can be as much as 1.0 m during spring tides (Figure 4). The **tidal influence** upstream in the estuary is very limited. The results from a water level recorder installed at the Ernest Oppenheimer Bridge, 9.5 km upstream, show limited tidal variation, less than 2 cm, only at high spring tides when the river flow is low.

4.3.4 The position of the mouth along the berm

Figure 5 shows observed positions of the estuary mouth from 1937 to 1990, obtained from aerial photographs and from topographical surveys (some of these were obtained from a monitoring programme undertaken by the CSIR for the Department of Environment Affairs).

At times the mouth is located at the northern bank and sometimes at the southern bank. The location is strongly influenced by the position where the mouth was breached (artificially or natural). The mouth breachings were alternatively undertaken on the north and south sides of the river by Namdeb and Alexcor respectively. The objective of these breachings was to protect low-lying infrastructure from being flooded.

In 1995 the mouth was situated at the southern bank and its position was fairly stable. This indicates an equilibrium between the scouring of the outer bend at the mouth, which drives a further migration to the south and the longshore transport which pushes the mouth to the north.

The location of the mouth could have a major influence on the salinity of the water reaching the salt marsh on the south bank near the mouth. When the location of the mouth at the southern position, considerable amounts of seawater enter the area at spring tides, but the salinity of the water entering the salt marsh would be much lower if the mouth were located at the northern bank. The needs of the salt marsh, therefore, should be considered before future mouth breachings.

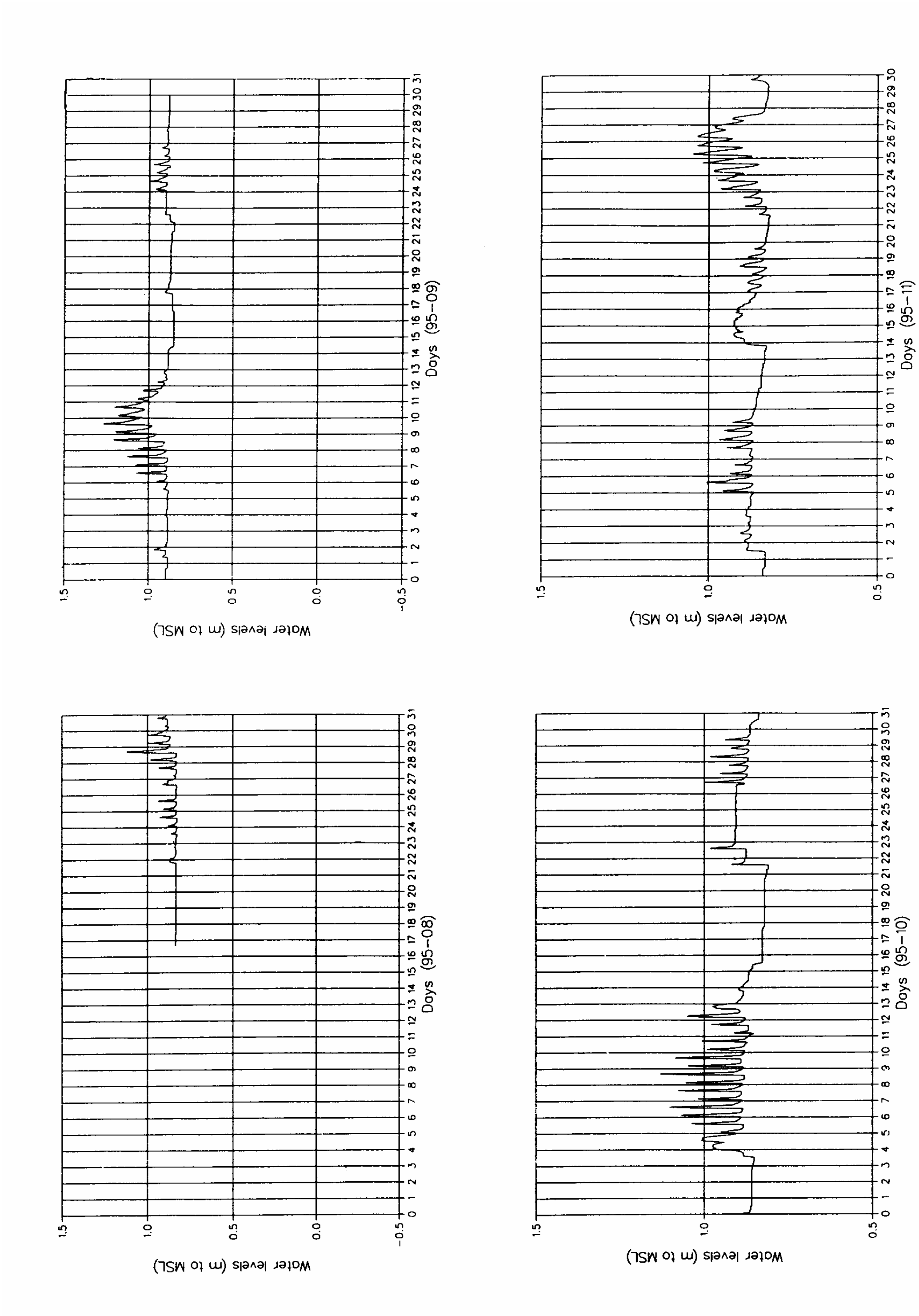


Figure 4a. Recorded water levels variations within the saltmarsh

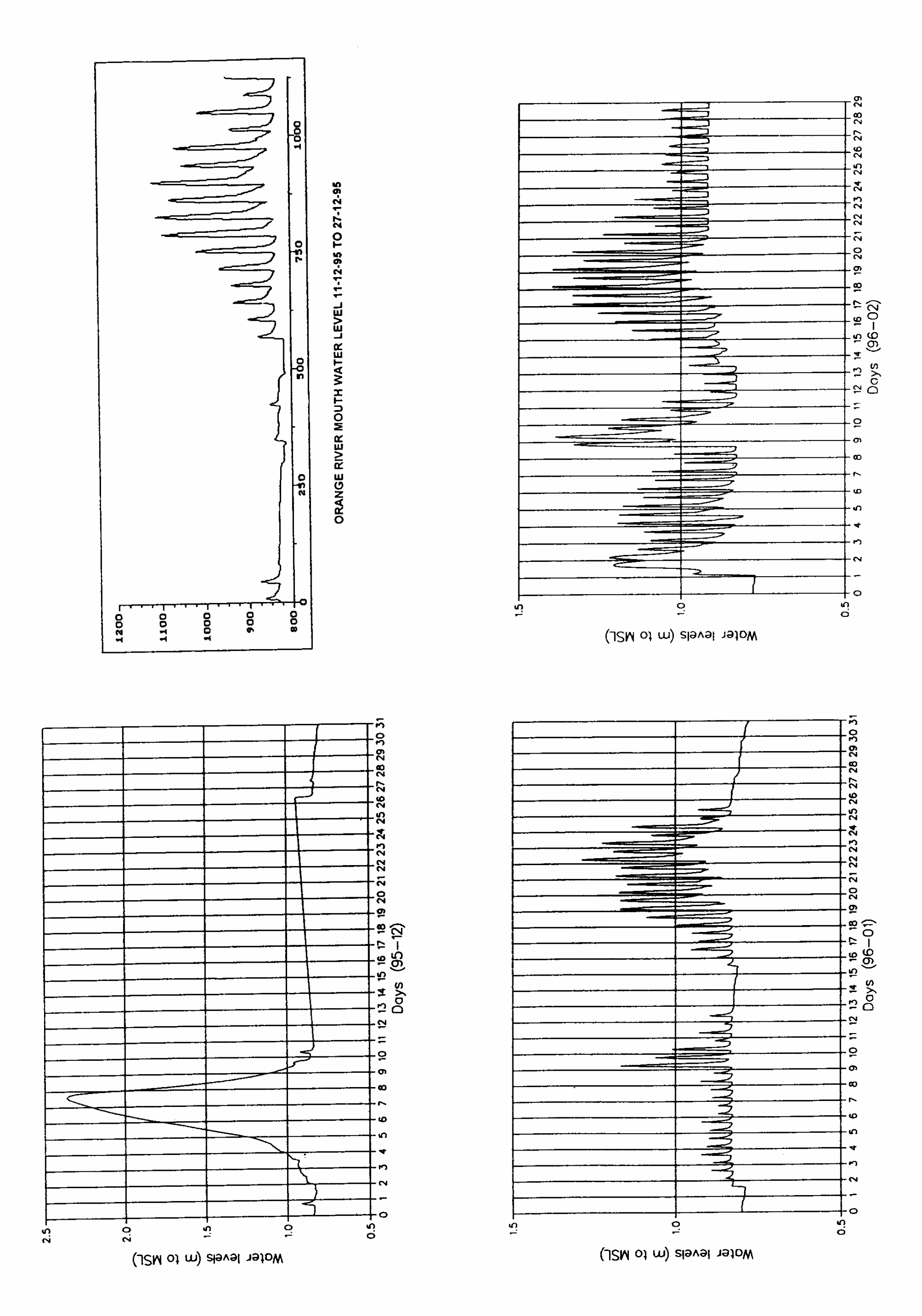
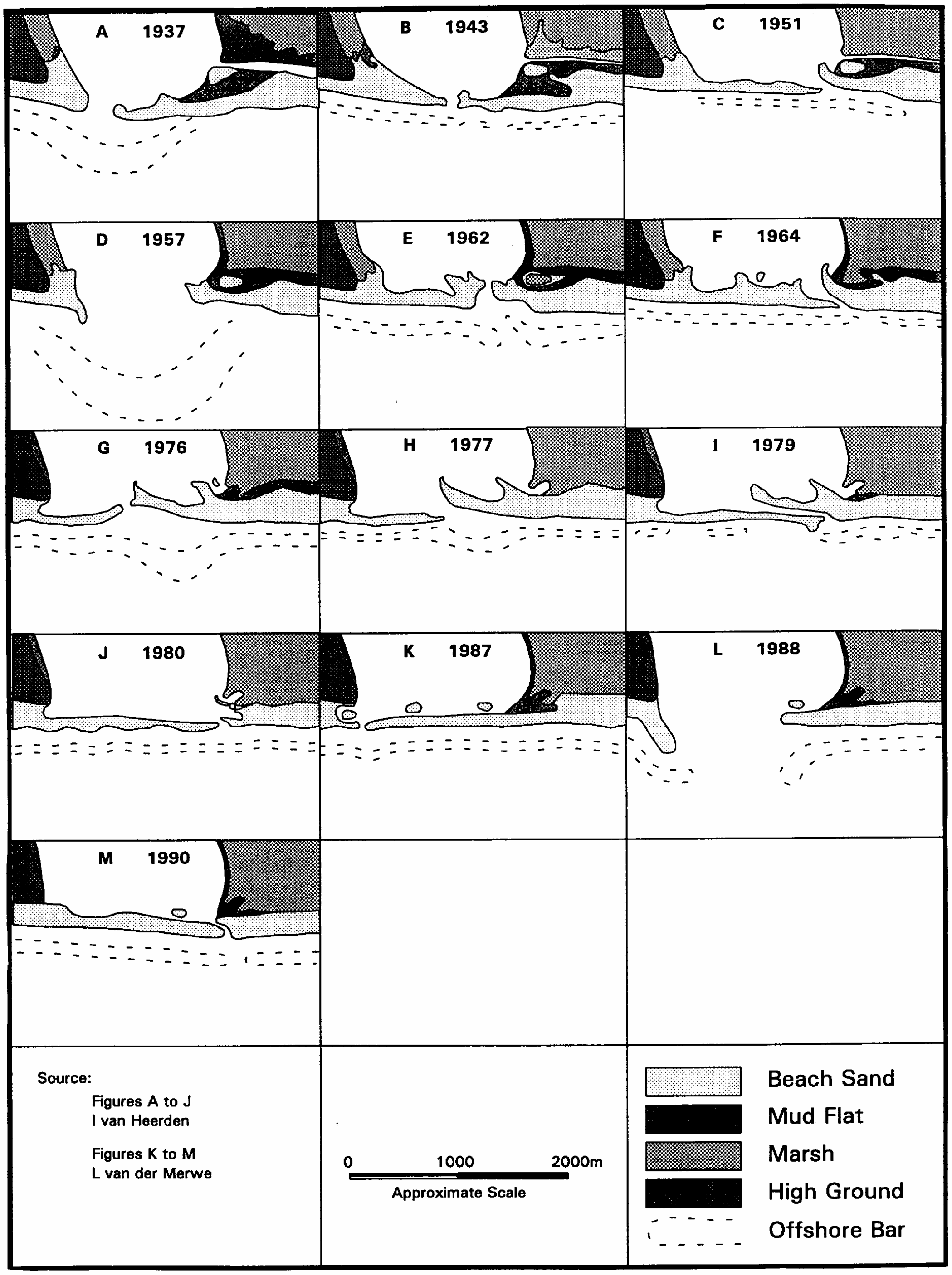


Figure 4b. Recorded water levels variations within the saltmarsh



Source:
Figures A to J
I van Heerden

Figures K to M
L van der Merwe

Figure 5. Mouth positions of the Orange River between 1937 and 1990

4.3.5 *The effects of the causeway*

The causeway through the salt marsh was constructed to provide easy access to the beach from Alexander Bay. The causeway is approximately 3 m + MSL, i.e. about 1.5 m above the adjacent salt marsh (CSIR, 1991). The causeway had a number of effects, which should be looked at in combination with other developments. These included the cutting off of the river channels through the salt marsh next to the Dunvlei Farm and the sewage oxidation ponds.

Initially this resulted in the area south of the causeway becoming isolated upstream from the main river, but with exchange of tidal flows and more saline water still taking place near the mouth between this area and the main river channels. This resulted in the enhancement of the ecological importance of the salt marsh in this area.

Later the connection between this saltmarsh and the main river near the mouth was or became blocked, which eventually, together with other influences, resulted in the destruction of this saltmarsh.

An isolated coastal lake developed behind the dunes in the lower part of the salt marsh and the water in this lake became highly saline, mainly because of ongoing evaporation.

4.3.6 *Flood control measures*

The first dykes were constructed in 1974 to protect Alexkor agricultural land from flooding. The dykes cut off two flood channels (that link up as the present sewage oxidation pond) that used to extend southwards into the salt marsh (CSIR, 1991) thus reducing flood flow to the salt marsh.

Dykes were also constructed by Namdeb on the north bank in 1974 (CSIR, 1978), to protect the golf course from flooding.

Dykes on both banks cause constriction of flow during floods. The effect of this is to increase the river flow velocity locally, which would tend to increase erosion along bends in the river course.

4.3.7 *Mining operations*

Alexkor have constructed a slimes dam to the east of the salt marsh. Fine material (from the slimes dam and overburden removal in the region) is transported by wind into the salt marsh, and saline seepage water has discharged into the peripheral salt marsh (resulting in hypersalinity) (CSIR, 1991). The excess of fine material and influences on salinity have also contributed to the die-back of marsh vegetation.

4.4 BACK FLOODING

4.4.1 Water levels at mouth breaching and the effects on back flooding

The estuary mouth of the Orange River used to close periodically during periods of low river flow before the commissioning of the major dams on the river. At times the river flow apparently ceased completely. There is anecdotal evidence for this, for example in Lawrence Green book "To the River's End".

Water releases from the dams for the generation of hydro-electricity, irrigation and other purposes have resulted in higher flows at the mouth during the dry periods and as a result the mouth hardly ever closes any more. An exception was the mouth closure during the spring of 1993 when the mouth was closed for a few months and December 1995 and December 1995 when the mouth closured for approximately three days respectively.

The berm of a closed estuary mouth normally builds up to levels of between + 2.5 to + 3.0 m MSL and natural mouth breaching occurs when the water levels exceed the level of the berm. This again differs between estuaries and is dependent on local sediment and wave characteristics and on the configuration of the mouth.

The maximum water level reached in the estuary at the natural mouth breaching in December 1995, when the mouth was only closed for approximately three days was + 2.35 m MSL (Figure 6). Higher water levels would probably have been reached if the mouth had been closed for a longer period. Figure 7 showing the topography of the salt marsh on the south bank indicates that the salt marsh area was almost completely flooded by the back flooding during this closure.

Artificial mouth breachings are often undertaken before the natural breaching levels are reached. Normally the reason for this is the protection of low lying properties. Such mouth breachings have also been undertaken at the Orange River mouth to prevent flooding of the oxidation ponds near Alexander Bay and/or flooding or erosion problems at the golf course on the north bank at Oranjemund.

4.4.2 The effects of major floods on the floodplain

Previous studies indicated that the major mechanism for inundating the saltmarshes was regular mouth closure and the related back flooding. The simulated runoff data (provided by WRP) for the Reference condition indicate that mouth closure was not as regular event and that mouth closure occurred for less than 10% during the 68-year period, in the order of once in four years for a brief period. In other words, the mouth closure only occurred during drier periods.

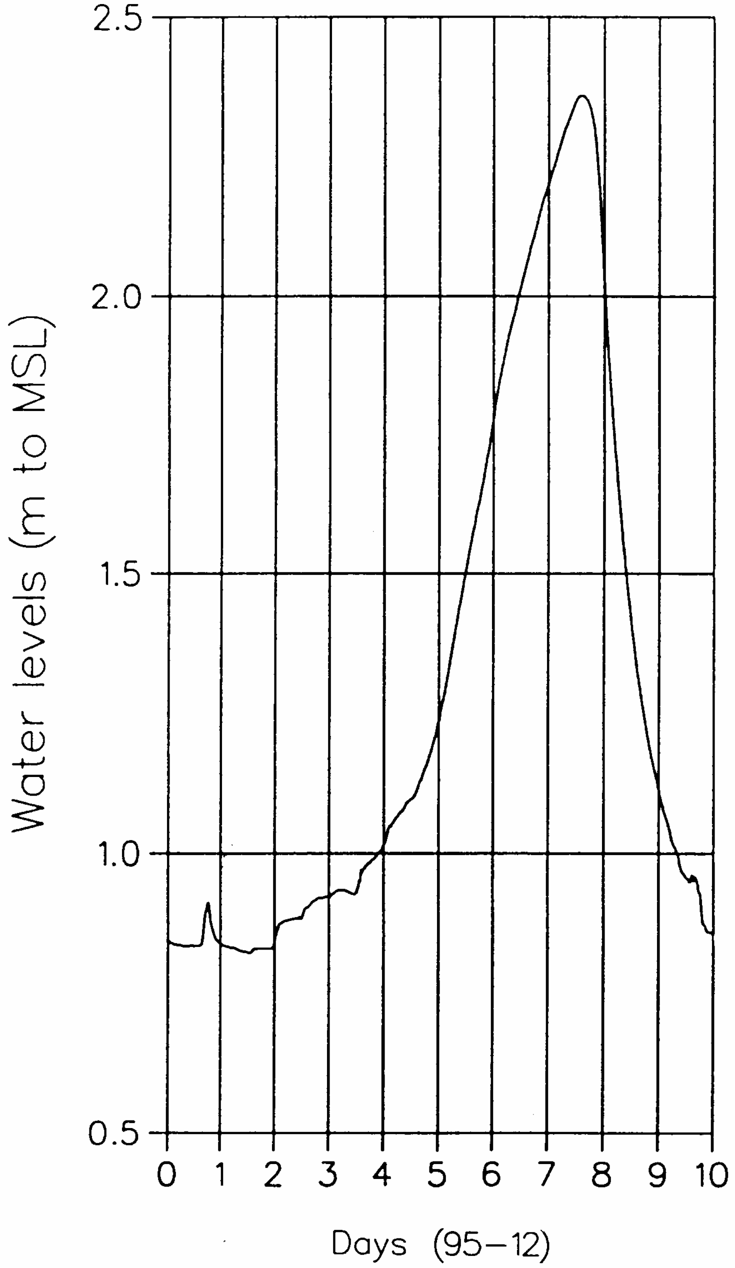


Figure 6. Recorded water levels within the saltmarsh during the mouth closure in December 1995

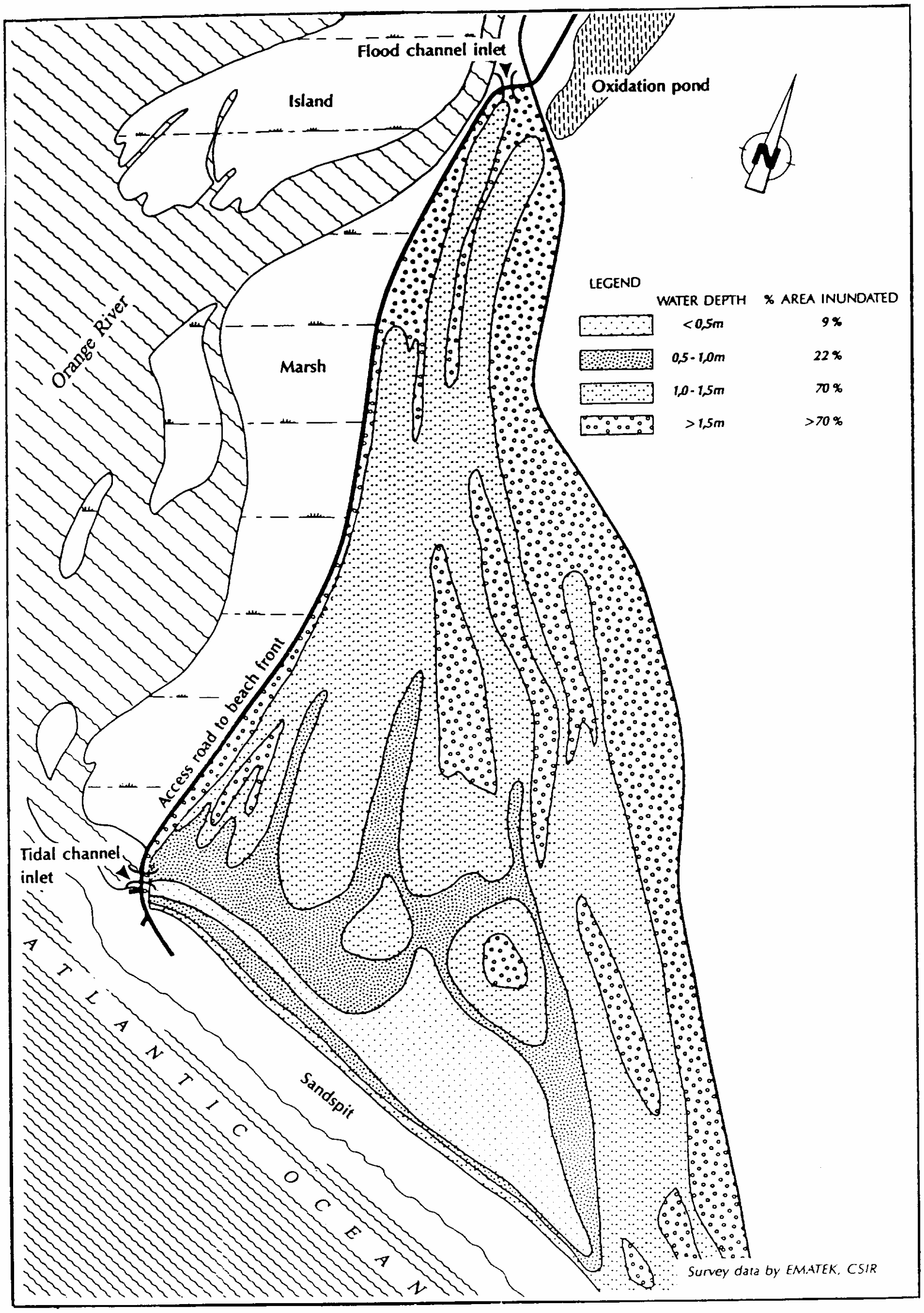


Figure 7. Map of the saltmarsh south of the estuary

An alternative mechanism for inundating the saltmarshes under the Reference condition could be the combined effect of high river inflows/floods and tidal variation. At water levels between 0.5 and 1.0 m MSL about 27% of the saltmarshes is inundated, where as at about 1.5 m MSL 70% of the marshes is inundated (Figure 7). The average mean spring high tide is about 1.1 m MSL. The additional 40 cm increase in water levels needed to raise the water level in the estuary from a normal high tide (1.1 m MSL) to a flood level (1.5 m MSL) is relatively easily achieved through the 'damming up' of the outflow during a spring high tide. This 'damming' effect by the tide during high flow events was observed by Orren (1979).

The extended surface area of the floodplain is estimated to be 14 x 10^6 m^2, therefore a 40 cm increase in water levels is equivalent to ~5 .6 x10^6 m^3. Under the Reference conditions the 1:2 year flood was estimated to be 2 832 x10^6 m^3 and the 1:5 year flood was estimated at 5 369 x10^6 m^3. Therefore, these floods were high enough to cause substantial inundation of the surrounding flood plain.

Unfortunately, an analysis of the simulated Present State average monthly flows also indicate a marked reduction in floods in comparison with the Reference condition, i.e. about a 40% reduction in high flow events in the 68-year dataset. It should therefore be noted that the reduction in major flood events might leave mouth closure as the only alternative mechanism for inundating the high saltmarshes of the Orange Estuary.

4.5 SALINITY DISTRIBUTIONS AND RIVER INFLOW

Salinity data on the estuary were available for the following sources:

- 13/14 January 1979 (CSIR, 1984)
- 25 August 1987 (CSIR, unpublished data)
- September 1993 (Harrison, 1997)
- Conductivity measurements in March/April 1993, July 1993, September 1993 and January 1994 (Seaman and Van As, 1998).

Shortfalls in all of these data sets were:

- Data were only collected in surface and bottom waters at each station (and not along a vertical profile) which made it difficult to determine the position of the halocline (i.e. extent of stratification)

- Station depths were not recorded during most of these surveys. Sampling depths had to be estimated from available bathymetric data (CSIR, 2000), as well as limited observations made during May 2003 (C Saltau, CSIR, Stellenbosch, personal observations).

Seaman and Van As (1998), although they collected salinity and temperature over about a 2 week period at a time, salinity ranges measured over the entire period at each station were reported, i.e. it was not known at what depth such data were collected or which measurement correlated to which date.

However, to at least provide some indication of the salinity distribution patterns that could be expected under different flow regimes, extracts from these data sets were used to reach preliminary conclusions (Table 15).

Table 15: Salinity data collected in the Orange River Estuary during January 1979, August 1987 and September 1993

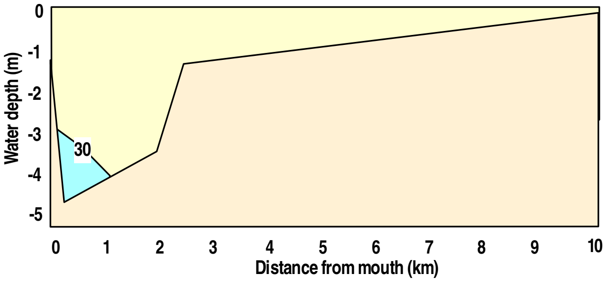
POSITION	***ESTIMATED DISTANCE FROM MOUTH in km (Estimated depth in m)***									
	0 (1.0)	***0.5 (4.5)***	***1.0 ( )***	***1.5 ( )***	***2 (3.3)***	***2.5 (1.3)***	***3 (<1)***	***3.5 (<1)***	***5.0 (<1)***	***7 (< 1)***
January 1979 (Average measured flow ~ 300 m³/s)										
Surface	*<2.85**	*<2.85**	-	-	-	*<2.85**	*<2.85**	*<2.85**		
Bottom	-	-	-	-	-	-	-	-	-	
August 1987 (Average measured flow ~ 30m³/s)										
Surface	*6-10*	*2*	-	-	*0*	*0*	-	-	-	
Bottom	*33.5*	*31.5*	-	-	*30.5*	*0*	-	-	-	
26 March – 12 April 1993 (Average measured flow ~ 15m³/s)										
*Water column***	-	*9 -36*	-	-	-	*6-36*	-	-	-	*0*
September 1993 (Average measured flow ~1 m³/s)										
Surface	-	*14.1*	-	-	-	-	*9.2*	-	*3.0*	-
Bottom	-	*29.3*	-	-	-	-	*22.2*	-	*16.5*	-
30 September 1993 (Average measured flow ~1 m³/s)										
*Surface***	-	-	*36*	*30*	-	*35*	*20*	-	-	-
*Bottom***	-	-	*36*	*36*	-	*35*	*19*	-	-	-

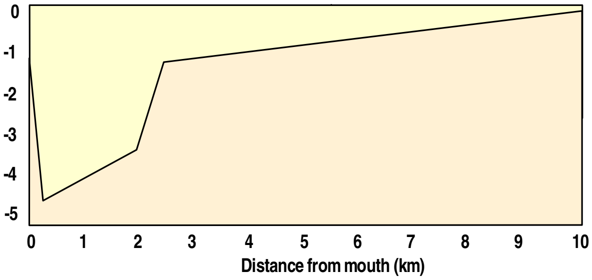
* ***Minimum value that could be measured by the salinometer used at the time, salinity was probably ~ 0 ppt***

** ***Using the following conversion: Conductivity (mS/cm) x 100 x 8/1000 ~ Salinity (ppt)***

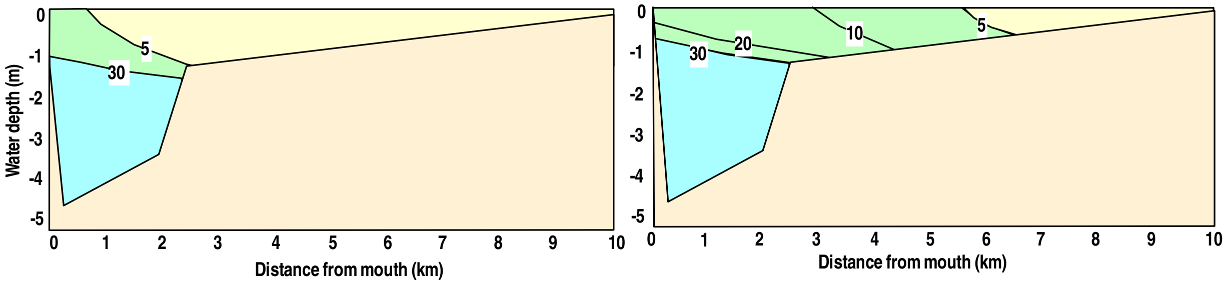
The following preliminary conclusions are made on salinity distribution patterns for the Orange River Estuary:

- At high river flows, i.e. greater than 50 m³/s salinities in the estuary will typically be fresh throughout with very limited saline intrusion at the mouth at times (January 1997). Salinity distribution patterns typically vary between:



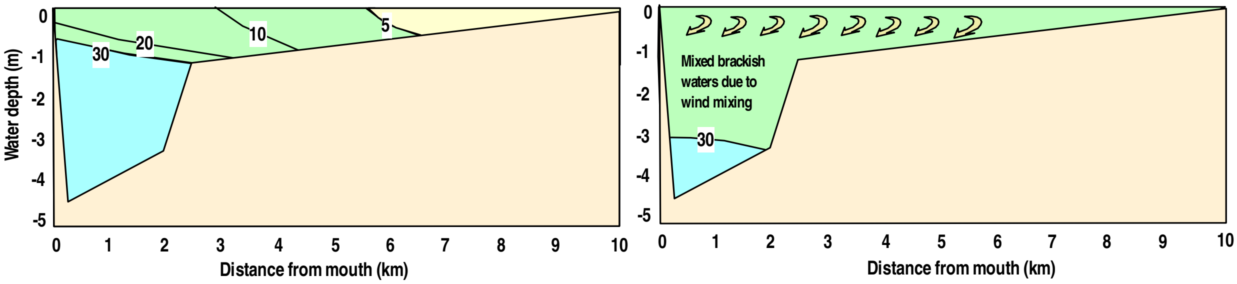


- At river flow between 50 to 10 m³/s the estuary is expected to be open to the sea with tidal intrusion and salinity distribution could range between (stronger intrusion associated with the lower flow ranges):



For the higher flow range (~50 m^3/s), strong vertical stratification occurs in the deeper basin area in the lower reaches, with salinities of greater than 30 ppt in bottom waters and between 0 and 10 ppt in the surface layer. Moving further upstream salinities decrease markedly with 0 ppt occurring approximately 3 km from the mouth (August 1987). At the lower flow range (~10 m^3/s) strong vertical stratification is still present in the deeper basin. Further upstream as the estuary becomes shallower, salinities decrease gradually with 0 ppt reached about 7 km from the mouth (March/April 1993).

- The only data reported for the closed phase was that of Harrison (1997) for September 1993, assumed to be just after closure. Based on the September 1993 the system is strongly stratification, particularly in the lower reaches, immediately after closure (September 1993), similar to the situation during the low flow range during the tidal phase (see above). No suitable measurements were available to establish salinity distribution patterns during periods of prolonged mouth closure. However, it is expected that with time, turbulence caused by wind mixing will eventually create a brackish zone throughout estuary, except perhaps in the deeper basin in the lower reaches where salinities could remain around 30 ppt for extended periods (i.e. turbulence generated by wind mixing may not be sufficient to erode this denser saline water at such depths). The range of salinity distribution is schematically illustrated below:



5. WATER QUALITY CHARACTERISTICS

5.1 SYSTEM VARIABLES

5.1.1 Temperature

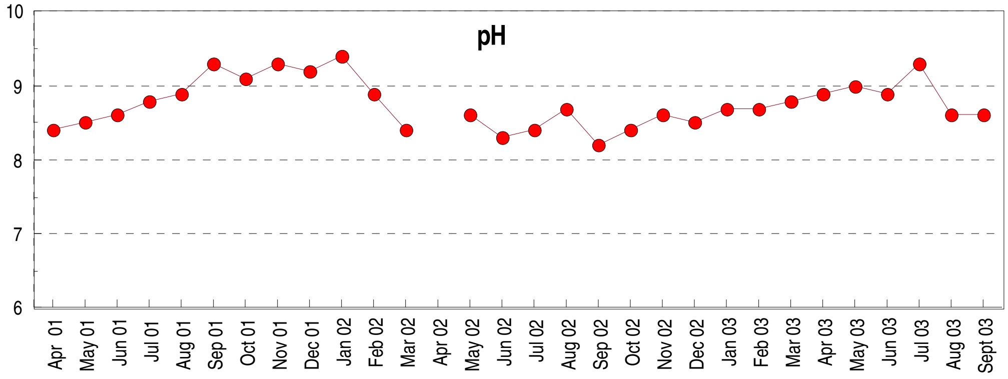
Temperature data on the Orange River Estuary was discussed by Brown (1959), Day (1981), CSIR (1984) Harrison (1997) and Seaman and Van As (1998).

Based on the historical data sets, temperature variation in the Orange River Estuary tend to be seasonal, with lower temperatures (around 15 ^{0}C) recorded in winter and early spring and higher temperatures (around 25 ^{0}C) in summer. However, with strong marine influence, i.e. in the bottoms water of the deeper basin in the lower reaches (salinities < 30 ppt), temperatures can be low (<16^{0}C) during summer as a result of upwelling (i.e. surfacing of colder seawater), a common feature along South Africa's west coast (DWAF, 1995).

5.1.2 pH

Reference Conditions for pH of the middle and lower Orange River, the freshwater source to the estuary, is expected to have between 6.5 and 7.5 For this study no data could be obtained on river water quality entering at the head of the estuary. The closest monitoring point to the Sir Ernest Oppenheimer Bridge (head of estuary) is that of Namwater at Sendelingsdrift (Rosh Pinah), about 70 km (as the crow fly) from the mouth (Mr Andries Kok, Namwater, Keetmanshoop, pers. comm.)

Monthly averages for the period April 2001 to September 2003 are provided below:



Taking into account that the pH at Vioolsdrift, some 280 km from the mouth, is estimated at between 7.1 and 8.3 (Southern Waters, pers. comm.), these higher pH levels probably reflect the influence of catchment activities, e.g. influences form agricultural activities.

The pH of seawater, the other source of water to the estuary, typically ranges between 7.9 and 8.2 (DWAF, 1995).

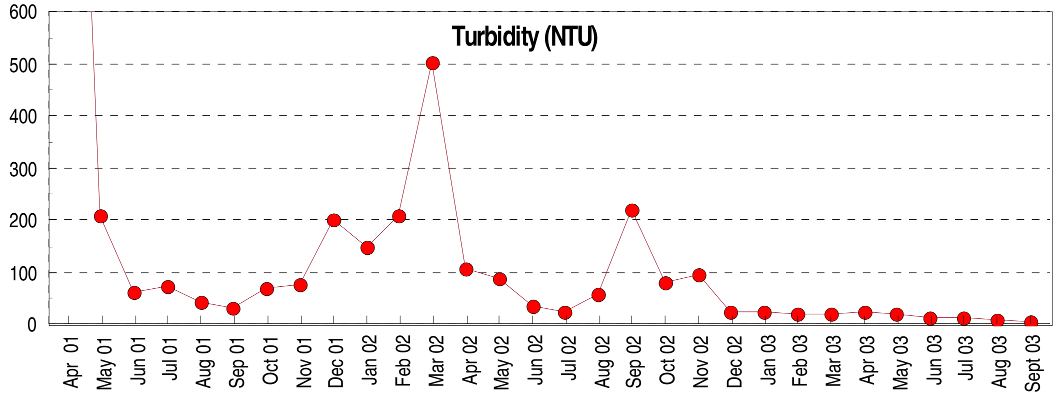
pH levels in the estuary were recorded on two occasions, in January 1979 and September 1993 (CSIR, 1984; Harrison, 1997). In January 1979 the estuary was fresh water dominated as a result of high river inflow. No marked trend was evident in the pH with average levels around 8.5. During September 1993, just after mouth closure, the estuary was strongly stratified, particular in the deeper basin area, as a result of significant marine influence just prior to closure. However, there was no marked difference between pH levels of the fresher surface layers and the saline bottom water, with average pH levels around 8.

Based on the above, pH variation in the Orange River Estuary is not expected to show strong seasonal or inter-annual variability and will probably typically range between 7.1 and 8.5, occasionally rising to above 9.

5.1.3 Turbidity/Suspended solids

The river water entering the Orange River Estuary is turbid, even under the Reference Condition. Measurements collected during a survey conducted on the river, as part of the Lower Orange River Management study, showed Secchi depth below Kakamas to be between 0.25 and 0.28 m (Southern Waters, pers. comm.). For this study, no data could be obtained on the turbidity of river water entering at the head of the estuary. The closest monitoring point to the Sir Ernest Oppenheimer Bridge (head of estuary) is that of Namwater at Sendelingsdrift (Rosh Pinah), about 70 km from the mouth (Mr Andries Kok, Namwater, Keetmanshoop, pers. comm.)

Monthly averages for the period April 2001 to September 2003 are provided below, showing that at time turbidity levels in river inflow could be very high.



Turbidity measurements and suspended solid concentrations in seawater is site specific and no data could be obtained for the west coast region. However, it is expected that these would typically be low.

Turbidity measurements in the estuary are available for September 1993 (Harrison, 1997). At the time the mouth of the estuary had just closed, still showing strong vertical stratification in the deeper basin near the mouth, the result of significant marine influence just prior to closure. Turbidity levels ranged between 12 and 45 NTU, showing a tendency to be higher in the fresher surface layers compared with the saline bottom water. At the time river inflow was very low (~ 1 m^3/s), therefore the relatively low turbidity levels. It is, however, expected that the freshwater reaches in the estuary typically will have higher turbidities due to the turbid nature of the river source water. This is also supported in a statement by Day (1981) that '*in winter the Secchi disc depth in the estuary was measured as 0.25 m*' – similar to reading obtained in the river below Kakamas (see above).

5.1.4 Dissolved Oxygen

Under the Reference Condition, dissolved oxygen levels in the lower Orange River were expected to be about 8 mg/l, representing well-oxygenated conditions (Southern Waters, pers. comm.). Although no measurements are available for the Present State, river inflow is still expected to be well-oxygenated. However, it has been reported that on occasions, algal blooms occur further upstream, for example in the Spitskop Dam. These make there way downstream, resulting in river water entering the system being almost anoxic. Such an event occurred during April 2003 when dissolved oxygen levels at Alexander Bay were down to 0.06 mg/L (Ms B Conradie, Department of Water Affairs and Forestry, Northern Cape Regional office, pers. comm.).

Although measured data on dissolved oxygen concentrations for the west coast could not be obtained, surface water in unpolluted and fairly turbulent areas, such as the surf zone adjacent to the Orange River mouth, is usually well-oxygenated.

Oxygen measurements were taken in the estuary on two occasions, namely in January 1979 and September 1993 (CSIR, 1984; Harrison, 1997). During January 1979 the estuary was fresh water dominated as a result of high river flow, with dissolved oxygen levels around 8 mg/l, representing well-oxygenated conditions. During September 1993, just after mouth closure, the estuary was also well-oxygenated (average concentration of 9 mg/l), despite strong stratification in the deeper basin area. Although no measurements could be obtained after a prolonged period of mouth closure, it is possible that strong stratification could prevent replenishment of the bottom waters in the deeper basin, resulting in a decrease in dissolved oxygen concentrations in this area. The severity of such a decrease will depend, for example on the duration of closures, as well as the organic content of the bottom waters and sediments at the time.

5.2 INORGANIC NUTRIENTS

5.2.1 Inorganic nitrogen

Data on inorganic nitrogen concentrations in the river inflow was obtained from data collected at Vioolsdrift, some 280 km from the estuary (Southern Waters, pers. comm.) and limited data (about 25 samples) collected from 1998 to 2003 at Rosh Pinah, 70 km (in a straight line) from the mouth (Ms M Conradie ,Namibia Water Corporation Ltd., pers comm.)

It is expected that under the Reference Condition for the lower Orange River would have been characterized by low concentrations, estimated to be about 250 µg/l. Based on monitoring data collected by the DWAF at Vioolsdrift for the period 1990 – 2002, Present State concentrations appear to be in a similar order of magnitude, with median and 95%ile concentrations at 10 µg/l and 481 µg/l, respectively. Data collected from 1998 to 2003 at Rosh Pinah show average nitrate –N concentrations less than 500 µg/l. Although it is likely that the agricultural activities along the river, downstream of this point do contribute significantly to inorganic nitrogen levels, river vegetation probably acts as a 'filter' resulting in levels reaching the estuary not being representative of eutrophic conditions. This is assumption is supported by the low inorganic nitrogen concentrations that was measured in the estuary (see below).

Inorganic nitrogen-N concentrations (particularly nitrate-N) in seawater along the west coast of South Africa are usually low (~ 20 µg/l), but during upwelling concentrations can increase to above 200 µg/l (DWAF, 1995). Upwelling occurs regularly between October and April in this area.

The only data available on inorganic nitrogen concentrations in the estuary is that collected by the CSIR in 1979 (CSIR, 1984) when nitrate + nitrite-N concentrations were low and fairly uniform throughout the estuary, averaging 31 µg/l. At the time the estuary was river dominated and it was expected to reflect low concentrations as measured in river inflow. Although there are no data available on the nutrient distribution pattern in the estuary during the tidal phase, it is expected that nutrient concentration would remain low throughout, except in the event where upwelling at sea could result in higher nutrient concentrations being introduced to the estuary, albeit limited to the deeper basin in the lower reaches. If this would occur it is likely to happen during the summer months, the season during which upwelling occurs along west coast of South Africa. During the closed phase it is expected that the estuary will become nutrient depleted.

5.2.2 *Dissolved Reactive Phosphate*

Reactive phosphate concentrations under the Reference Condition for the lower Orange River would have been characterized by low concentrations. It is estimated that Reference Conditions concentrations for Reactive phosphate-P would have been about 5 µg/l. Based on monitoring data collected by the DWAF at Vioolsdrift for the period 1990 – 2002, Present State concentrations appear to be in similar orders of magnitude, with median and 95%ile concentrations at 22 µg/l and 63 µg/l, respectively (Southern Waters, pers. comm.). Again, although it is likely that the agricultural activities along the river, downstream of this point do contribute significantly to inorganic nutrient levels, river vegetation probably acts as a 'filter' resulting in phosphate evels reaching the estuary not being very high. This assumption is supported by the low phosphorous concentrations that were measured in the estuary (see below).

Similar to inorganic nitrogen, reactive phosphate-P concentrations in seawater along the west coast of South Africa are usually low, but during upwelling concentrations can increase to above 50 µg/l (DWAF, 1995).

The only data available on phosphorous in the estuary, is total phosphorus concentrations that was measured in 1979 (CSIR, 1984). Total phosphorous-P concentrations were low and fairly uniform throughout the estuary, averaging 11 µg/l. It is expected that phosphorous concentrations in the estuary will remain low during both the freshwater dominated and closed phases. However, during the tidal, upwelling at sea could result in higher concentrations being introduced to the estuary, but this will be limited to the deeper basin in the lower reaches during summer.

5.3 TOXIC SUBSTANCES

For once off sampling of toxic substances (e.g. trace metals) in highly dynamic systems such as estuaries, it is considered more appropriate to sample environmental components which tend to integrate or accumulate change over time, such as sediments.

Trace metal concentration in river water was measured at Rosh Pinah, about 70 km from the mouth on about 25 occasions during 1998 to 2003 (Ms M Conradie ,Namibia Water Corporation Ltd., pers comm.). Average concentrations measured for different trace metals are listed in Table 16. These values are considered to be relatively low, not reflecting any marked anthropogenic inputs of such toxic substances.

The only available data on toxic substances in the Orange River Estuary is sediment trace metal data collected by the CSIR in January 1997 (Orren, 1979). The results showed that sediments in the estuary mainly comprised of fine sand and muds, with and anaerobic layer extending to within 1 cm from the surface in places. Sediment trace levels measured are listed in Table 17.

Table 16: Trace metal concentrations measured in the river at Rosh Pinah from 1998 to 2003

DATE	***CONCEWNTRATION ((µg/L)***					
	Fe	***Mn***	***Cu***	***Zn***	***Cd***	***Pb***
15/06/2003	*40*	*<10*	*20*	*10*	*<10*	*<20*
09/03/2003	*210*	*30*	*80*	*20*	*<10*	*<20*
20/01/2003	*550*	*50*	*20*	*30*	*<10*	*<20*
01/12/2002	*70*	*10*	*40*	*40*	*<10*	*<20*
29/10/2002	*3050*	*50*	*80*	*60*	*<10*	*<20*
03/10/2002	*3200*	*40*	*60*	*80*	*<10*	*<20*
08/09/2002	*900*	*10*	*10*	*<10*	*<10*	*<20*
31/07/2002	*1000*	*90*	*60*	*60*	*<10*	*<20*
04/04/2002	*570*	*10*	*10*	*20*	*<10*	*<20*
17/03/2002	*880*	*10*	*10*	*10*	*<10*	*<20*
10/10/2001	*304*	*10*	*<10*	*10*	*<10*	*<20*
08/09/2001	*83*	*<10*	*<10*	*<10*	*<10*	*<20*
06/04/2001	*10*	*<10*	*<10*	*<10*	*<10*	*<20*
17/05/2000	*5200*	*200*	*16*	*21*	*<10*	*<20*
12/08/1999	*140*	*20*	*<10*	*<10*	*<10*	*<20*
11/02/1999	*170*	*20*	*20*	*10*	*<10*	*<20*
06/11/1998	*255*	*17*	*11*	*<10*	*<10*	*<20*
12/10/1998	*413*	*27*	*25*	*41*	*<10*	*<20*

Table 17: Trace metal concentrations measured in the sediments of the Orange River Estuary in January 1979

TRACE METAL	***CONCENTRATION (µg/g dry mass)***	
	Range	***Average***
Cadmium	*0.017 – 0.06*	*0.032*
Copper	*7.8 – 17.2*	*10.8*
Lead	*2.4 – 8.7*	*5.4*
Zinc	*14.7 – 51.9*	*23.1*

The highest trace metal concentrations were always found in the fine anaerobic layers, as would be expected since fine anaerobic sediments are usually indicative of depositional areas. In this case, it is difficult to distinguish whether accumulation was as a result of anthropogenic influences or of natural origin. It is, for example possible for conditions to arise where total trace metal concentrations in sediment are high, but completely linked to the natural structure of clay minerals in which case the trace metals will not be bio-available. Geochemical ratios of aluminium versus trace metal concentration are typically used to establish this.

Although no data are available on sediment concentrations of other toxic substances, e.g. pesticides, it is possible that extensive agricultural practices in the catchment could have resulted in some accumulation. However, it is likely that floods act as 'resetting' mechanisms in this regard, when large quantities of sediment (and associated toxic substances) are scoured from the estuary.

6. ABIOTIC STATES FOR ORANGE RIVER ESTUARY

Based on the limited data available, four Abiotic States were derived for the Mhlanga Estuary, of which the occurrence and duration varies depending on river inflow rate. These states are:

STATE	*FLOW RANGE*
1: Open, river dominated	*> 50 m^3/s*
2: Predominantly Open, with marine influence	*10 – 50 m^3/s*
3: Closed, for extended period	*< 10 m^3/s*

The transitions between the different states will not be instantaneous, but will gradually take place. The estimates of the occurrences of the different states by direct correlation with river flow is based on expert opinion and limited data available from Vioolsdrift Gauging Station (D8H003).

ABIOTIC STATE 1: OPEN, RIVER DOMINATED

Typical flow patterns: *At river flows greater than 50 m^3/s the mouth will normally be open and because of the strong river flow limited or no seawater intrusion in the estuary will take place.*

***Confidence**: Low*

***State of the mouth**: The mouth of the Orange Estuary will be fully open at this state. Generally the mouth is a relatively narrow (100 – 400 m) opening in the beach spit. After a flood the mouth would be considerable wider by a few hundred metres, as the spit is know to be extensively eroded.*

***Confidence**: Low*

***Flood plain inundation patterns**: The water level will be very high during floods inundating the flood plains. Such floods will scour the mouth and after the flood the water level can drop very low at low tides until the mouth becomes restricted again. At flows between 50 and 300 m^3/s, the mouth will normally be wide open and only limited backing up of water, increasing the water level and flooding of floodplain would occur. At flows higher than 300 m^3/s significant back flooding starts to occur.*

***Confidence**: Low*

***Amplitude of tidal variation (indicative of exposure of inter-tidal areas during low tide**): Limited tidal variation will occur during a flood when the water level is high, but tidal variations will occur again when the flood flows are reduced.*

***Confidence:** Medium*

***Retention times of water masses**: The retention time will normally be less than one day. Some back water areas might have longer retentions periods of a few days at a time.*

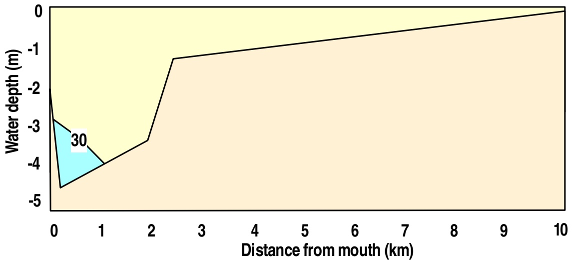
***Confidence:** Low*

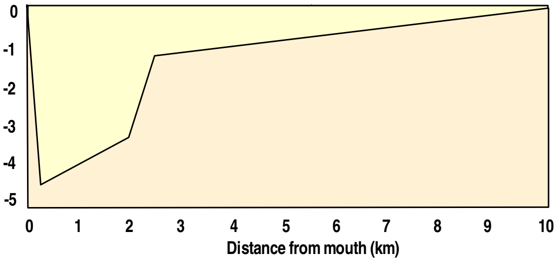
***Total volume**: No data available to provide any details on total volume*

***Confidence**: -*

ABIOTIC STATE 1: OPEN, RIVER DOMINATED CONTINUED…

Salinity distributions in the estuary: *The estuary will be mostly fresh during this open river dominated state, with limited salinity penetration in the mouth area at high tide.*





Confidence: *Low*

System variables (Temperature, suspended solids, turbidity and dissolved oxygen):

Temperature varies seasonally depending when this state occurs, with lower temperatures (~15 ^{0}C) in winter and higher temperatures (~25 ^{0}C) in summer.

pH typically range between 7.1 and 8.5.

Turbidity will be high, with Secchi depth around 0.25 m.

System will be well-oxygenated.

Confidence: *Medium*

Inorganic Nutrients:

Nutrient concentrations will typically be low, characteristic of concentrations in river inflow.

Confidence*: Low*

ABIOTIC STATE 2: PREDOMINANTLY OPEN, WITH MARINE INFLUENCE

Typical flow patterns: *At inflows 10.0 – 50.0 m^3/s the mouth will predominantly be open.*

Confidence*: medium*

State of the mouth*: The mouth will predominantly be open. Generally the mouth is a relatively narrow (100 – 400 m) opening in the beach spit.*

Mouth closure will occur occasionally, but only for a few days at a time. For example, the mouth closure events of December 1995.

Confidence*: Medium*

Water levels and flood plain inundation patterns*: The water level will probably vary between 0.0 and + 1.1 m MSL because of tidal influence. This will be much lower than in the Closed state and much of the flood plain will be permanently exposed. Flooding and drying of the intertidal area will occur.*

Limited inundation of surrounding flood plain and saltmarshes might occur, due to brief mouth closure. The extent to which the flood plain will be inundated will depend on the water level in the estuary and the height of the berm. For example, the maximum water level reached in the estuary at mouth breachings in December 1994 and December 1995, when the mouth was only closed for a few days, was about + 2.30 m MSL.

Confidence: *Medium*

ABIOTIC STATE 2: PREDOMINANTLY OPEN, WITH MARINE INFLUENCE CONTINUED…

Amplitude of tidal variation (indicative of exposure of inter-tidal areas during low tide)*: The mean tidal range at the mouth of the Orange River is approximately 0.4 m and can be as much as 1.0 m during spring tides.*

Confidence: *High*

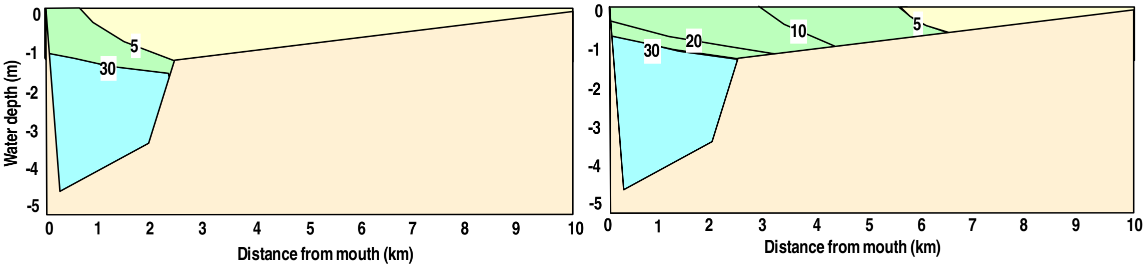
Retention times of water masses*: The retention time will be longer than in the 1: Open, river dominated state varying from a day to a few days (if brief closure should occur) depending on the inflow. Pretension time will also be longer in side channels and backwater areas.*

Confidence: *Low*

Total volume*: No data available to provide any details on total volume*

Confidence*: -*

Salinity distributions in the estuary: *For the higher flow range (~50 m^3/s), strong vertical stratification occurs in the deeper basin area in the lower reaches, with salinities of greater than 30 ppt in bottom waters and between 0 and 10 ppt in the surface layer. Moving further upstream salinities decrease markedly with 0 ppt occurring approximately 3 km from the mouth. At the lower flow range (~10 m^3/s) strong vertical stratification is still present in the deeper basin. Further upstream as the estuary becomes shallower, salinities decrease gradually with 0 ppt reached about 7 km from the mouth.*



Confidence: *Low*

System variables (Temperature, pH, suspended solids, turbidity and dissolved oxygen)*:*

Temperature varies seasonally depending when this state occurs, with lower temperatures (around 15 ^{0}C) in winter and higher temperatures (around 25 ^{0}C) in summer. In the deeper basin in the lower reaches (salinities < 30 ppt), temperatures can be expected to remain low (around 14-16^{0}C), even during summer.

pH typically range between 7.1 and 8.5.

Turbidity will be high, with Secchi depth around 0.25 m.

System will be well-oxygenated.

Confidence: *Medium*

Inorganic Nutrients:

Nutrient concentrations will typically be low, except in the event where upwelling at sea could introduce inorganic nutrients to the estuary, but this will be limited to the deeper basin in the lower reaches during summer.

Confidence*: Low*

ABIOTIC STATE 3: CLOSED FOR EXTENDED PERIOD

Typical flow patterns: At inflows lower than 10.0 m^3/s the mouth will predominantly be close. The water losses because of seepage of water through the berm and evaporation will be similar to the river flow entering the estuary. The water level on the estuary will depend on the river flow, seepage and the height of the berm. A breaching will occur when the inflow increases the water level in the estuary so that it exceeds the height of the berm.

Confidence: Low

State of the mouth: Mouth closed for extended periods at a time

Confidence: Low

Water levels and flood plain inundation patterns: Extended inundation of surrounding flood plain and saltmarshes, due to mouth closure and related back flooding will occur, especially at the higher water levels associated with long periods of closure. The extent to which the flood plain will be inundated will depend on the water level in the estuary and the height of the berm before the next breaching occurs. The berm of a closed estuary mouth normally builds up to levels of between + 2.5 to + 3.0 m MSL. If the mouth should close for extensive periods at a time the berm can even build up to 3.5 m MSL.

Confidence: Low

Amplitude of tidal variation (indicative of exposure of inter-tidal areas during low tide): No tidal variation.

Confidence: High

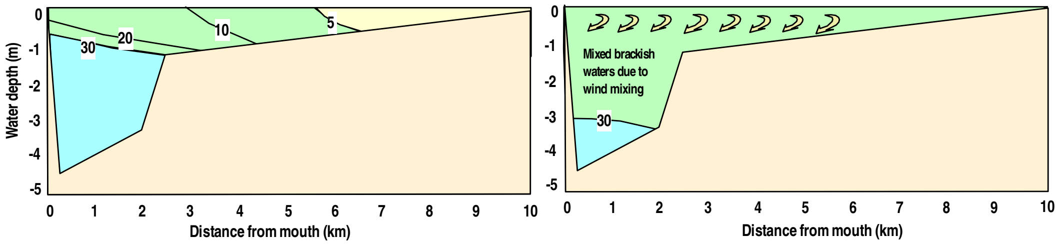
Retention times of water masses: The retention time will vary from a weeks to months depending on the duration of the closed state. Under new present day conditions mouth closure could occur for a few weeks at a time, depending on the extend of the hydropower releases.

Confidence: Low

Total volume: No data available to provide any details on total volume

Confidence: -

Salinity distributions in the estuary: Taking into account the strong stratification that occurs in the lower reaches of the estuary during the tidal phase (see above), it is expected that at the onset of mouth closure salinity distribution pattern will be similar to that of the tidal phase. With time, turbulence caused by wind mixing will eventually create a brackish zone throughout estuary, except perhaps in the deeper basin in the lower reaches where salinities could remain around 30 ppt for extended periods (i.e. turbulence generated by wind mixing may not be sufficient to erode this denser saline water at such depths). The estuary will become fresher due to continuous inflow of fresh water and decreasing of overwash events (at higher berms levels).



Confidence: Low

ABIOTIC STATE 3: CLOSED FOR EXTENDED PERIOD CONTINUED…

System variables (Temperature, pH, suspended solids, turbidity and dissolved oxygen):

Temperature variation will be seasonal depending when this state occurs, with lower temperatures (around 15 ^{0}C) in winter and higher temperatures (around 25 ^{0}C) in summer.

pH typically range between 7.1 and 8.5.

Still expected to be relatively turbid (Secchi depth around 0.25 m), except when river inflow becomes very low (~ 1 m^3/s)

System will be well-oxygenated, but during prolonged closure, dissolved oxygen levels in bottom waters (> 30 ppt) of the deeper basin these waters could decrease. The severity of such a decrease will depend on the duration of closures, as well as the organic content of the bottom waters and sediments at the time.

Confidence: *Medium*

Inorganic Nutrients:

Estuary will become nutrient depleted.

Confidence:

7. SEDIMENT DYNAMICS

The Orange River Estuary is classified as a river dominated micro-tidal estuary. It usually consists of a braided channel system with many islands in the upper estuary, which feeds into a relatively smaller and shallow open tidal basin area. The tidal basin is separated from the Atlantic Ocean by a sand bar, through which a mouth opening of a few hundred metres is usually present. The inlet is maintained by fluvial discharge, and additional fluvial sediment passes through the estuary and is deposited in the sea, where it is dispersed. Fluvial sediment extends from the upper estuary to close to the bar, and tidal deltas are absent or poorly developed (Cooper 2002).

During large resetting floods in the river, large volumes of sediment are flushed out from the entire estuary, removing many of the islands between the braided channels, scouring out the basin area and flushing a large part of the sand bar into the ocean. Vertical scour of at least eight metres deep was recorded at the bridge during the 1988 flood (Swart et al 1990), while the salt marsh eroded laterally by about 400m (Bremner et al 1990). Bremner et al (1990) state that nearly all sediment transported during the 1988 floods was derived from bank erosion and river-bed scour downstream of the major dams. Thus, although the dams trap much of the catchment sediments, large volumes of sediment still reach the estuary (an estimated total of 81 million tons during the 1988 floods).

The increased cohesion of riverine sediments and stabilisation of sand bars by vegetation in the braided channel area means that relatively higher magnitude floods are necessary to effect significant morphological change. During large floods, an ephemeral delta is deposited in the sea consisting of sediments from the sand bar, augmented by eroded channel sediments and material from the river catchment. The additional fluvial sediment volume may produce significant coastal progradation that requires several years to redistribute. The fluvial sediment transported to the estuary in any given year does not necessarily reflect the average annual sediment flux in the river. Sediment delivery is a highly episodic process in which wet years deliver much more of the sediment to the estuary. For example, infrequent, severe floods occurring every 10 to 20 years are responsible for delivering the majority of beach material to the California coast (California Beach Restoration Study 2002). In the offshore zone, sediments on the inner continental-shelf mudbelt are associated with the Orange River prodelta, and are dominated by laminated clay-rich sediments (Meadows, et al 2002). During the falling stage of the flood hydrograph, fluvial sediments are again deposited throughout the estuary with large depositions in the upper estuary area. It is probable that initial post-flood mud deposition is succeeded by a rapid downstream migration of fine sand as bed-load, which soon infills the estuarine channel and reduces the tidal prism. After the flood has passed, the sand bar across the mouth is rapidly rebuilt by coastal processes.

Smaller river floods tend to move some of the sediment from the upper estuary towards the tidal basin area through scouring of the braided channels or erosion of the islands. During periods of low river flow, tidal flows through the mouth (especially during spring flood tides) transport littoral sediment into the tidal basin area. The marine sediment is non-cohesive and much coarser than the fluvial sediment.

Overall, large floods are crucial in maintaining the long-term dynamic equilibrium with respect to the sediment regime in the Orange River Estuary.

The available information indicates that presently, the depth and bed morphology over most of the estuary are generally relatively similar to that of the Reference Condition. Under the Present State the braided/meandering channels in the upper estuary are deemed to be more stable, but probably slightly narrower and/or shallower, due to reduced intermediate river flows.

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

Due to the reduction in large floods from the Reference condition to the Present state, the system would have been reset more frequently, thus increasing overall variability in morphology, sediment processes and characteristics. The residence period and average extent of marine sediments (carried into the tidal basin during flood tides) would also have been less.

The morphology of the inter-tidal area has been impacted through the estuary bank adjacent to the golf course being artificially stabilised. Similarly, the salt marsh area has also been cut off from the main estuary through the fixing of the southeastern estuary bank (road, oxidation pond protection, etc.). This has also resulted in a reduction of the estuary mouth-location envelope (i.e. reduced excursion of the mouth). In the inter-tidal zone, the morphological impacts of roads and bank protection are much larger than impacts of more stable braided channels and mouth excursion reduction. However, most morphological change in the sub-tidal zone is due to reduced river flows and reduced smaller floods (1 in 2 to 1 in 10 year).

8. REHABILITATION OF SALTMARSH AREA

8.1 GENERAL

The current rehabilitation project on the saltmarsh aim is that the Orange River mouth again complies with the requirements for classification as a Ramsar site, i.e. it will be removed from the Montreux Records, and not necessarily that a situation be recreated as close as possible to natural conditions.

The following options were considered in the restoration process:

- The connection through the causeway of the pan in the lower saltmarsh behind the dunes with the main channel of the estuary.
- Removal of local obstructions within the saltmarsh to enhance the influx of seawater further.
- Inflow of freshwater upstream in the saltmarsh area.
- Additional openings in the causeway and/or complete removal of the causeway.
- Reduction in river flow to allow the mouth to close and thereby permit back-flooding.
- The danger of prolonged periods of low flow and mouth closure.
- Mechanical closure of the estuary mouth.

8.2 REQUIREMENT FOR BACK-FLOODING

Back-flooding during closed river mouth conditions will cause inundation of the degraded saltmarsh with fresh, or brackish, water. This would result in a reduction in (excessive) salinity concentrations in the soil layer at the surface and create beneficial conditions for the rehabilitation of the saltmarsh vegetation.

Mouth closure occurred regularly before the constructing of the large dams on the Orange River. This was associated with the occurrence of low river flows during the winter months. At times the mouth was probably closed for periods of up to a few months. Rainfall in the catchment area at the end of winter and early spring resulted in an increase in river flow and in water levels at the mouth (which would have inundated the saltmarsh) and eventually in a breaching of the mouth. The dynamics of the mouth are determined by the factors described in Chapter 4.

A more constant flow pattern was established after the completion of the dams because of water releases for irrigation and for the generation of electricity. This resulted in elevated base flows through the mouth, preventing closure and back-flooding. The elimination of mouth closure and of back-flooding may have been an factor in the deterioration of the saltmarsh. Mouth closure has occurred only a few times in the past twenty years. During the spring of 1993 the mouth closed for a few months. Closures also occurred for a few days in

December 1994 and in December 1995 when water level recordings were obtained from the recorders installed in the saltmarsh (see Figure 7).

The re-establishment of an annual low flow period to allow the mouth to close could be an important requirement for the restoration and long-term viability of the saltmarsh.

8.3 PROLONGED PERIODS OF LOW FLOWS AND MOUTH CLOSURE

Further reduction in river flow of the Orange River to meet the demands for freshwater, is expected. A concern is therefore that the reduction in river flow in the future could cause frequent and prolonged mouth closures.

Under natural conditions the low flow period and mouth closure occurred during the winter months. In the future an increased abstraction for irrigation in summer, combined with the high evaporation, could lead to more closed mouth conditions and a shift in seasonality of the closed mouth conditions from winter in the past to summer in the future.

Future reduction of river flow and shift in seasonal flow variations could have serious consequences for the estuary.

9. MONITORING REQUIREMENTS

Monitoring is urgently required on the Orange River estuary to ensure a **high confidence** in the predictions stated in this report, i.e. such as would be required for a Intermediate or Comprehensive level study. The following abiotic components need to be monitored:

9.1 HYDRODYNAMICS

Hydrodynamics monitoring is urgently required on the Orange River estuary to ensure that:

- The *recommended flow and flood regime typical of the recommended Category is reaching the estuary*, and
- The *recommended flow and flood regime maintain the required habitat* for birds, fish, macrophytes, microalgae and water quality.

Accurate continuous flow record of river inflow: A flow gauging station should be installed to measure river inflow near the head of estuary, e.g. Brandkaros. Futhermore, the gauging station at Vioolsdrift needs to be re-calibrated to improve its accuracy at low flows. An accurate record of the low flows entering the Orange estuary is required for a minimum of 5 years (Intermediate level) to 15 (Compressive level), depending on future mouth closure frequency.

Continuous water level recordings: A continuous water level recorder should be installed at the mouth of the estuary and in the salt marsh near the beach to monitor the tidal influence. For a more detailed study, continuous water level recorder for a minimum of 5 years (Intermediate level) to 15 (Compressive level), depending on future mouth closure frequency, would be required.

Daily observations: Where possible, daily mouth observations should be logged when the mouth is nearly closed or closed. The time at which the observation was made and the state of the tide must also be recorded, ideally at low tide. For a more detailed study observations for a minimum of 5 years (Intermediate level) to 15 (Compressive level), depending on future mouth closure frequency, would be required.

Wind, wave and sea-current conditions: Available data should be accessed, but no measurements are specified as part of a baseline monitoring.

Annual Aerial photographs: New full colour, geo-referenced rectified aerial photographs at 1: 5 000 scale covering the entire estuary (based on the geographical boundary), and taken at low tide in summer, are required. This is also a requirement for future macrophyte surveys. These photographs must include the breaker zone near the mouth. Repetitive, systematic and comparative oblique photographs taken of the mouth, tidal basin and upper estuary area, also provide useful information on some characteristics of the estuary and clearly show certain variabilities, dynamics or changes.

9.2 SEDIMENT DYNAMICS

Sediment monitoring is urgently required on the Orange River estuary to ensure that:

- The *recommended flow and flood regime maintain the required habitat* for birds, fish, macrophytes and microalgae.

Sediment analyses is not usually a requirement of a rapid or intermediate level study. However, in the case of the Orange River System with its high sediment volumes and drastically reduce floods, a deeper level of insight is urgently required, to predict with a much higher degree of accuracy the impacts of future water resource development on this estuary.

Sediment grabs: Representative grab samples should be collected, both from the adjacent beach and sand bar, and along the entire estuary at 100 m to 300 m intervals, using a Van Veen or a Zabalocki-type Eckman grab for particle size analyses, cohesive nature and organic content. The samples should not only be collected from the centerline of the main channel, but also across the estuary, including the inter- and supra-tidal areas.

Sediment grab sampling requires seasonal sampling (spring, summer, autumn and winter) for one to three years to understand sediment processes better and link with biotic requirements.

Sediment cores: Core samples should be collected using a corer (for historical sediment characterization) on the same grid spacing as the grab samples. Sediment cores require at least once-off sampling, but ideally just after a medium to large flood as well as a year (or two) later.

Bathymetric/topographical surveys: Surveys should be conducted intensively in the beach, bar, mouth and lower basin region –(~25 m interval). Upstream cross-section profiles should be measured along the entire estuary at ~300 m intervals (from the +5 m MSL contour on the left bank, trough the estuary to the +5 m MSL contour on the right bank) using D-GPS and echo-sounding. The survey should provide data on beach slopes, berm height and width, mouth sediment dynamics and cross section profiles upstream of the mouth (including channel and island dimensions and elevations). The surveys should be repeated with 2 year intervals, including extra measurements after floods, with ideally a minimum record of about 15 years. Alternatively, numerical models could be used to simulate longer-term processes.

Sediment load near the head of estuary (including grain size distribution and detritus component – particulate carbon/loss on ignition): Daily intervals for a minimum 5 years.

Ideally, both suspended- and bed-load should be monitored. The measurements could be done at Brandkaros, but ideally within a few kilometers upstream of the Oppenheimer Bridge.

Suitable sediment data records cannot be acquired in the short term, as some of the critical processes/dynamics have decadal (or longer) time scales. Therefore, if sediment processes in estuaries are to be better understood and quantified, long-term programmes will have to be implemented. In this regard it is recommended that the DWAF implement such monitoring activities timeously in Orange River Estuary, particularly as it is earmarked for substantial water abstraction in future.

9.3 WATER QUALITY

Water quality of river inflow: Water quality of river inflow should be measured near the head of the estuary. System variables (pH, DO, turbidity, suspended solids, TDS and temperature), nutrients (inorganic nitrogen [nitrite, nitrate and ammonia], reactive phosphate and silicate) and toxic substances (where relevant) should be measured.

Water quality in estuary: The following samples should be, at least during a open phase and closed phase collected:

- Salinity and temperature profiles (also required for hydrodynamics)
- System variables (pH, DO, turbidity, suspended solids)
- Inorganic nutrients (nitrate/nitrite, ammonia, reactive phosphate and reactive silicate)

10. CONCLUSIONS AND RECOMMENDATIONS

The following recommendations are made:

- The potential negative effects of back-flooding, for example on the sewage works and the golf course near Oranjemund, should be investigated.

- The danger exists that further drastic reductions in river flow could result in prolonged periods of closure of the estuary mouth. It is recommended that DWAF be requested to undertake further investigations on the flow requirements of the estuary to prevent this from happening.

- Proper estimates of flow required to keep the mouth open can not be undertaken because of lack of information. It is essential that detailed investigations, including monitoring, are undertaken to determine the correlation between river flow and mouth conditions. It is therefore recommended that the flow gauge at Brandkaros be reinstalled and calibrated for low flows and that a permanent water level recorder again be installed in the salt marsh near the beach to monitor the tidal influence.

11. REFERENCES

ADAMS, J.B. and BATE, G.C. 1994. The effect of salinity and inundation on the estuarine macrophyte *Sarcocornia perennis* (Mill.) A.J. Scott. *Aquatic Botany* 47: 341 - 348.

Bremmer, J.M., Rogers, J., and Willis, J.P. 1990. Sedimentological aspects of the 1988 Orange River floods. *Transactions of the Royal Society of South Africa.* Vol. 47, Part 3, pp247-294.

Brown, A C, 1959. The ecology of South African estuaries. Part IX: Notes on the estuary of the Orange River. *Trans. Roy. Soc. S. Afr*. **35**(5): 463-473.

Brown, C.A. 2003. Draft report: Lower Orange River Management Study – Task 8.3: Additional environmental flow tasks: Riverine. Unpublished report for Ninham Shand, Cape Town.

California Beach Restoration Study 2002. Part 3, Chapter 7, Impediments To Fluvial Delivery Of Sediment To The Shoreline. Page 7-1 to 7-48. January 2002.

Cooper J. A. G. 2002. The role of extreme floods in estuary-coastal behaviour: contrasts between river- and tide-dominated microtidal estuaries, Sedimentary Geology, Volume 150, Issues 1-2, 15 June 2002, Pages 123-137

Cowan G.I., 1995. Wetlands of South Africa. Department of Environmental Affairs and Tourism, Pretoria

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

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

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

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

CSIR, 1994b. Great Brak Estuary management programme. Report on the monitoring results for the period April 1993 to March 1994. *CSIR Contract Report* EMAS-C 94013, Stellenbosch.

CSIR, 1997. Orange River mouth. Saltmarsh rehabilitation project. Report submitted to Alexcor. *CSIR Contract report ENV/S-C 97131.*

CSIR, 2001. Orange River mouth. Conservation and development Plan: Intuitional Support Study. *CSIR Contract report ENV-S-C 2001-075.*

CSIR. 1984. Health of South African Estuaries, Orange River – Buffels (Oos). *CSIR Report* WE005. Durban.

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

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

DAY, J H. 1981. Estuarine ecology with particular reference to southern Africa. A A Balkema, Cape Town.

De Dekker RH. 1988. The wave regime on the inner shelf of the Orange River and its implications for sediment transport. Suid-Afrikaanse Tydskrif vir Geologie, 91(3):358-371.

DEAT 2001. South African Estuaries: Catchment Land-Cover: National Summary Report. Pretoria: Directorate Environmental Information & Statistics, Department of Environmental Affairs & Tourism. On line: http://www.environment.gov.za/soer/estuary/tables.html.

Department of Water Affairs and Forestry (DWAF) 1995. South African water quality guidelines for coastal marine waters. Volume 1: Natural Environment. Pretoria.

Department of Water Affairs and Forestry (DWAF) 1996. Orange River Development Project Replanning Study. Refinement of the instream flow requirements for the Orange River.

DWA, 1990. Orange River ecology. Assessment of environmental water requirements for the Orange River mouth. *DWA Report no:* V/D400/01/E001, Compiled by Brunette Kruger Stofberg Inc Consulting Engineers.

DWA, 1990. Orange River ecology. Assessment of environmental water requirements for the Orange River mouth. *DWA Report no:* V/D400/01/E001, Compiled by Brunette Kruger Stofberg Inc Consulting Engineers.

McKenzie R.S. and Craig A.R 2000. Evaluation of river losses from the Orange River using hydraulic modelling. *Journal of Hydrology* 241 (2001): 62-69.

Michael E. Meadows; John Rogers; Julia A. Lee-Thorp; Mark D. Bateman; Richard V. Dingle. (2002). Holocene geochronology of a continental-shelf mudbelt off southwestern Africa. *The Holocene*, Volume: 12 (1): 59 - 67. Arnold, January 2002.

Orren, M J, Eagle, G A, Hennig, H F-K O and Green, A. 1979. Preliminary results of an environmental survey on the Orange River Estuary. In: 4th National Oceanographic Symposium. 10 – 13 July. Cape Town, South Africa.

Reddering JSV and Rust IC. 1990. Historical changes and sedimentary characteristics of Southern African estuaries. South African Journal of Science, Vol 86: 425-428.

Seaman, M T and Van As, J G, 1998. The environmental status of the Orange River mouth as reflected by the fish community. *WRC Report* No. **505/1/98**. Pretoria.

Shillinton FA, Brundrit JB, Lutjeharms JRE, Boyd AJ, Agenbag JJ and Shannon LV. 1990. The coastal current circulation during the Orange River flood 1988. *Transactions of the Royal Society of Southern Africa 47*: 307-330.

Swart, D.H., Crowley, J.B., Moller, J.P. and De Wet, A. 1990. Nature and behaviour of the flood at the river mouth. *Transactions of the Royal Society of South Africa,* 47 (3): 217-245.

Turpie, J.K., Adams J.B., Joubert, A., Harrison, T.D., Colloty, B.M., Maree, R.C., Whitfield, A.K., Wooldridge, T.H., Lambert, S.J., Taljaard, S. and Van Niekerk, L. (2002) Assessment of the conservation status of South African estuaries for use in management and water allocation. *Water SA* **28:** 191-203.

Van Heerden, I.L. 1986. Fluvial sedimentation in the ebb-dominated Orange Estuary. *South African Journal of Science* 82: 141 - 147.