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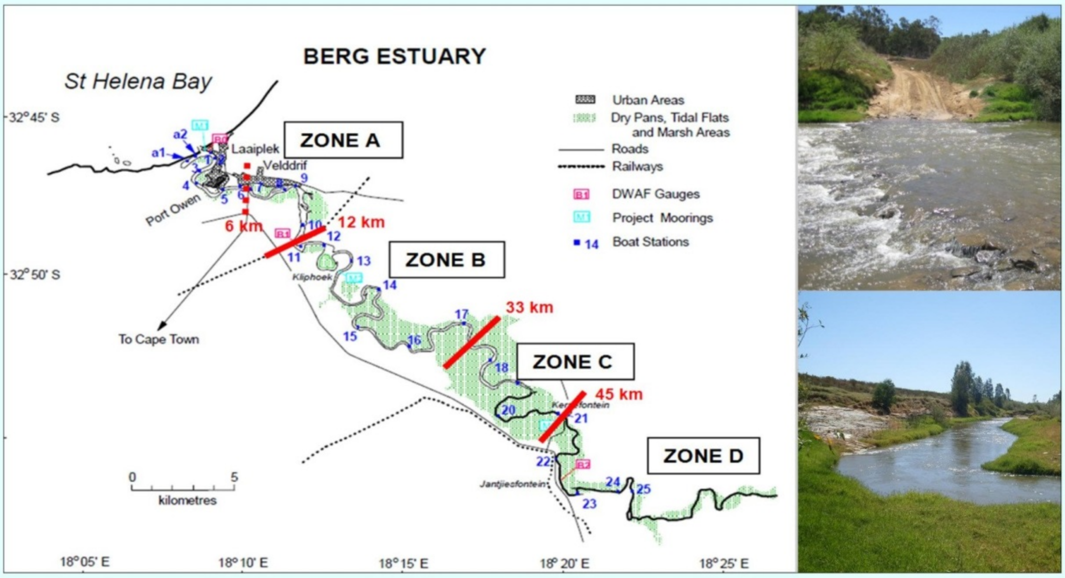
DEPARTMENT OF WATER AFFAIRS
DIRECTORATE : OPTIONS ANALYSIS

PRE-FEASIBILITY AND FEASIBILITY STUDIES FOR AUGMENTATION OF THE WESTERN CAPE WATER SUPPLY SYSTEM BY MEANS OF FURTHER SURFACE WATER DEVELOPMENTS

Report No 1 : Ecological Water Requirement Assessments

Volume 3 : Berg Estuary Environmental Water Requirements



Final

June 2012

Department of Water Affairs
Directorate: Options Analysis

PRE-FEASIBILITY AND FEASIBILITY STUDIES FOR AUGMENTATION OF THE WESTERN CAPE WATER SUPPLY SYSTEM BY MEANS OF FURTHER SURFACE WATER DEVELOPMENTS

APPROVAL

Title	:	Ecological Water Requirement Assessments Berg Estuary Environmental Water Requirements
Consultants	:	Western Cape Water Consultants Joint Venture
Report status	:	Final
Date	:	June 2012

STUDY TEAM: Approved for the Joint Venture:

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RECORD OF IMPLEMENTATION DECISIONS
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EXECUTIVE SUMMARY

BACKGROUND

This report presents the results of the Ecological Water Requirements (EWR) for the Berg River Estuary.

In July 2008, the then Department of Water Affairs and Forestry (now Department of Water Affairs; DWA) appointed the Western Cape Water Consultants Joint Venture to undertake Pre-feasibility and Feasibility level investigations of the potential development of six surface water options, namely:

- the Michell's Pass Diversion Scheme;
- the First Phase Augmentation of Voëlvlei Dam;
- Further Phases of Voëlvlei Dam Augmentation;
- the Molenaars River Diversion;
- the Upper Wit River River Diversion;
- Further Phases of the Palmiet Transfer Scheme.

This entailed investigations in three major catchments, *viz*. Breede, Palmiet and Berg Catchments.

Southern Waters sub-consulted Anchor Environmental Consultants, on behalf of the JV, to undertake a comprehensive EWR determination for the Berg River Estuary.

Assumptions and Limitations

The brief was undertaken based on the following assumptions and limitations:

- No new data were collected for this study. It was based on data from a monitoring programme conducted on the Great Berg system in 2002-2005 (DWAF 2007).
- The overall confidence in the hydrology for the estuary was **low,** because of:
    - low confidence in the accuracy of the stage measurements at the Misverstand weir;
    - no information on abstractions between Misverstand and the estuary;
- The accuracy of the predicted abiotic states for the Berg River Estuary (and hence biotic characteristics) and the distribution of these states under the Reference condition, present state and future flow scenarios depends largely on the accuracy of the simulated runoff data and measured flow data.

Criteria for confidence limits attached to statements in this study were as follows:

LIMIT	DEGREE OF CONFIDENCE
Low	If no data were available for the estuary or similar estuaries (i.e. < 40%)
Medium	If limited data were available for the estuary or other similar estuaries (i.e. 40-80%)
High	If sufficient data were available for the estuary (i.e. > 80%)

GEOGRAPHICAL BOUNDARIES

The geographical boundaries for the Berg River Estuary are:

Downstream boundary: Estuary mouth (32° 46.193'S; 18° 8.649'E)

Upstream boundary: 70 km from the mouth (32° 56.388'S; 18° 26.620'E) to the extent of tidal influence

Lateral boundaries: 5 m contour above Mean Sea Level (MSL) along each bank

PRESENT ECOLOGICAL STATUS (PES)

The Estuarine Health Index scores allocated to the Berg River Estuary (PES) were:

VARIABLE	WEIGHT	Score	WEIGHTED score
Hydrology	25	72	18
Hydrodynamics and mouth condition	25	90	23
Water quality	25	40	10
Physical habitat alteration	25	59	15
Habitat health score			**65**
Microalgae	20	75	15
Macrophytes	20	54	11
Invertebrates	20	50	10
Fish	20	56	11
Birds	20	78	16
Biotic health score			**63**
ESTUARINE HEALTH SCORE			**64**

The EHI score for the Berg River Estuary, was 64, translating into a PES of Category C:

EHI Score	PES	Description
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	**C**	**Moderately modified**
41 – 60	D	Largely modified
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

Although the PES of the Berg River Estuary is Category C, it is likely that the estuary is on a negative trajectory of change, because of the extremely low lowflows under the present state (< 1 m^3s^-1), particularly during the summer months. Maintaining the *status quo* is therefore likely to result in continued decline in condition.

IMPORTANCE OF THE BERG RIVER ESTUARY

The Estuarine Importance Scores (EIS) allocated to the Berg River Estuary were as follows:

Criterion	Score	Weight	Weighted score
Estuary Size	100	15	15
Zonal Rarity Type	90	10	9
Habitat Diversity	100	25	25
Biodiversity Importance	98	25	25
Functional Importance	100	25	25
ESTUARINE IMPORTANCE SCORE			99

The EIS for the Berg River Estuary, based on its present state, is 99, i.e., the estuary is highly important.

ECONOMIC VALUE OF THE BERG ESTUARY

Total economic value of the Berg estuary is estimated to be R75.6 million, with by far the largest component of this value being derived from turnover in the property sector (R48.6 million), followed closely by visitor expenditure (R18.3 million) and nursery value (R8.1 million). Subsistence and existence value make relatively small contributions to total economic value. This places the Berg estuary firmly on the upper end of the value spectrum for temperate estuaries in South Africa.

ECOLOGICAL RESERVE CATEGORY

The recommended Ecological Reserve Category (ERC) represents the level of protection assigned to an estuary.

For estuaries, the first step is to determine the 'minimum' ERC, based on its PES. The relationship between EHI Score, PES and minimum ERC is set out in the table below.

EHI Score	PES	Description	Minimum ERC
91 – 100	A	Unmodified, natural	A
76 – 90	B	Largely natural with few modifications	B
61 – 75	C	Moderately modified	C
41 – 60	D	Largely modified	D
21 – 40	E	Highly degraded	-
0 – 20	F	Extremely degraded	-

NOTE: *Should the PES of an estuary be either an E or F, recommendations must be made as to how the status can be elevated to at least achieve a Category D (as indicated above).*

PES dictates the minimum ERC. The degree to which PES needs to be elevated depends on the level of **importance** and level of **protection or desired** protection of a particular estuary:

Current/desired protection status and estuary importance	Recommended Ecological Reserve Category	Policy basis
Protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area (based on complementarity)		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category
Important	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D category

* *BAS = Best Attainable State*

In addition to being categorised as a 'highly important estuary' (see above), the Berg River Estuary has also been targeted as a Desired Protected Area (DWAF 2004a). Therefore, according to the guidelines for assigning a recommended ERC, the condition of the estuary should be elevated to a Category A or the Best Attainable State (BAS).

QUANTIFICATION OF ECOLOGICAL RESERVE SCENARIOS

A summary of the suite of future runoff scenarios evaluated as part of this project is provided below. Each comprises different inflow scenarios from the Berg catchment, respectively.

Scenario Name	Scenario Description	Summer lowflow (m^3s^{-1})	Historic Firm Yield (Mm^3)	Historic Firm Yield: wrt. BRD (%)	Revised Estuary MAR (1920-2004)
Present state	Present day with Berg River Dam in Place	0.3	547	0	500
Scenario 1	Present day without Berg River Dam	0.3	462	-85	594
Scenario 2	Augmentation of Voelvlei dam - Phase1 - No raising. $3m^3s^{-1}$ diversion	0.3	574	27	471
Scenario 3	Augmentation of Voelvlei dam - Phase2a - No raising. $20m^3s^{-1}$ diversion	0.3	591	44	450
Scenario 4	Augmentation of Voelvlei dam - Phase2b - $20m^3s^{-1}$ diversion, raise Voelvlei dam by 9 m	0.3	613	66	394
Scenario 5	Raised Misverstand, Imposed resdss ifrC. Ifr = 23% of natural flow	0.3	571	24	405
Scenario 6	Raised Misverstand, Imposed resdss ifrD. Ifr = 15% of natural flow	0.3	585	38	396

Scenario Name	Scenario Description	Summer lowflow (m^3s^{-1})	Historic Firm Yield (Mm^3)	Historic Firm Yield: wrt. BRD (%)	Revised Estuary MAR (1920-2004)
Scenario 7	Present day with Berg River Dam in Place	0.9	539	-8	506
Scenario 8	Raised Misverstand, Imposed resdss ifrD. Ifr = 15% of natural flow	0.15	587	40	395
Scenario 9	Present state with increased lowflows	Dec 2, Jan 1.5, Feb - Mar 1, Apr 3	529	-18	513
Scenario 10	Present state with increased lowflows and improved anthropogenic	Dec 2, Jan 1.5, Feb - Mar 1, Apr 3	529	-18	513

The ERCs for the different scenarios were:

VARIABLE	WEIGHT	PD	SCENARIO									
			1	2	3	4	5	6	7	8	9	10
EHI		64	66	62	61	59	59	58	65	58	67	72
ERC		C	C	C	C	D	D	D	C	D	C	C

Impacts of the various flow scenarios examined in this study on economic value of the Berg estuary was estimated for turnover in the real estate sector, visitor expenditure, and the nursery value of the estuary. Total estimated value for the Berg estuary for these three components examined for the future flow scenarios is R75.0 million per annum at present. This value increases marginally under most of the future scenarios (aside from Scenario 9), due to increases in all components of value under these scenarios up a maximum of R78.6 million per annum under Scenario 10. Under Scenario 9, modest increases in real estate turnover are offset by the lack of any change in recreational utility and a reduction in nursery value. It should be noted that all of the changes in value are all very small relative to the overall value of the system (all <5%), and should be treated with caution given that they are all less than the confidence limits surrounding these value estimates.

RECOMMENDED ECOLOGICAL WATER REQUIREMENT

The evaluation of the simulated runoff scenarios is used to derive the recommended EWR. The recommended EWR is defined as the runoff scenario (or a slight modification thereof) that represents the highest reduction in river inflow that will keep the estuary in the ERC.

Given the extent of the existing water resources infrastructure in the catchment (e.g. Berg River Dam) and the extent of transformation, it would be impractical to improve the condition of the Berg River Estuary to a Category of A, or indeed a Category B. Using flow alone, the condition could only be improved by 3% (from 64 to 67%). Even if, non-flow related mitigation measures, such as removing unutilised infrastructure in the lower estuary, reducing agricultural impacts on the floodplain, reducing the application of fertilizers in the catchment and eradicating illegal gill net fishing in the estuary, were also implemented the condition would not reach a Category B. Thus, the BAS for the estuary is thus a **Category C.**

Most of the scenarios evaluated in this study resulted in the Berg River Estuary dropping into lower category than PES mainly because the summer lowflows were lower than Present Day. Reduced summer lowflows increase the upstream extent of saline water penetration. The impact of reduced high flows was less pronounced.

In addition, the condition of the Berg River Estuary is on a negative trajectory, as it has probably not yet adjusted to the presence of the Berg River Dam. There is also considerably uncertainty about the magnitude of the inflows in summer. Thus, **Scenario 7**, the Present inflow scenario with marginally reduced minimum summer low requirements of 0.6 x m^3s^{-1} was selected as the recommended EWR for the Berg River Estuary.

Summary of the flow distribution for the recommended EWR (Scenario 7 with minimum summer lowflows of 0.6 m^3s^{-1}) for the Berg River Estuary

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	46.97	30.38	14.58	5.30	7.03	8.36	23.43	64.98	120.14	220.34	185.50	139.78
90%ile	22.06	12.70	2.71	1.46	1.24	1.81	7.51	29.83	63.86	114.04	117.06	54.26
80%ile	15.53	8.51	0.93	0.90	0.90	0.90	5.61	13.83	37.23	60.90	85.14	38.81
70%ile	11.56	6.26	0.60	0.90	0.90	0.90	3.91	10.26	31.42	46.06	55.93	32.27
60%ile	9.69	4.88	0.60	0.90	0.90	0.90	2.08	8.59	19.69	36.07	44.29	23.95
50%ile	8.28	4.02	0.60	0.90	0.90	0.90	1.42	6.90	16.13	27.74	28.66	20.15
40%ile	7.56	3.74	0.60	0.90	0.90	0.90	1.00	5.43	11.46	21.97	22.95	15.90
30%ile	6.69	3.31	0.60	0.90	0.90	0.90	0.90	4.33	9.78	17.19	19.04	14.13
20%ile	6.22	2.73	0.60	0.90	0.90	0.90	0.90	3.43	7.75	13.22	15.91	11.00
10%ile	5.22	2.32	0.60	0.90	0.90	0.90	0.90	2.73	6.19	8.81	11.34	8.44
1%ile	3.79	0.60	0.60	0.60	0.60	0.60	0.90	1.49	3.61	4.67	7.28	4.83

Allowing the condition of the Berg River Estuary to further decline from PES may have the following implications:

- Nuisance macroalgal growth during the summer months, with negative impacts on bird fauna, recreational usage and aesthetics (i.e. ‘loss of value’).
- Increase in abundance and occurrence of nuisance macrophytes, notably water hyacinth in the upper estuary and *Enteromorpha* in the lower estuary, with negative impacts on marginal salt marsh vegetation, intertidal invertebrate populations

inhabiting sand and mudflats in the lower estuary, bird fauna of the estuary, and recreational usage and aesthetics.

- Reduced numbers of estuarine dependent fish and invertebrate species, particularly those that use the upper reaches of the estuary as a spawning and nursery ground.
- Reduced cueing effect to estuarine dependent invertebrate and fish species, and a possible reduction in diversity and abundance of fish in the estuary.

These are also likely to have a ripple effect on economic good and services provided by the adjacent marine environment, e.g. the marine fisheries.

Thus, it is strongly recommended that decisions regarding the future state of the Berg River Estuary carefully consider potential impacts on all users. Given the importance of the Berg River Estuary, every effort should also be made to implement the measures required to mitigate the non-flow related impacts on the system, such as:

- eradicate invasive alien vegetation (especially dense tree stands) from floodplains;
- remove derelict, redundant and old quays, jetties, wharfs and revetments; and rehabilitate banks to natural sediments;
- prohibit dredge spoil dumping (from lower main channel as well as marina) in inappropriate areas;
- install additional culverts into road and rail bridge embankments;
- manage agricultural practises in the estuary to avoid trampling of estuarine vegetation by livestock;
- manage agricultural practises in the catchment to minimise nutrient and sediment loads entering the estuary;
- control fish factory effluent discharged to the estuary to reduce nutrient loading to the system;
- upgrade the sewage treatment works in the catchment to reduce nutrient inputs to the estuary.

ECOLOGICAL SPECIFICATIONS

Ecological Specifications and thresholds of potential concern (TPC) were defined for a **Category C.**

RESOURCE MONITORING PROGRAMME

The status of baseline data currently available for different abiotic and biotic components in the Berg River Estuary, after completion of the Berg River Baseline Monitoring Programme, is summarised in the report. No new data were collected as part of this RDM study. Detailed data are available for most abiotic and biotic components. The report does, however, identify a number of important data gaps that, if addressed, would improve the confidence of this and any future reserve determination studies.

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GLOSSARY AND ABBREVIATIONS

BAS	Best Attainable State
BRD	Berg River Dam
C.A.P.E.	Cape Action Plan for People and the Environment
CCT	City of Cape Town
CD	Chief Directorate
CPUE	Catch-per-nit-effort
CSIR	Centre of Scientific and Industrial Research
DEA: MCM	Department of Environmental Affairs: Marine and Coastal Management
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphate
DO	Dissolved Oxygen
DRP	Dissolved Reactive Phosphate
DRS	Dissolved Reactive Silicate
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EHI	Estuarine Health Index
EIS	Estuarine Importance Score
ERC	Ecological Reserve Category
EWR	Ecological Water Requirement
H	High
L	Low
M	Medium
MAR	Mean Annual Runoff
MCM	Million Cubic Metres
MCM/a	Million Cubic Metres per annum
MSL	Mean Sea Level
NMMU	Nelson Mandela Metropolitan University
NWA	National Water Act (1998)
PES	Present Ecological Status
ppt	part per thousand
RDM	Resource Directed Measures
REI	River Estuary Interface
RQO	Resource Quality Objectives
SA	South Africa
VV	Voelvlei Dam
WMA	Water Management Area
WCWSS	Western Cape Water System Supply Study
WTP	Willingness to pay

1 INTRODUCTION

1.1 BACKGROUND

The Western Cape Water Supply System (WCWSS) serves the City of Cape Town (CCT), other urban users and irrigators. It comprises infrastructure owned and operated by both the CCT and the Department of Water Affairs (DWA).

The Western Cape Reconciliation Strategy Study reviewed the future water requirement scenarios of greater Cape Town and the reconciliation options for meeting these water requirements within a planning horizon to 2030. It identified potential suites of options for meeting future water demand from the WCWSS. It also identified various alternative implementation options, which offered flexibility in planning, such that possible changes in the projected water requirements could be accommodated. One set of implementation options is to further develop the surface water resources of the Berg and Breede Water Management Areas (WMAs).

In July 2008, the then Department of Water Affairs and Forestry (now DWA) appointed the Western Cape Water Consultants Joint Venture to undertake Pre-feasibility and Feasibility level investigations of the potential development of six surface water options, namely:

- the Michell's Pass Diversion Scheme;
- the First Phase Augmentation of Voëlvlei Dam;
- Further Phases of Voëlvlei Dam Augmentation;
- the Molenaars River Diversion;
- the Upper Wit River River Diversion;
- Further Phases of the Palmiet Transfer Scheme.

This entailed investigations in three major catchments, *viz*. Breede, Palmiet and Berg Catchments.

Southern Waters sub-consulted Anchor Environmental Consultants, on behalf of the JV, to undertake a comprehensive Ecological Water Requirement (EWR) determination for the Berg River Estuary.

1.1.1 Ecological Water Requirements and the Ecological Reserve

The South African National Water Act (NWA; DWAF 1994) provides for the protection of water resources through the apportioning of an agreed amount of the water available in a system to facilitate maintenance of the natural environment in some pre-agreed condition. This water needs to be of an appropriate volume and quality, and be available at the appropriate time of the year, to fulfil its purpose, and is known as the Ecological Reserve.

To arrive at the Ecological Reserve, the Ecological Water Requirements (EWRs) for the maintenance of affected rivers, estuaries, wetlands and groundwater are first determined for a range of future conditions. These are then assessed against other requirements in the basin, such as provision of water for off-stream use, as part of a consultative process to decide on acceptable future conditions for the various ecosystems (DWAF 2007; Dollar *et al*. 2008). The agreed future condition and the EWRs for maintaining such become the Ecological Reserve.

1.2 OBJECTIVES OF THE REPORT

This report provides the background data and deliberations for the EWR study on the Berg River Estuary.

1.3 ESTUARINE SPECIALIST TEAM

The specialist team responsible for this study is given in Table 1.1.

1.4 Overview of the process for determination of the EWRs for estuaries

The procedures used for the comprehensive level EWR determination for estuaries are provided in detail in *Resource directed measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAF 2008) and summarised in Figure 1-1.

Human-resource requirements for a comprehensive determination are summarised in Figure 1-2.

Table 1.1 Lead specialists responsible for the various components of the Estuarine EWR

Role/Expertise	Lead specialists	Contact details
Project co-leader	Dr Barry Clark	Anchor Environmental Consultants barry.clark@uct.ac.za
Hydrology	Mr Anton Sparks	Aurecon Consulting Engineers
Hydrodynamics	Lara van Niekerk/ Roy van Ballegooyen (Numerical modelling)	CSIR, Stellenbosch, lvnieker@csir.co.za
Sediment dynamics	Mr Andre Theron	CSIR, Stellenbosch, atheron@csir.co.za
Water quality	Ms Susan Taljaard	CSIR, Stellenbosch, staljaar@csir.co.za
Microalgae	Dr Gavin Snow	Nelson Mandela Metropolitan University, gavinsnow@nmmu.ac.za
Vegetation	Prof Janine Adams	Nelson Mandela Metropolitan University, janine.adams@nmmu.ac.za
Invertebrates	Prof Tris Wooldridge	Nelson Mandela Metropolitan University, tris.wooldridge@nmmu.ac.za
Fish	Dr Barry Clark	Anchor Environmental Consultants barry.clark@uct.ac.za
Project co-leader; Birds, Economics	Dr Jane Turpie	Anchor Environmental Consultants jane.turpie@uct.ac.za

1.5 Assumptions and limitation for this study

The following assumptions apply:

- No new data were collected as part of this study. Deliberations were based on information collated and collected during the intensive monitoring programme conducted on the Great Berg system in 2002-2005 (DWAF 2007).

- Confidence in the hydrology for the Berg River Estuary is **low**, owing to the following:
    - o low accuracy of the stage measurements at the Misverstand weir ;
    - o poor data on abstractions by irrigators downstream of Misverstand Dam.
- The accuracy of the predicted abiotic states (and hence biotic characteristics) for the Berg River Estuary and the distribution of these states under the Reference condition, present state and future flow scenarios depends on the accuracy of the simulated runoff data and measured flow data.

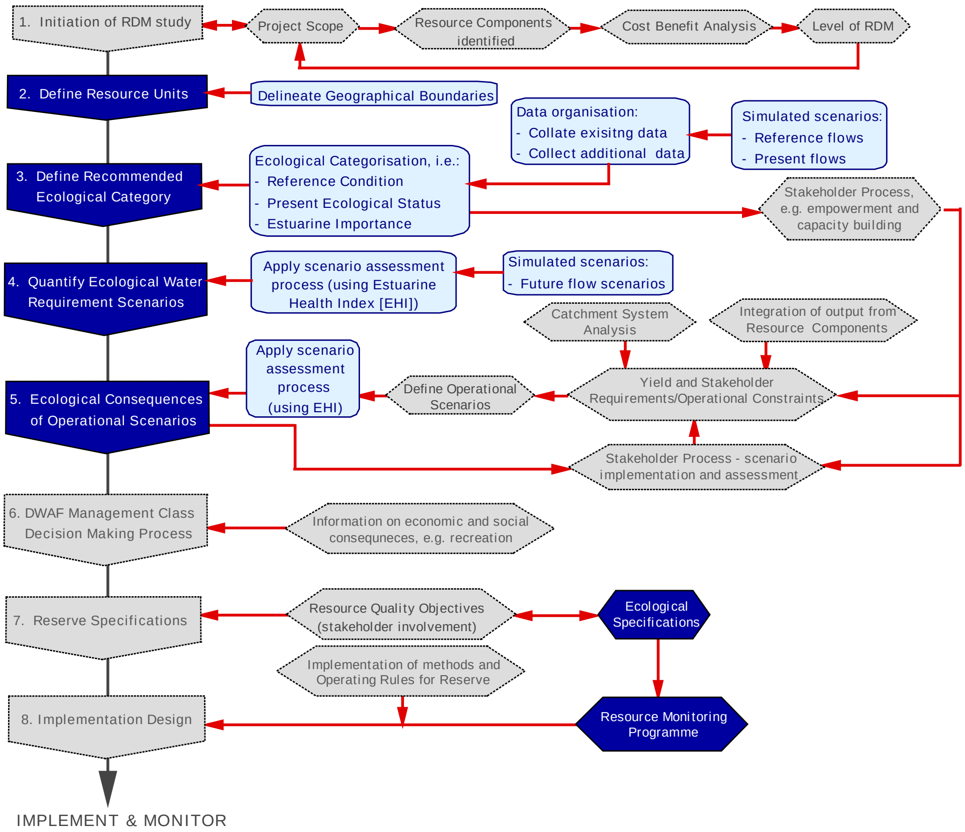


Figure 1-1 Procedures for a comprehensive EWR determination for an estuary, in context of the broad RDM process (components not addressed in this study are indicated by hatched line boxes; DWAF 2008)

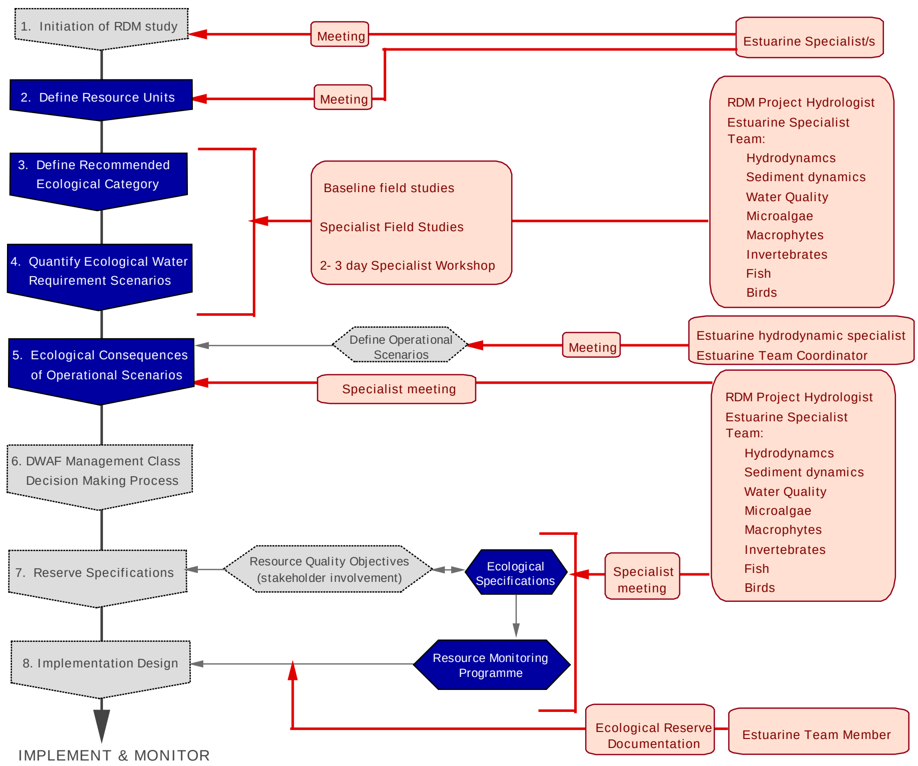


Figure 1-2 Human resource requirements for a comprehensive EWR determination for estuaries (DWAF 2008).

1.6 Definition of confidence levels

Criteria for the confidence limits attached to statements in this study are (Table 1.2):

Table 1.2 Confidence levels for an Estuarine EWR study

Presupposed confidence level	Situation	Expressed as percentage
Low	If no data were available for the estuary or similar estuaries	< 40%
Medium	If limited data were available for the estuary or other similar estuaries	40% – 80%
High	If sufficient data were available for the estuary	> 80%

2 DEFINITION OF RESOURCE UNIT

2.1 Introduction

The Berg River Estuary is located approximately 130 km north of Cape Town on the West Coast of South Africa. The mouth of the estuary is permanently open mouth, and was canalised in the late 1966's to facilitate the use of the estuary as a fishing port. Tidal oscillations propagate upstream for about 69 km, although saline water has not been known to penetrate this far. Day (1981) has reported that a salinity of 9 was recorded at Kersefontein in February 1979, some 45 km from the mouth. The estuary meanders upstream through extensive dry pans, tidal flats and marsh areas, rising only 1 m in the first 50 km.

The main channel of the estuary is about 100-200 m wide near the mouth, becoming progressively narrower and shallower upstream. Depth is about 3-5 m on average, but extends up to 9 m in places. The total volume of the estuary is estimated to be about 12 Mm^3. The catchment lies entirely within the Western Cape Province, which receives most precipitation during the winter rainfall season. Four major dams have been built in the catchment, including the Wemmershoek Dam (surface area = 3 km^2, storage capacity = 59.9 Mm^3), the Voëlvlei Dam (surface area = 15 km^2, storage capacity = 170 Mm^3/a), Misverstand Dam (storage capacity = 7.9 Mm^3), and the recently (2008) completed Berg River Dam (storage capacity = 130 Mm^3/a, surface area = 4.88 km^2). There are also numerous smaller farm dams throughout the eastern part of the catchment. A diversion weir and balancing dam have also recently been constructed on the Berg River, all forming part of the Berg River Supplement Scheme, designed to augment inflows to the Berg River Dam. The weir is situated a short distance downstream of the confluence with the Dwars River, and water is abstracted and pumped up to the Berg River Dam when flows in the river are higher than the volume required for the environmental water requirements. Nominal abstraction capacity is 6 m^3s^{-1}.

An interbasin transfer scheme also links the Theewaterskloof Dam on the Riviersonderend in the Breede Catchment with the Berg River. This scheme is currently not functioning owing to concerns regarding the transfer of bloom forming algae from the Theewaterskloof Dam to the Berg River Dam. Prior to the construction of the Berg River Dam, water was released into the upper Berg, just upstream of the confluence with the Wolvekloof tributary, through a siphon. This water was used to meet irrigation requirements on the Berg River during summer and for farming of exotic rainbow trout (*Oncorhynchus mykiss*) in the upper Berg. Water was released sporadically during late spring, summer and early autumn primarily during the months of December, January and March (Snaddon and Davies 2000). The scheme has been in existence since the 1980s.

The present-day mean annual runoff (MAR) of the Berg River is estimated to be around 520.4 Mm^3/a, which is *c.* 46% lower than under natural conditions.

The Berg River Estuary is one of three permanently open estuaries on the west coast. It is one of the largest estuaries in the country, with a total area of 61 km^2. The estuary is one of the most important in the country in terms of its conservation value. The extensive floodplains in the middle and upper reaches of the system make it unique in the south-western Cape. It has been identified as an important bird area (Barnes 1998) and a desired protected area in the conservation planning assessment conducted for C.A.P.E. (Turpie and Clark 2007) as well as in other studies (e.g. Turpie *et al.* 2002; Turpie 2004).

2.2 Geographical boundary

For the purposes of this comprehensive-level determination of the EWR on the Berg River Estuary, the geographical boundaries are defined as follows (Figure 2-1):

Downstream boundary:	Estuary mouth (32° 46.193'S; 18° 8.649'E)
Upstream boundary:	70 km from the mouth (32° 56.388'S; 18° 26.620'E) to the extent of tidal influence
Lateral boundaries:	5-m contour above Mean Sea Level (MSL) along each bank

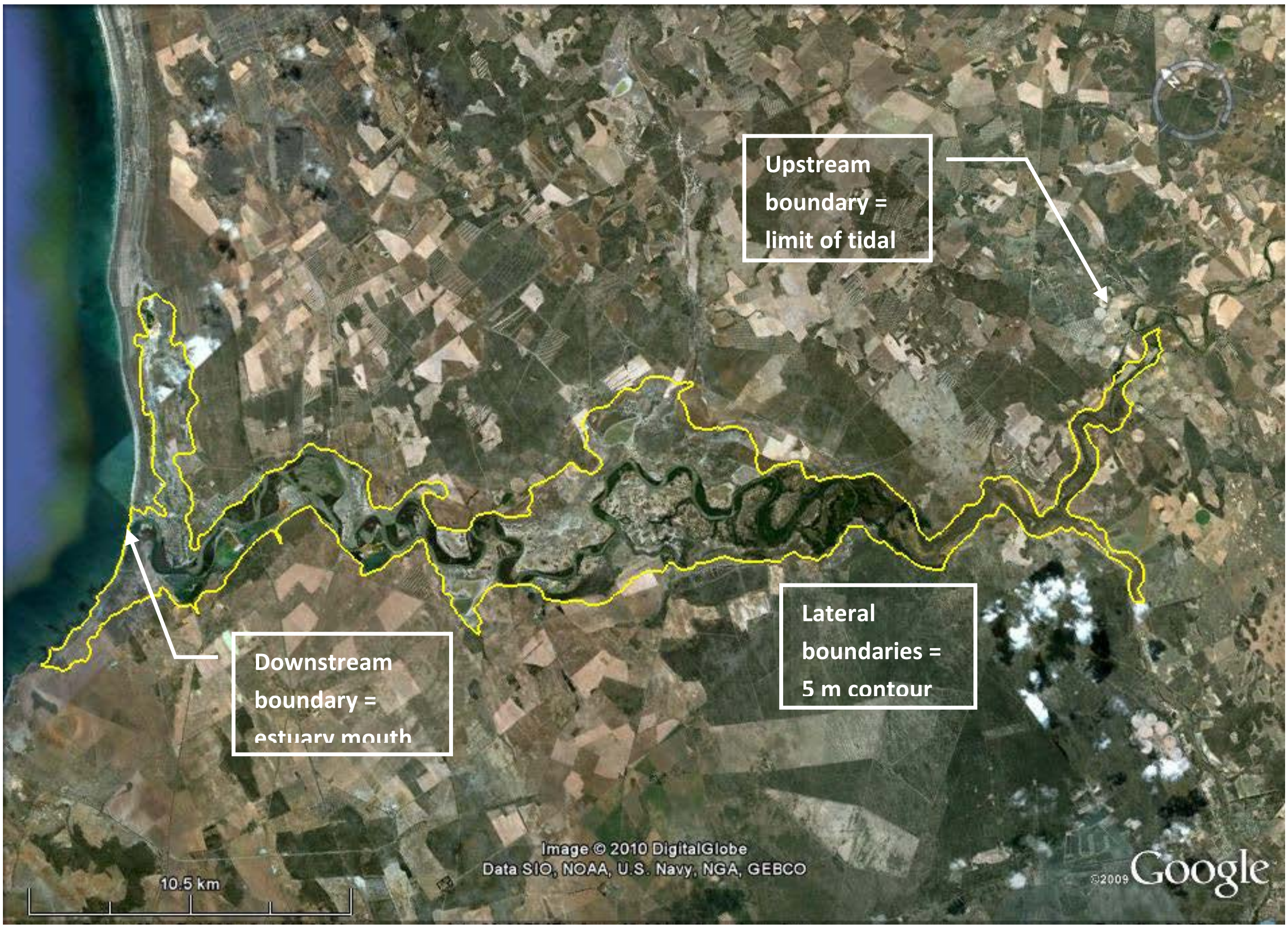


Figure 2-1 Geographical boundaries of the Berg River Estuary.

3 ECOLOGICAL RESERVE CATEGORISATION

3.1 Abiotic Components

3.1.1 Typical abiotic states

Based on available literature, a number of characteristic 'states' can be identified for the Berg River Estuary, related to tidal exchange, salinity distribution and water quality. These are primarily determined by river inflow patterns, state of the tide and wave conditions. The different states are listed in Table 3.1.

Table 3.1 Summary of the abiotic states that can occur in the Berg River Estuary

State	Name	Flow range (m^3s^{-1})
1	Severe marine-dominated - saline intrusion extends further than 45 km upstream of mouth (i.e. into Zone D	< 0.5
2	Marine-dominated - saline intrusion extends up to 45 km from mouth (i.e. downstream of Zone D	0.5-1.0
3	Small to medium freshwater inflow – marine influence evident up to 33 km from mouth (i.e. downstream of Zone C)	1.0-5.0
4	Medium to high freshwater inflow – marine influence only evident up to 12 km from mouth (i.e. downstream of Zone B)	5.0-25.0
5	Freshwater-dominated – estuary is fresh throughout (i.e. Zones A-D)	>25.0

The transition between the different states will not be instantaneous, but will take place gradually.

To assess the occurrence and duration of the different abiotic states selected for the estuary during the different scenarios, a number of techniques were used:

- colour coding (Table 3.1) was used for the full tables of simulated monthly river flow reaching the estuary for each scenario, to highlight the occurrence of the different abiotic states related to the different flow ranges;
- summary tables of the occurrence of different flows at increments of the 10%ile are listed separately to provide a quick comprehensive overview; and
- median (50%ile) and drought (10%ile) monthly flows were used to provide a conceptual overview of the annual distribution of abiotic states under the different scenarios.

The abiotic characteristics for the different states are summarised below. For a more detailed discussion refer to the Abiotic specialist report (Appendix C).

A summary of the typical physical and water quality characteristics of different abiotic states in the Berg River Estuary is provided in Table 3.2 (for details refer to Abiotic Specialist Report).

Water quality characteristics in the estuary are dependent on the abiotic states that in turn, are dependent on the river inflow regime. For example, reduced river inflow from the Reference condition to present state particularly during summer, has resulted in increased intrusion of higher saline waters further upstream. In the case of the Berg River Estuary, anthropogenic influences (i.e. other than river inflow volume) have also significantly contributed to the change in water quality from

Reference condition to present state, particularly in terms of inorganic nutrients (DIN and DIP). Two main sources are evident, namely catchment development (mainly agriculture) – introducing elevated DIN and DIP concentrations during high river flows – and the fishing harbour and fish processing industry, introducing elevated nutrients to the lower reaches primarily during the summer season.

Table 3.2 Summary of hydrodynamic and water quality characteristics of different abiotic states in the Berg River Estuary. Where present day conditions differ from the Reference condition, this is indicated on the table (different colours are used to distinguish between selected concentration ranges of the different water quality parameters – refer to §3.1.1 for details).

PARAMETER	STATE 1	STATE 2	STATE 3	STATE 4	STATE 5
River flow (m^3/s)	**0.5**	0.5-1	**1-5**	**5-25**	**>25**
Mouth condition	**Open**	**Open**	**Open**	**Open**	**Open**
Inundation	No Inundation of floodplain	No Inundation of floodplain	No Inundation of floodplain	No Inundation of floodplain	**Extensive** inundation of floodplain
Salinity (ppt)	35 | 33-20 | 20-5 | 5	33 | 30-10 | 10-5 | <5	Present 33-25 | 25-5 | <5 | <5 or 33-20 | 20-5 | <5 | <5 Reference	33-5 | <5 | <5 | <5	<5 | <5 | <5 | <5
Temperature (°C)	12-20 | 20-25 | 26 | 26		13-20 | 20-25 | 24 | 24	12-18 | 12-18 | 12-18 | 12-18	
pH	7.5-8.3 | 7.5-8.3 | 7-8.5 | 7-8.5				
DO (mg/l)	4-6 | 4-6 | 4-6 | 4-6		4-6 | 4-6 | >6 | >6	>6 | >6 | >6 | >6	
Transparency (Sechhi depth in m)	>1.2 | ~0.7 | <0.2 | <0.2			~0.7 | <0.2 | <0.2 | <0.2	<0.2 | <0.2 | <0.2 | <0.2
DIN (µg/l)	~300 | ~300 | <80 | <80	~300 | <80 | <80 | <80	Present <80 | ~300 | >800 | >800 or ~300 | <80 | <80 | <80 Reference	Present 300 | >800 | >800 | >800 or <80 | <80 | <80 | <80 Reference	Present >800 | >800 | >800 | >800 or <80 | <80 | <80 | <80 Reference
DIP (µg/l)	Present >100 | ~60 | <30 | <30 or ~60 | ~60 | <30 | <30 Reference	Present >100 | <30 | <30 | <30 or ~60 | <30 | <30 | <30 Reference	Present <30 | <30 | <30 | ~60 or ~60 | <30 | <30 | <30 Reference	Present <30 | ~60 | ~60 | ~60 or <30 | <30 | <30 | <30 Reference	Present ~60 | ~60 | ~60 | ~60 or <30 | <30 | <30 | <30 Reference
DRS (µg/l)	<1000 | <1000 | <1000 | ~2000		<1000 | <1000 | ~2000 | ~2000	Present <1000 | >3000 | >3000 | >3000 or <1000 | ~2000 | ~2000 | ~2000 Reference	Present >3000 | >3000 | >3000 | >3000 or ~2000 | ~2000 | ~2000 | ~2000 Reference

NOTE: *For the purposes of this assessment the estuary was sub-divided into 4 zones representing from left to right: Zone A (0-12 km), Zone B (12-33 km), Zone C (33-45 km) and Zone D (45-70 km).*

In characterising the hydrodynamic and water quality characteristics within each abiotic state the estuary was sub-divided into four distinct zones (Figure 3-1), defined using salinity distributions and channel bathymetry.

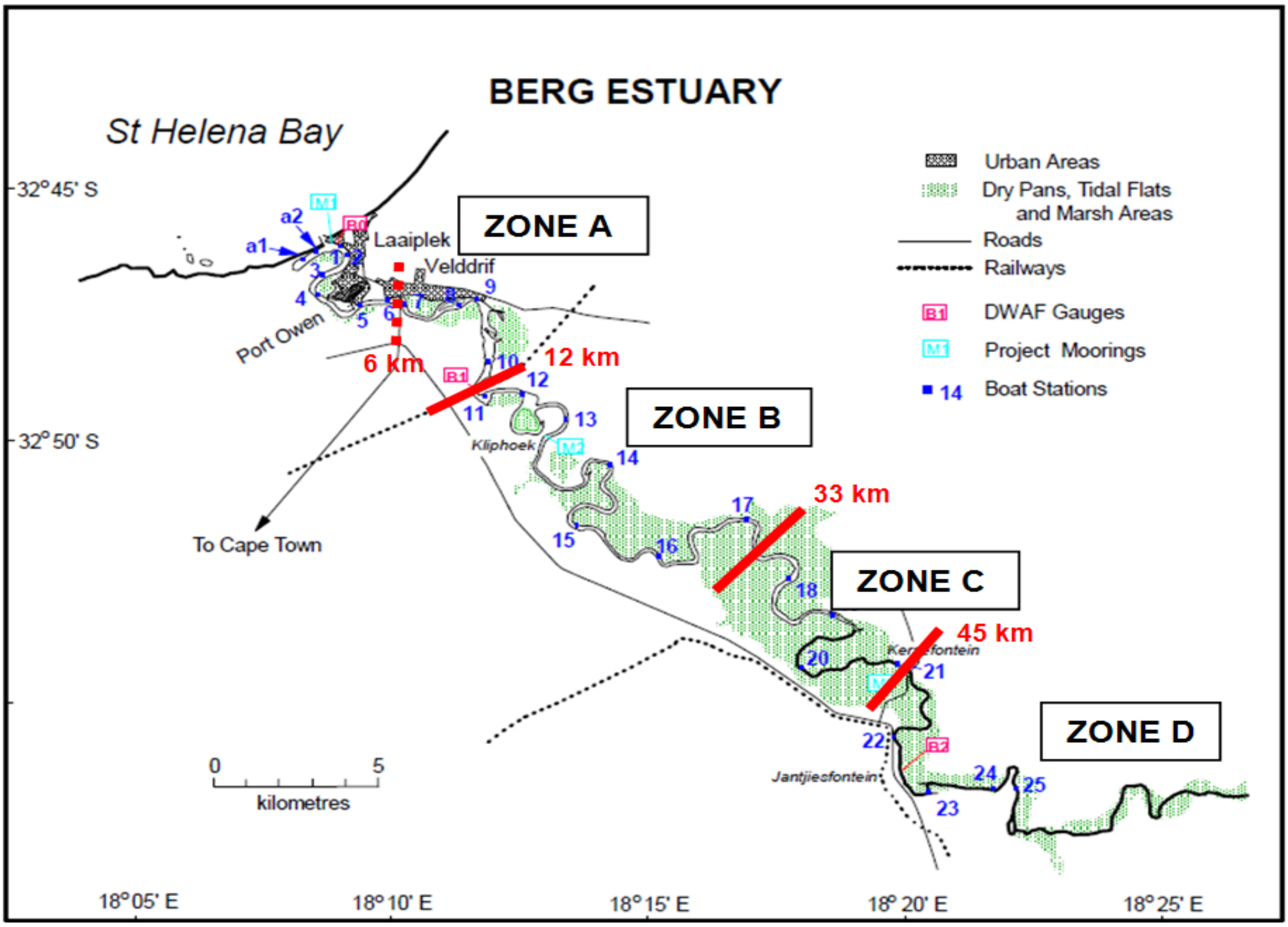


Figure 3-1 Abiotic zones identified for the Berg River Estuary (map adapted from DWAF 2007).

3.1.2 The Reference condition

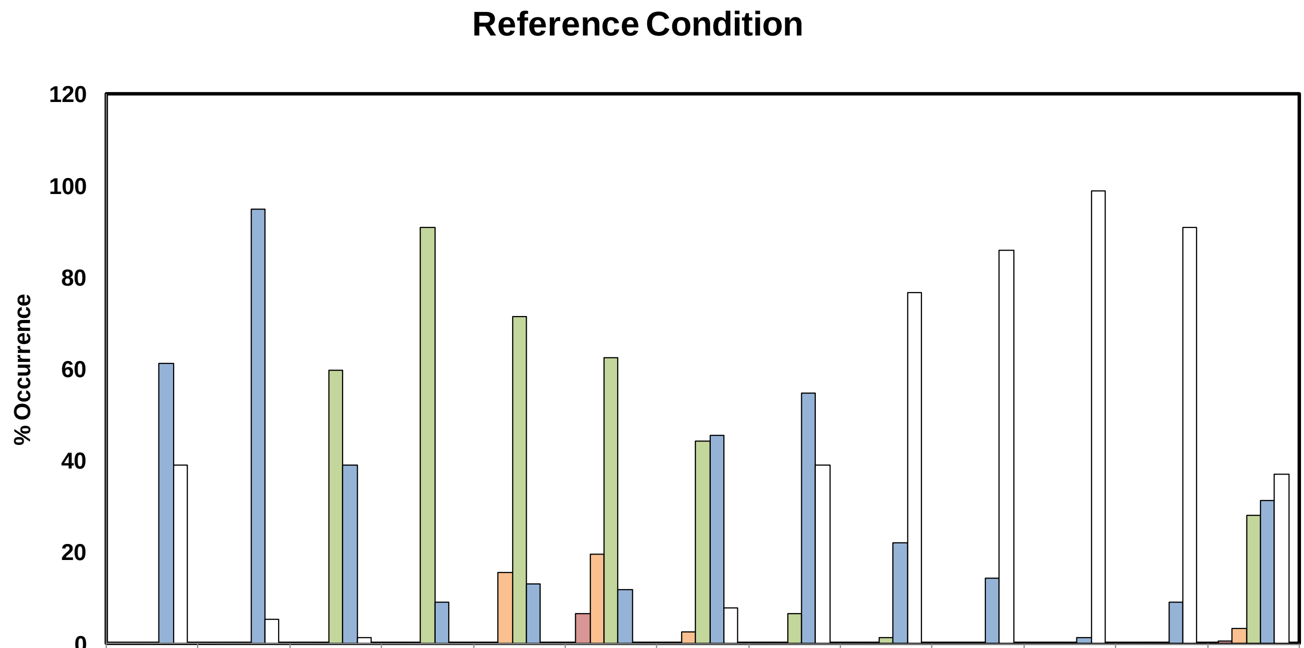
3.1.2.1 Seasonal variability in river inflow

According to the hydrological data provided for this study, under the Reference condition the MAR, into the Berg River Estuary was 916.02 Million m^3.

The flow distributions (mean monthly flows in m^{3}s^{-1}) under the Reference condition for the Berg River Estuary, derived from a 77-year simulated data set are provided in Table 3.3. A graphic representation of the percentage occurrence of the various abiotic states is presented in Figure 3-2. The full 77 years of simulated monthly runoff data for the Reference condition is provided in Table 3.4.

Table 3.3 A summary of the monthly flow (in m^3s^{-1}) distribution for the Berg River under the Reference condition.

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	53.86	42.78	24.07	13.96	12.30	15.55	49.24	134.55	197.10	226.10	233.14	137.63
95%ile	49.04	25.04	13.16	8.03	6.59	9.84	35.03	94.90	151.88	188.72	147.66	95.42
90%ile	39.57	21.20	9.12	4.99	5.47	5.69	16.98	72.81	129.50	143.53	129.15	83.35
80%ile	31.86	17.17	6.86	3.71	3.51	4.02	13.70	43.21	91.75	99.61	101.51	59.27
70%ile	28.64	14.09	5.72	2.93	2.58	3.40	9.02	29.08	67.69	88.27	82.95	51.75
60%ile	24.21	11.89	5.02	2.54	2.11	2.87	7.24	24.30	51.02	76.64	69.81	44.29
50%ile	21.48	10.53	4.54	2.35	1.54	1.78	5.94	20.97	44.27	65.02	62.56	39.31
40%ile	19.76	9.52	3.92	2.14	1.35	1.37	4.79	18.92	34.97	51.18	57.13	36.08
30%ile	18.33	8.82	3.37	1.81	1.18	1.08	3.94	14.62	27.46	41.21	45.73	31.88
20%ile	16.51	8.15	2.97	1.59	1.05	0.85	3.03	9.81	20.43	30.33	39.44	29.25
10%ile	13.81	6.98	2.61	1.45	0.90	0.58	2.09	5.53	14.61	21.54	33.53	25.07
1%ile	10.63	5.60	1.88	1.09	0.70	0.33	0.72	2.76	5.38	8.70	24.23	16.75



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0	0	0	0	0	6	0	0	0	0	0	0	0.5
State 2	0	0	0	0	16	19	3	0	0	0	0	0	3.1
State 3	0	0	60	91	71	62	44	6	1	0	0	0	28.0
State 4	61	95	39	9	13	12	45	55	22	14	1	9	31.3
State 5	39	5	1	0	0	0	8	39	77	86	99	91	37.0

Figure 3-2 Graphic presentation of the occurrence of the various abiotic states under the Reference conditions

Table 3.4 Simulated monthly flows to the Berg River Estuary for the Reference Condition (m^3s^{-1})

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1928	19.38	8.14	3.01	1.43	0.81	0.51	7.39	22.89	26.43	66.83	60.66	33.34	21.71
1929	16.10	7.45	4.00	2.55	2.13	2.23	3.31	2.78	2.82	18.40	30.34	79.63	15.91
1930	31.91	12.91	4.61	1.59	1.11	0.68	11.29	21.18	18.87	21.49	67.14	65.35	22.33
1931	32.07	12.36	3.19	1.74	16.85	9.31	2.31	27.29	50.10	47.39	43.07	36.05	24.44
1932	21.22	8.19	2.57	1.44	1.14	0.89	1.26	10.98	69.50	100.57	65.86	32.79	26.55
1933	21.15	10.06	3.18	1.75	1.13	2.21	2.49	20.55	20.05	22.62	25.99	33.63	15.01
1934	31.64	17.99	5.13	1.71	1.04	1.40	9.57	18.72	25.21	44.83	51.23	41.75	21.64
1935	19.45	9.85	3.54	4.20	2.58	1.41	1.60	11.62	12.44	19.32	40.29	48.19	15.77
1936	26.46	8.72	5.80	3.75	1.38	3.54	10.52	20.97	92.79	116.70	52.15	26.84	31.10
1937	15.55	7.45	2.19	2.95	1.97	0.80	14.10	25.67	24.11	30.30	37.23	42.19	18.26
1938	22.45	11.30	4.01	1.58	3.11	1.77	4.97	32.20	21.94	21.17	57.21	35.34	19.27
1939	16.41	8.09	4.13	1.89	5.33	4.04	8.88	16.64	50.56	40.05	32.62	26.71	19.24
1940	18.18	13.09	5.04	5.78	3.85	1.13	36.10	94.63	131.68	116.86	112.10	156.22	58.44
1941	51.79	17.05	4.54	2.02	1.09	0.53	1.39	44.81	195.79	79.45	94.55	36.54	44.27
1942	19.52	9.46	2.61	2.35	2.34	3.24	4.80	7.05	19.53	59.84	97.26	55.84	24.17
1943	26.79	15.85	5.70	1.90	1.05	0.73	6.62	36.81	133.77	95.77	119.70	55.46	42.36
1944	30.04	15.08	8.34	3.20	1.06	0.48	4.41	76.41	143.54	181.95	124.36	39.14	52.29
1945	15.80	8.68	3.27	1.50	0.89	1.01	4.99	12.23	14.67	30.42	49.35	95.20	21.09
1946	45.64	14.75	3.91	1.50	0.81	4.43	4.26	14.85	16.08	102.43	62.65	28.24	25.91
1947	19.66	10.39	2.88	1.23	1.13	5.85	8.20	28.98	36.99	80.76	57.68	64.10	27.51
1948	38.62	13.93	3.82	1.68	0.95	0.48	7.92	9.15	19.77	41.23	58.40	41.28	20.60
1949	29.64	21.16	8.81	2.28	1.04	0.51	31.33	16.48	13.12	140.16	49.51	51.97	31.31
1950	35.10	22.12	10.42	4.38	2.53	0.84	34.77	19.88	124.39	90.60	64.45	42.94	37.92
1951	24.94	17.38	6.14	1.68	1.02	1.09	5.46	29.47	34.87	58.95	135.42	91.75	34.23
1952	30.85	23.02	9.52	2.12	0.98	0.62	60.43	95.94	50.72	94.47	131.79	39.59	45.27
1953	14.67	11.21	5.66	2.40	1.42	1.23	18.77	129.24	72.71	225.46	177.48	51.81	59.41
1954	21.48	10.40	4.23	2.31	10.86	5.63	3.42	3.77	25.52	77.06	203.52	59.52	35.72
1955	30.43	21.13	6.38	2.25	1.29	0.98	4.37	20.53	76.59	88.73	104.17	39.31	33.61
1956	17.98	7.86	2.71	1.58	9.31	6.61	4.15	91.60	98.10	152.62	113.80	45.19	46.49
1957	53.03	26.09	3.77	1.25	5.94	2.93	2.52	32.37	28.72	18.38	44.19	29.22	21.85
1958	15.84	8.87	2.79	1.27	0.88	0.75	14.34	151.39	51.22	21.58	36.49	30.92	29.06
1959	21.70	11.28	2.83	1.45	0.83	1.23	3.67	25.89	63.84	31.07	18.63	15.46	17.97
1960	10.69	5.47	1.91	1.62	1.23	0.77	1.56	9.73	47.51	33.69	57.08	73.71	21.54
1961	28.39	8.08	2.00	1.00	1.48	3.61	12.71	10.12	201.27	88.15	141.20	48.41	45.88
1962	49.19	24.77	5.13	1.67	0.78	0.33	0.73	2.68	13.29	47.28	113.26	52.63	26.99
1963	17.56	12.19	6.63	2.39	6.55	2.84	2.28	8.85	45.93	52.23	66.82	37.96	23.21
1964	22.42	17.20	6.16	2.30	4.55	11.97	13.32	31.10	32.18	25.72	48.08	25.08	21.69
1965	12.74	6.49	2.93	1.55	0.67	12.00	8.43	7.78	27.31	82.85	61.83	36.12	23.14
1966	17.31	5.88	1.76	1.12	0.71	0.32	15.17	17.74	87.61	50.29	34.49	29.36	23.13
1967	22.78	11.84	5.30	3.13	1.95	1.01	15.95	47.60	64.67	89.62	74.65	32.11	31.76
1968	40.10	18.46	4.85	4.38	2.18	1.01	4.78	4.70	17.22	21.85	34.33	38.58	17.63
1969	26.68	10.96	3.38	1.33	0.95	0.46	0.68	24.32	61.26	65.02	71.96	45.90	26.92
1970	21.23	8.55	4.10	1.96	1.32	1.74	2.42	5.17	16.66	42.21	57.99	29.64	17.51
1971	10.82	5.64	2.26	1.47	2.08	1.23	6.59	19.37	29.38	29.99	32.11	24.48	15.16
1972	13.02	5.72	4.54	2.09	1.07	2.13	1.80	5.63	6.19	60.48	44.16	29.44	15.63
1973	18.72	7.35	6.89	2.89	1.54	0.99	1.22	26.99	79.08	38.92	326.92	82.05	48.83
1974	35.64	18.60	6.31	3.29	1.98	1.36	8.24	70.41	41.11	85.49	62.56	25.06	30.37
1975	18.37	9.52	3.95	2.17	1.40	1.25	8.23	7.19	114.97	94.59	52.44	29.35	28.89
1976	15.79	53.62	33.29	14.68	5.15	3.52	17.46	79.45	161.87	197.90	173.54	54.38	67.87
1977	25.02	9.66	6.72	2.86	2.04	2.38	7.01	13.77	9.03	6.65	37.56	38.14	14.84
1978	21.15	9.34	3.84	2.75	4.45	3.47	2.34	19.21	47.00	26.34	33.65	25.65	17.41
1979	39.22	11.88	3.38	3.34	2.39	1.64	7.62	28.74	39.26	20.95	27.45	17.15	18.08
1980	13.01	32.45	21.16	13.73	6.08	4.17	4.17	5.39	14.51	68.87	76.55	76.22	31.01
1981	20.93	10.53	9.11	8.89	4.26	4.95	14.23	20.19	42.33	38.98	39.89	19.43	23.63
1982	23.00	9.70	8.46	5.00	4.81	4.92	3.16	65.61	118.53	120.30	45.92	50.65	40.43
1983	19.52	6.77	3.06	1.82	1.35	3.82	3.67	121.82	27.50	74.09	39.33	68.74	33.86
1984	45.45	11.64	12.79	7.81	5.67	22.64	13.80	19.78	79.53	109.27	88.18	36.31	37.60
1985	17.90	8.56	4.72	2.40	1.25	3.08	10.77	21.32	58.05	84.03	127.39	51.37	35.97
1986	17.24	8.31	3.30	4.14	2.88	2.88	3.99	47.65	59.83	74.84	102.07	51.74	33.26
1987	22.67	9.42	7.07	2.74	1.32	1.78	13.97	23.12	44.27	50.49	44.96	47.48	26.22
1988	18.62	9.20	2.96	1.98	2.61	13.31	11.39	24.25	32.03	67.58	82.76	85.29	31.17
1989	29.67	16.24	5.33	2.37	3.16	1.53	45.71	56.52	69.01	148.58	71.78	23.78	42.80
1990	11.35	6.05	3.77	2.35	1.85	1.55	3.04	27.76	94.23	186.75	77.31	90.51	44.46
1991	33.97	16.26	7.28	4.98	6.78	5.78	16.67	23.17	149.38	105.46	43.39	40.03	42.99
1992	49.00	18.87	9.13	3.97	2.39	1.17	42.43	56.66	65.46	228.13	69.30	26.03	49.55
1993	13.77	5.91	2.85	2.43	2.26	4.25	6.70	8.73	167.62	70.84	29.52	29.54	30.00
1994	20.00	9.53	4.04	2.92	2.65	4.23	2.30	14.83	35.12	90.89	83.72	26.35	26.00
1995	36.56	11.94	14.64	4.61	3.60	3.96	4.92	11.16	100.93	76.01	88.97	131.76	43.74
1996	56.51	39.36	19.31	5.00	2.74	3.67	4.81	10.88	128.05	41.13	62.82	30.06	39.14
1997	10.44	13.22	5.29	3.32	1.30	2.86	6.02	59.53	37.92	60.30	33.34	20.39	23.90
1998	13.83	21.26	8.56	2.34	1.75	2.92	6.47	16.99	42.81	61.33	99.26	96.33	34.16
1999	25.77	8.85	3.06	3.54	1.37	3.04	3.02	18.00	25.19	48.63	36.57	58.29	24.74
2000	16.91	7.12	2.60	2.63	1.52	2.92	4.44	29.85	31.50	196.62	136.34	104.34	48.39
2001	30.83	14.92	4.99	8.93	3.10	3.38	6.22	32.74	48.01	88.10	71.23	33.96	30.99
2002	27.19	11.91	4.87	2.21	1.19	2.53	3.73	5.06	6.22	9.35	70.16	41.44	17.97
2003	23.12	9.31	4.60	2.53	1.34	0.95	5.30	4.26	28.14	29.87	62.37	18.11	19.55
2004	19.93	8.67	2.52	2.66	0.91	0.79	5.94	23.53	67.36	53.11	93.10	33.85	30.94

State 1	< 0.5	State 2	0.5-1	State 3	1 - 5	State 4	5 - 25	State 5	>25

3.1.2.2 Reference flood regime

Table 3.5 summarises the occurrence of floods in the Berg River Estuary under Reference Conditions, based on simulated monthly data. The flood analyses were based on an average lowflow of about 35 m^3s^{-1}, i.e. very lowflow conditions. About 81% of the floods experienced under the Reference condition occurred between June and September, with 24% of these in August.

Table 3.5 Occurrence of floods in the Berg River Estuary under the Reference condition based on simulated monthly data.

Flood size (Daily average flow in m^3s^{-1})	Volume (Mm3)	Flood area and duration		
		Area (ha)	Area (%)	Duration (days)
100	15	3789.4	54.7	5-7
200	42	4347.1	62.7	5-10
300	65	5000.8	72.2	7-10
400	96	5471.1	79.0	7-14
500	125	5810.1	83.9	10-14
600	149	6149.6	88.8	10-15
800	203	6692.4	96.6	10-20
1000	257	6927.9	100.0	10-20

Table 3.6 Occurrence of floods and extent of floodplain inundation under the Reference Condition based on simulated monthly flow data for a 77-year period.

Flood size (Daily average flow in m^3s^{-1})	Area (ha)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	% Occurrence/ flood size class	% Floodplain inundated	% Occurrence/
100-200	3789.4	14	1	1	0	0	0	3	9	9	6	12	24	6.2	50-70	13
200-300	4347.1	5	1	0	0	0	0	2	1	8	7	9	11	8.5		
300-400	5000.8	5	1	0	0	0	0	0	4	6	7	10	12	4.8	70-80	9
400-500	5471.1	0	0	0	0	0	0	1	2	7	9	11	3	4.9		
500-600	5810.1	0	0	0	0	0	0	0	2	4	5	8	3	3.6	80-90	6
600-800	6149.6	0	0	0	0	0	0	0	4	5	14	7	6	2.4		
800-1000	6692.4	0	0	0	0	0	0	0	0	2	6	6	1	3.9	>90%	6
>1000	6927.9	0	0	0	0	0	0	0	3	10	10	11	2	1.6		
Annual % occurrence		8	1	0	0	0	0	2	8	16	21	24	20			34

Table 3.6 summarises the extent of inundation of the floodplain for the 77-year Reference Conditions simulation. Under these conditions, the floodplain would have been inundated for c. 34% of the months. Ninety to 100% of the floodplain would have been inundated for *c*. 6 % of the months; 80 to 90% for *c*. 6% of the months; 70 to 80% for *c*. 9% of the months; and 50 to 70% for *c*. 13 % of the months. Floods with flows between 100 and 300 m^3s^{-1} result in the 50-70% inundation levels. The effect of these size-class floods is relatively sensitive to antecedent conditions, i.e. whether they arrive as a single event or as a combination of pulses. The latter significantly increases the extent of inundation, e.g., from 50% to 60%. Under natural conditions,

these floods would have fairly gradual rising and falling arms, and would have arrived in a mixture of discrete and combined floods, however, water-resource developments in a catchment tend to reduce complex flood patterns to short, sharp pulses. Thus, for the EWR study, for comparative reasons, the assumption was made that flood peaks are discreet. The net result of this is that smaller floods (i.e. those with daily average flows smaller than 300 m^3s^{-1}) under present day and future floods conditions are likely to inundate a smaller area and for a shorter period than those of a comparable magnitude under reference conditions. While this has not been tested empirically (i.e. by running a set of scenarios to characterise the changes in flood inundation that would occur if a changing sequence of flood peaks occurred and not discrete flood events), this has been inferred from the changes in flood hydrograph shapes or sequencing from some of the preliminary results and the results of Beck and Basson (2007) who simulated a period of flooding (i.e. a sequence of floods in a winter period).
Confidence: Medium

3.1.2.3 Reference lowflows

On average, winter lowflows, occurring between June and July, would have inundated *c*. 37 % of the floodplain under the Reference condition, compared with *c.* 35 % under the present state.

3.1.2.4 Droughts

Hydrological drought conditions in the Berg River Estuary are defined as years in which the annual inflow (million m^3) fell below the Reference condition 10%ile, i.e. 506 million m^3. Figure 3-3 illustrates that this condition occurred *c*. 14 times, i.e., 18% of the time. However, it rarely lasted for more than one consecutive year (on only three occasions did it last for 2-3 consecutive years). Importantly, in none of these periods did the MAR drop below 450 million m^3.

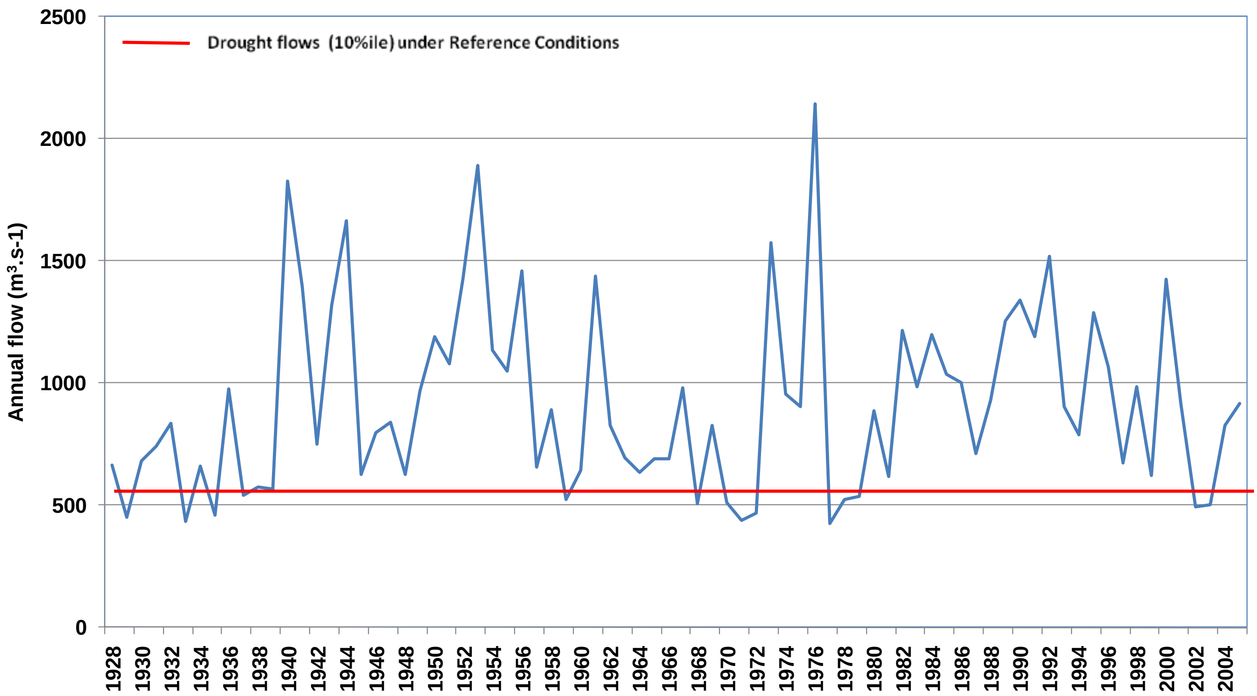


Figure 3-3 Drought conditions in the Berg River Estuary under the Reference Condition

3.1.2.5 Reference sediment processes

Intertidal sand and mudflats under Reference condition would have occupied approximately 133 ha in the estuary, most of which would have been found in lower (56% or 74 ha) estuary with the remainder split between the middle (29% or 39 ha) and upper estuary (15% or 20 ha). Periodic floods would have restricted build-up of riverine sediment in the estuary and restricted the ingress of marine sediment into the system, or at least would have flushed these out on a regular basis.
Confidence: Low.

3.1.3 Present state

3.1.3.1 Seasonal variability in river inflow

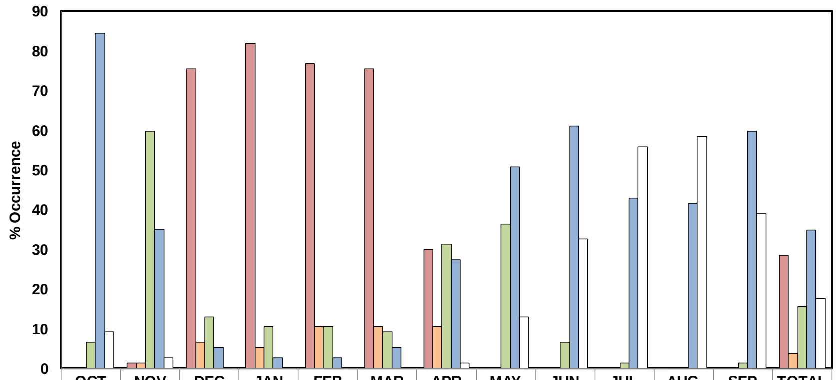
According to the hydrological data provided for this study, the present day MAR into the Berg River Estuary is 520.38 Million m^3. This is a reduction of 46% compared to the natural MAR of 963.76 Million m^3.

The occurrences of flow distributions (mean monthly flows in m^3s^{-1}) for the present state of the Berg River Estuary, derived from a 77-year simulated data set, are provided in Table 3.7. A graphic representation of the occurrence of the various abiotic states is presented in Figure 3-4. The full 77-year series of simulated monthly runoff data for the present state is provided in Table 3.8.

Table 3.7 A summary of the monthly flow (in m^3s^{-1}) distribution under the present state.

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	46.97	30.38	14.58	5.30	7.03	8.36	23.43	64.98	120.14	220.34	185.50	139.78
95%ile	35.07	13.58	4.01	2.80	2.01	4.95	12.30	43.24	86.39	140.93	135.57	91.40
90%ile	22.06	12.70	2.71	1.46	1.24	1.81	7.51	29.83	63.86	114.04	117.06	54.26
80%ile	15.53	8.51	0.90	0.34	0.66	0.62	5.61	13.83	37.23	60.90	85.14	38.81
75%ile	13.31	7.61	0.48	0.30	0.40	0.49	5.33	11.87	35.96	54.02	69.25	35.74
70%ile	11.56	6.26	0.30	0.30	0.30	0.30	3.91	10.26	31.42	46.06	55.93	32.27
60%ile	9.69	4.88	0.30	0.30	0.30	0.30	2.08	8.59	19.69	36.07	44.29	23.95
50%ile	8.28	4.02	0.30	0.30	0.30	0.30	1.42	6.90	16.13	27.74	28.66	20.15
40%ile	7.56	3.74	0.30	0.30	0.30	0.30	1.00	5.43	11.46	21.97	22.95	15.90
30%ile	6.69	3.31	0.30	0.30	0.30	0.30	0.53	4.33	9.78	17.19	19.04	14.13
25%ile	6.57	3.13	0.30	0.30	0.30	0.30	0.38	3.95	8.60	14.29	17.33	11.31
20%ile	6.22	2.73	0.30	0.30	0.30	0.30	0.31	3.43	7.75	13.22	15.91	11.00
10%ile	5.22	2.32	0.30	0.30	0.30	0.30	0.30	2.73	6.19	8.81	11.34	8.44
1%ile	3.79	0.62	0.30	0.30	0.30	0.30	0.30	1.49	3.61	4.67	7.28	4.83

1. Extreme marine	2. Marine dominated	3. Small pulse	4. Large pulse	5. Freshwater dominated



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0	1	75	82	77	75	30	0	0	0	0	0	28.4
State 2	0	1	6	5	10	10	10	0	0	0	0	0	3.7
State 3	6	60	13	10	10	9	31	36	6	1	0	1	15.5
State 4	84	35	5	3	3	5	27	51	61	43	42	60	34.8
State 5	9	3	0	0	0	0	1	13	32	56	58	39	17.6

Figure 3-4 Graphic illustration of the occurrence of the various abiotic states under the present state

Table 3.8 Simulated monthly flows to the Berg estuary for the present state ($m^3.s^{-1}$).

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1928	6.49	3.09	0.30	0.30	0.30	0.30	1.65	7.58	9.79	25.47	21.96	15.24	8.23
1929	6.71	2.65	0.30	0.30	0.38	0.30	0.30	1.50	3.06	5.22	8.35	37.09	6.15
1930	8.61	5.53	0.30	0.30	0.30	0.30	5.39	5.92	8.04	7.01	25.35	23.57	8.13
1931	11.79	4.95	0.30	0.30	11.42	4.91	0.38	12.44	18.75	19.68	16.79	15.00	10.39
1932	8.32	3.48	0.30	0.30	0.30	0.30	0.30	2.57	27.62	39.94	48.10	22.20	13.29
1933	9.85	3.81	0.30	0.30	0.30	0.30	0.36	5.37	6.31	7.53	9.96	11.24	5.26
1934	8.72	9.32	0.30	0.30	0.30	0.30	3.89	5.32	9.76	17.37	16.95	14.88	7.95
1935	7.87	4.02	0.30	0.30	0.30	0.30	0.30	3.90	4.46	5.87	11.38	14.18	4.99
1936	7.61	3.76	0.71	0.75	0.30	1.05	3.30	5.18	37.92	59.78	32.16	15.65	14.77
1937	6.96	2.63	0.30	0.30	0.30	0.30	6.43	6.42	8.52	13.07	11.79	15.03	6.53
1938	7.79	4.10	0.30	0.30	0.30	0.30	0.47	7.71	7.74	11.43	22.41	11.06	6.75
1939	5.98	2.71	0.30	0.30	0.58	0.30	3.57	4.52	19.76	17.25	13.77	10.99	7.28
1940	7.10	4.51	0.30	1.54	1.13	0.30	11.38	42.10	72.78	111.90	106.87	147.30	42.93
1941	30.96	8.68	0.30	0.30	0.30	0.30	0.30	14.11	114.90	55.42	86.28	23.11	28.47
1942	10.13	3.82	0.30	0.30	0.66	0.57	1.02	2.83	6.77	24.32	34.89	35.73	10.76
1943	12.97	7.00	0.30	0.30	0.30	0.30	1.13	9.48	59.96	67.12	120.27	42.95	27.49
1944	15.56	6.82	0.40	0.30	0.30	0.30	0.86	32.53	77.94	168.30	122.61	24.21	38.18
1945	7.51	3.55	0.30	0.30	0.30	0.30	0.64	4.20	6.01	13.91	18.56	47.58	9.12
1946	15.43	6.29	0.30	0.30	0.30	1.01	1.19	4.12	6.71	54.76	22.39	11.67	11.00
1947	7.66	4.29	0.30	0.30	0.30	5.08	5.32	6.90	10.53	37.24	21.54	32.25	11.57
1948	18.74	6.06	0.30	0.30	0.30	0.30	1.96	3.12	7.81	15.85	21.68	14.40	8.14
1949	9.28	12.67	2.89	0.30	0.30	0.30	16.71	3.83	6.64	83.00	17.33	25.93	15.61
1950	18.84	12.75	3.04	1.41	0.67	0.30	9.05	4.77	68.08	61.18	48.19	29.86	22.25
1951	11.78	7.78	0.30	0.30	0.30	0.30	0.43	7.61	11.34	22.32	84.43	76.53	19.29
1952	14.81	12.96	2.60	0.30	0.30	0.30	37.35	47.80	20.26	75.26	131.63	22.06	31.14
1953	6.98	4.89	0.59	0.30	0.30	0.30	6.13	56.31	34.08	228.90	168.16	33.87	45.77
1954	11.01	4.44	0.30	0.30	4.27	1.78	1.01	2.33	8.60	27.74	151.32	41.92	21.98
1955	19.59	9.96	0.32	0.30	0.30	0.30	0.30	6.28	30.85	44.89	78.33	22.30	18.47
1956	8.28	2.82	0.30	0.30	5.64	3.20	1.68	39.66	48.42	133.32	114.92	32.02	33.19
1957	42.83	13.51	0.30	0.30	0.37	0.30	0.35	11.09	9.80	11.53	17.58	10.56	10.56
1958	6.55	3.85	0.30	0.30	0.30	0.30	6.84	83.87	18.33	16.98	26.75	19.47	15.86
1959	11.50	5.39	0.30	0.30	0.30	0.30	0.99	7.82	21.37	14.29	9.69	7.07	7.18
1960	4.50	1.79	0.30	0.30	0.30	0.30	0.30	2.64	16.28	13.81	23.75	30.33	8.39
1961	10.01	3.54	0.30	0.30	0.30	0.47	5.87	3.33	115.71	42.12	129.37	33.13	29.28
1962	38.25	12.78	0.63	0.30	0.30	0.30	0.30	1.48	5.57	12.02	52.10	26.47	13.14
1963	7.52	6.25	1.05	0.33	0.64	0.30	0.48	2.81	16.13	18.91	28.90	20.95	9.46
1964	10.24	8.97	0.94	0.30	2.20	4.74	5.50	7.19	10.79	12.36	20.20	8.39	8.43
1965	5.20	2.38	0.30	0.30	0.30	1.85	2.27	2.90	8.79	31.78	22.17	18.56	8.66
1966	6.62	2.24	0.30	0.30	0.30	0.30	5.64	4.00	35.78	18.48	15.74	14.33	9.14
1967	7.93	4.86	0.30	0.30	0.30	0.30	6.43	13.59	19.94	43.97	66.75	18.81	15.92
1968	28.68	9.21	0.30	0.30	0.30	0.30	1.87	2.42	5.32	5.74	9.02	10.79	6.86
1969	7.79	4.77	0.30	0.30	0.30	0.30	0.30	6.06	19.58	22.42	25.65	19.86	9.44
1970	9.69	3.53	0.30	0.30	0.30	0.30	0.54	1.75	4.62	13.92	16.57	9.67	5.71
1971	5.23	1.65	0.30	0.30	0.30	0.30	2.90	4.36	9.28	7.94	9.09	8.47	4.69
1972	5.16	1.67	0.30	0.30	0.30	0.30	0.30	1.95	3.79	21.74	12.05	10.45	5.54
1973	6.79	2.56	0.30	0.30	0.30	0.30	0.30	13.89	33.71	18.13	240.39	49.65	31.13
1974	19.44	7.85	0.35	0.35	0.30	0.30	2.86	23.12	11.70	35.23	42.56	13.93	13.90
1975	6.95	3.13	0.30	0.30	0.30	0.30	8.52	3.12	40.44	43.72	32.91	16.27	13.61
1976	5.97	34.09	13.44	5.42	1.09	0.65	5.11	25.37	134.17	194.65	161.65	35.79	52.24
1977	9.68	3.49	1.23	0.30	0.30	0.91	2.96	3.18	4.43	2.91	7.42	7.99	4.50
1978	5.48	2.54	0.30	0.30	0.30	0.30	0.30	4.73	17.29	10.28	11.28	11.31	5.95
1979	9.28	3.79	0.30	1.28	0.30	0.30	1.14	11.68	11.13	9.39	6.82	3.97	5.59
1980	2.73	16.08	7.89	3.69	1.86	0.30	0.30	3.85	6.40	29.77	46.75	45.19	14.49
1981	5.98	3.02	2.32	3.81	0.85	5.65	11.76	10.56	13.01	15.78	19.07	5.10	8.87
1982	7.86	4.28	0.97	0.81	0.85	0.71	0.30	16.29	50.62	117.25	33.99	39.27	23.54
1983	6.26	1.55	0.30	0.30	0.30	0.53	0.36	59.02	7.34	51.92	28.66	61.18	18.71
1984	34.28	2.87	2.88	1.82	1.40	16.96	6.33	5.51	36.92	77.73	68.69	17.20	23.51
1985	4.93	1.94	0.30	0.30	0.30	0.30	3.99	10.29	16.95	53.77	107.20	44.08	20.97
1986	5.53	2.41	0.30	0.30	0.30	0.30	0.54	16.33	21.81	33.06	89.97	37.73	17.99
1987	9.74	3.16	0.30	0.30	0.30	0.30	5.40	9.54	20.99	27.80	18.90	39.08	11.98
1988	5.84	3.33	0.30	0.30	0.30	5.42	5.25	9.01	10.24	30.08	38.00	89.31	17.03
1989	12.61	7.56	0.30	0.30	0.68	0.30	14.45	34.50	37.68	127.34	85.31	11.93	28.39
1990	4.32	0.37	0.30	0.30	0.30	0.30	0.30	10.18	37.01	106.47	85.59	99.76	29.29
1991	20.44	7.83	0.30	0.30	0.45	0.32	5.85	9.09	83.51	109.54	28.05	32.35	25.59
1992	45.17	10.11	1.41	0.30	0.30	0.30	19.03	15.36	36.52	217.64	65.26	11.04	35.90
1993	5.21	0.71	0.30	0.30	0.30	0.30	1.11	5.58	61.06	50.74	14.89	10.54	13.23
1994	6.46	3.20	0.30	0.30	0.30	0.62	0.30	6.79	9.92	36.64	55.26	8.35	11.35
1995	24.48	5.52	18.17	1.82	0.99	0.42	1.08	4.89	36.49	52.92	70.91	137.41	30.39
1996	52.67	29.21	8.68	2.58	1.96	0.97	1.42	7.55	97.89	26.54	45.46	22.06	25.54
1997	4.12	3.73	0.30	0.96	0.30	0.30	0.77	28.03	13.11	29.78	14.81	5.89	9.25
1998	6.59	13.87	2.93	0.30	0.30	0.30	1.61	9.22	14.33	26.08	58.63	75.49	18.22
1999	17.20	3.81	0.30	0.41	0.30	0.45	0.30	7.96	18.56	20.69	13.85	30.52	10.25
2000	6.21	2.63	0.30	0.59	0.30	0.30	0.69	9.16	11.64	134.09	112.96	121.13	34.00
2001	16.04	8.95	1.15	5.26	1.95	0.62	1.44	13.47	15.68	43.45	47.50	20.15	15.43
2002	14.33	5.81	0.45	0.30	0.30	0.30	0.99	3.95	6.83	7.59	26.10	10.24	7.18
2003	6.57	3.98	0.30	0.30	0.30	0.30	2.16	2.78	14.16	11.98	27.59	6.81	7.09
2004	9.10	3.72	0.30	0.30	0.30	0.30	1.46	10.26	37.29	25.43	45.43	19.41	13.35

State 1 < 0.5 State 2 0.5-1 State 3 1 - 5 State 4 5 - 25 State 5 >25

3.1.3.2 Present flood regime

Table 3.9 and Table 3.10 summarise the occurrence of floods in the Berg River Estuary under the present state based on simulated monthly data. The flood analyses were based on an average winter lowflow of about 12 m^3s^{-1}, i.e. low winter low flow conditions. (On average low flows occurring between June and July will inundate about 35% of the floodplain). About 82% of the floods experienced under the present state occurred between June and September, with 24% of these in August. In total the floodplain experienced some inundation for 30% of the months under the present state. For about 4% of the months in the 77-year simulation period, floods inundated between 90 to 100% of the floodplain. Similarly for about 3% of the months, floods inundated between 80 and 90% of the floodplain (Figure 3-5, while between 70 and 80% of the floodplain were inundated in ~7% of the months in the simulation period (Figure 3-6). Between 50 and 70% of the flood plain will be inundated for about 16 % of the months. Floods with daily average flows of between 100 to 300 m^3s^{-1} (Figure 3-7 and Figure 3-8) result in these lower levels of inundation.

Table 3.9 Occurrence of floods in the Berg River under the present state based on simulated monthly data.

Flood size (Daily average flow in m^3s^{-1})	Volume (M m^3)	Flood area and duration		
		Area (ha)	Area (%)	Duration (days)
100	15	3521.1	50.8	5 - 7
200	42	4329.5	62.5	5 - 10
300	65	4901.3	70.7	7 - 10
400	96	5393.1	77.8	7 - 14
500	125	5759.3	83.1	10 - 14
600	149	6105.2	88.1	10 - 15
800	203	6684.2	96.5	10 - 20
1000	257	6827.4	98.5	10 - 20

Table 3.10 Occurrence of floods and extend of floodplain inundation under the present state based on simulated monthly flow data for a 77-year period

Flood size (Daily average flow in	Area (ha)	No of floods in month during simulated 77 year period												% Occurrence /flood size class	% inundation	% Occurrence
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep			
100-200	3521.1	11	3	2	0	0	1	3	8	17	18	20	24	12	50-70	16
200-300	4329.5	3	1	0	0	0	0	0	2	2	10	9	9	4		
300-400	4901.3	3	1	0	0	0	0	1	4	11	7	6	11	5	70-80	7
400-500	5393.1	2	0	0	0	0	0	0	1	2	8	7	3	2		
500-600	5759.3	0	0	0	0	0	0	0	2	2	4	2	1	1	80-90	3
600-800	6105.2	0	0	0	0	0	0	0	0	4	4	5	2	2		
800-1000	6684.2	0	0	0	0	0	0	0	1	1	0	5	2	1	>90 %	4
>1000	6827.4	0	0	0	0	0	0	0	0	3	11	12	3	3		
Annual % occurrence		7	2	1	0	0	0	1	7	15	23	24	20			30

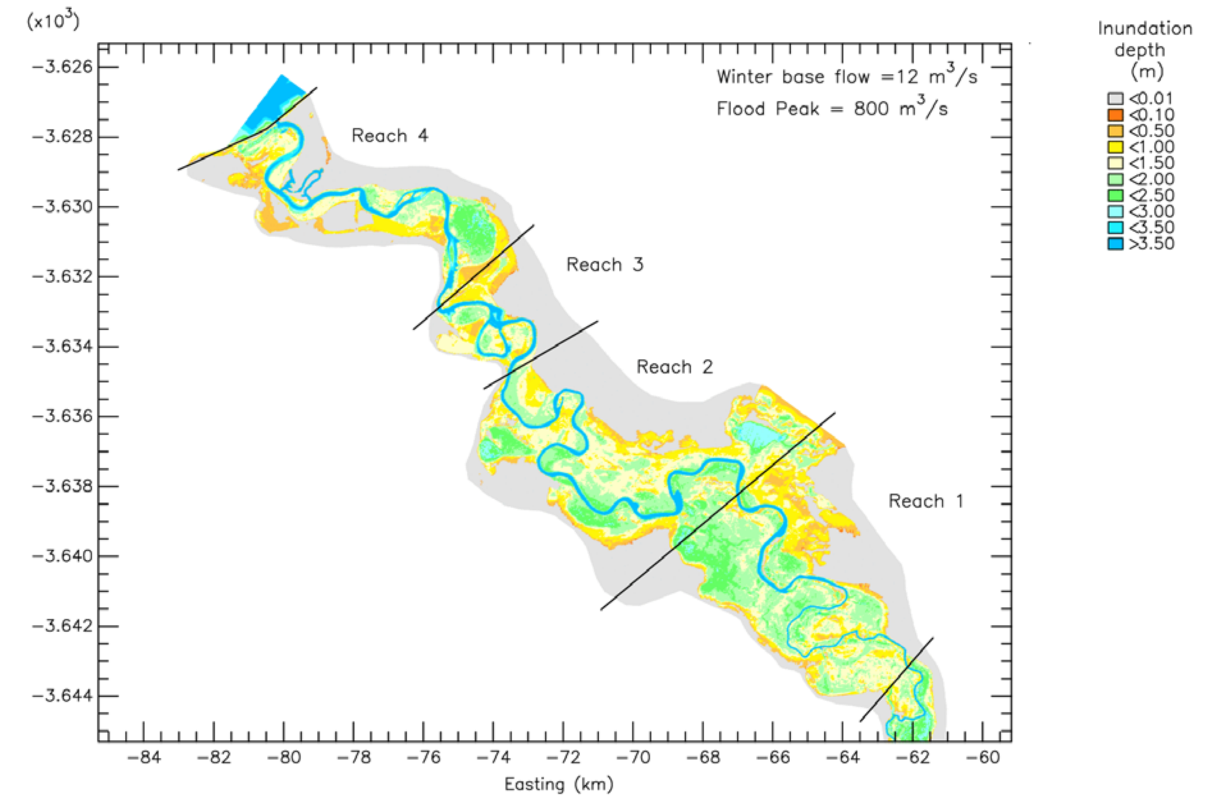


Figure 3-5 Flood extent for an 800 m^3s^{-1} flood under present-day low flow conditions.

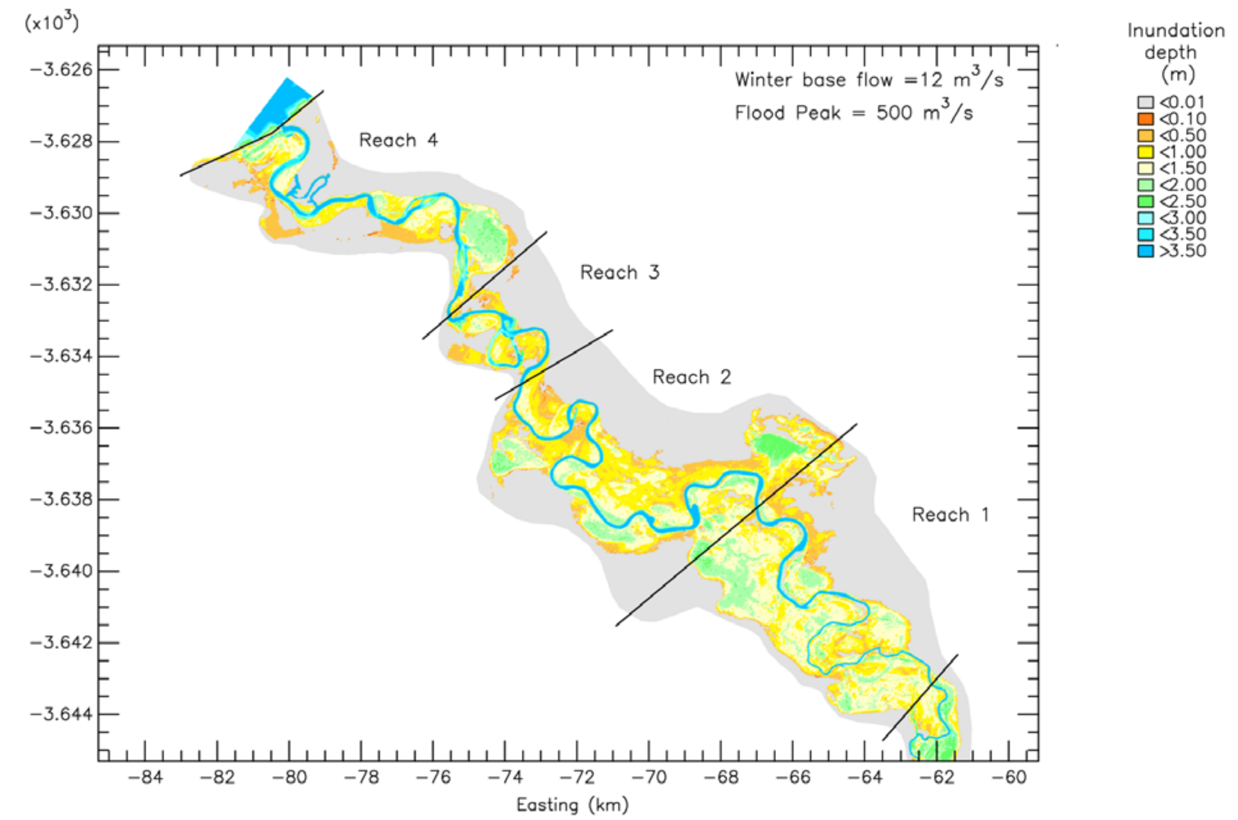


Figure 3-6 Flood extent for a 500 m^3s^{-1} flood under present-day low flow conditions.

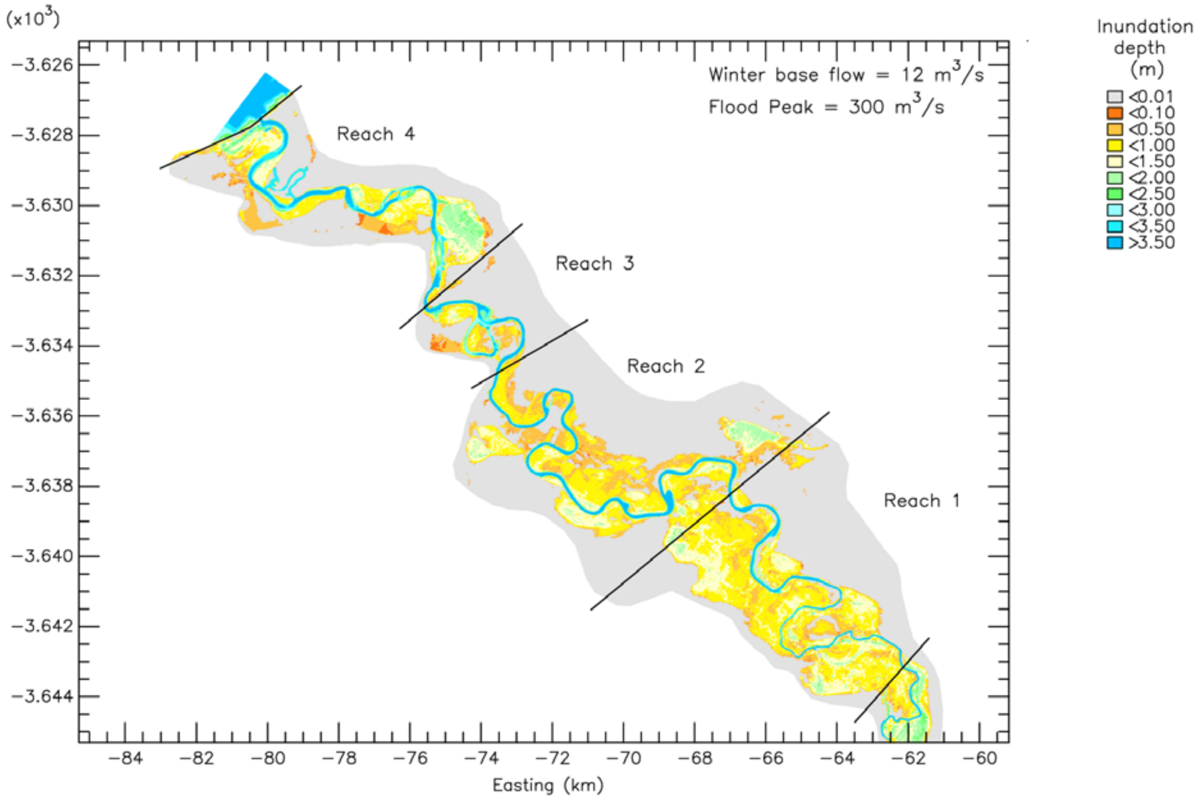


Figure 3-7 Flood extent for a 300 m^3s^{-1} flood under present-day low flow conditions.

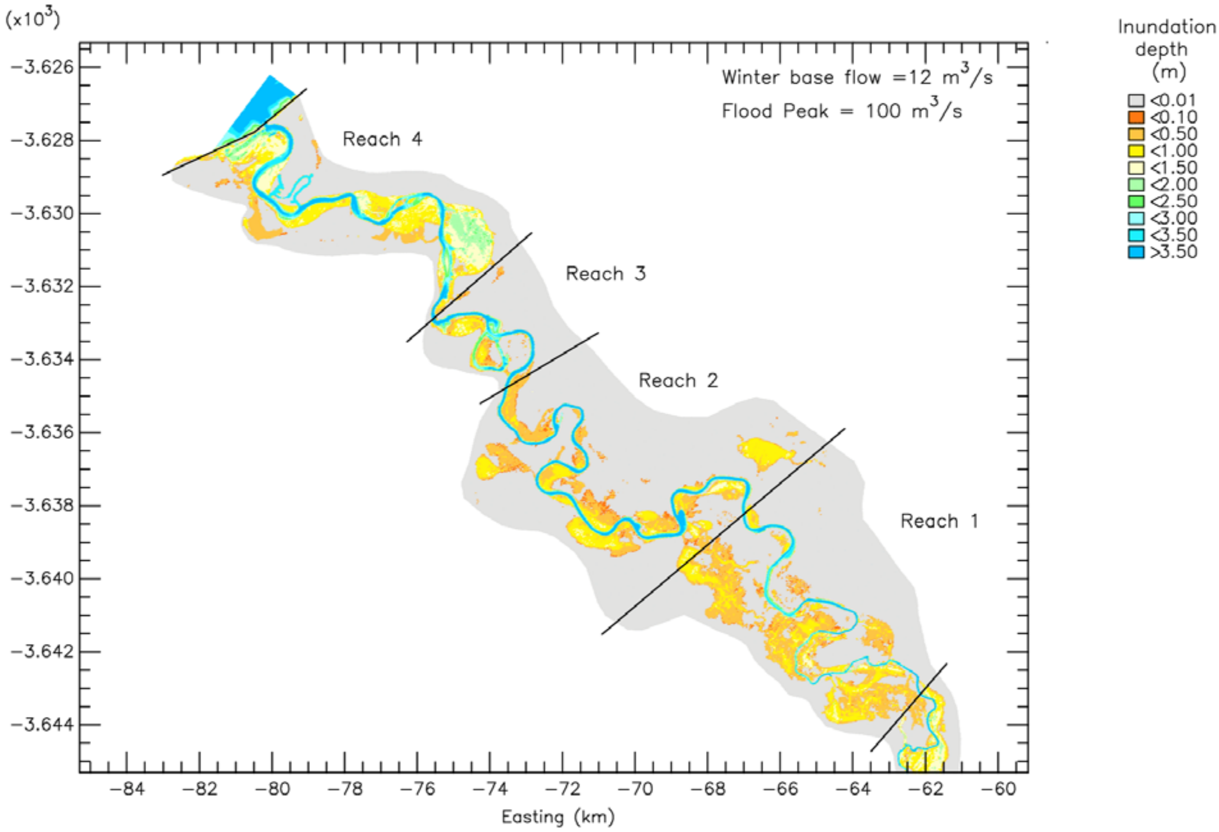


Figure 3-8 Flood extent for a 500 m^3s^{-1} flood under present-day low flow conditions.

These size classes of floods are relatively sensitive to antecedent flood volumes, i.e. whether they arrive as a single event or in combination with other flood events. The latter increases the level of inundation significantly, e.g. from 50% to 60%. Water-resource development in the catchment will have the effect of reducing complex flood patterns to short, sharp pulses. Thus, for the EWR analysis the assumption was made that flood peaks would be discreet events.

Tidal and subtidal (marine) water level variations in the estuary also influence the extent of flooding in the system, but only really in the lower reaches. Under normal (non-flood flow conditions) tidal water level variability dominates in the region between the mouth and 12 km upstream under neap tide conditions and up to between 45 and 50 km upstream under spring tide conditions. Upstream of this water levels are dominated by freshwater inflows should they be of any significance (*i.e.* winter base flows or greater). The magnitude of sub-tidal water level fluctuations are comparable to neap tide water level variations between 12 km and approximately 50 km upstream. Depending on the magnitude and sign of subtidal water level variability, the magnitude of the tidal water level variability exceeds that associated with small floods (< 100 m^3s^{-1}) from the mouth to approximately 33 km to 45 km upstream for spring tides, and from the mouth to approximately 20 km upstream under neap tides. For larger floods (> 500 m^3s^{-1}) tidal water level fluctuations only dominate downstream of approximately the railway bridge under spring tides and only in the lower 2 to 5 km of the estuary under neap tides.

3.1.3.3 Frequency of drought conditions

Hydrological drought conditions in the Berg River Estuary are defined as years in which the annual inflow falls below the Reference condition 10%ile, i.e., 506 million m^3. Under the present state, annual flows less than 506 million m^3 occur approximately 66% of the time. Furthermore, an analysis of last 77 years shows at least two extended drought periods, lasting up to 12 consecutive years each (Figure 3-9). This compared to 18% in the Reference condition, with only three periods longer than one year, and none longer than three consecutive years. In addition, the severity of drought is considerably more marked under the present state, when the MAR drops below 250 million m^3 (did not drop below 450 million m^3 in Reference condition).

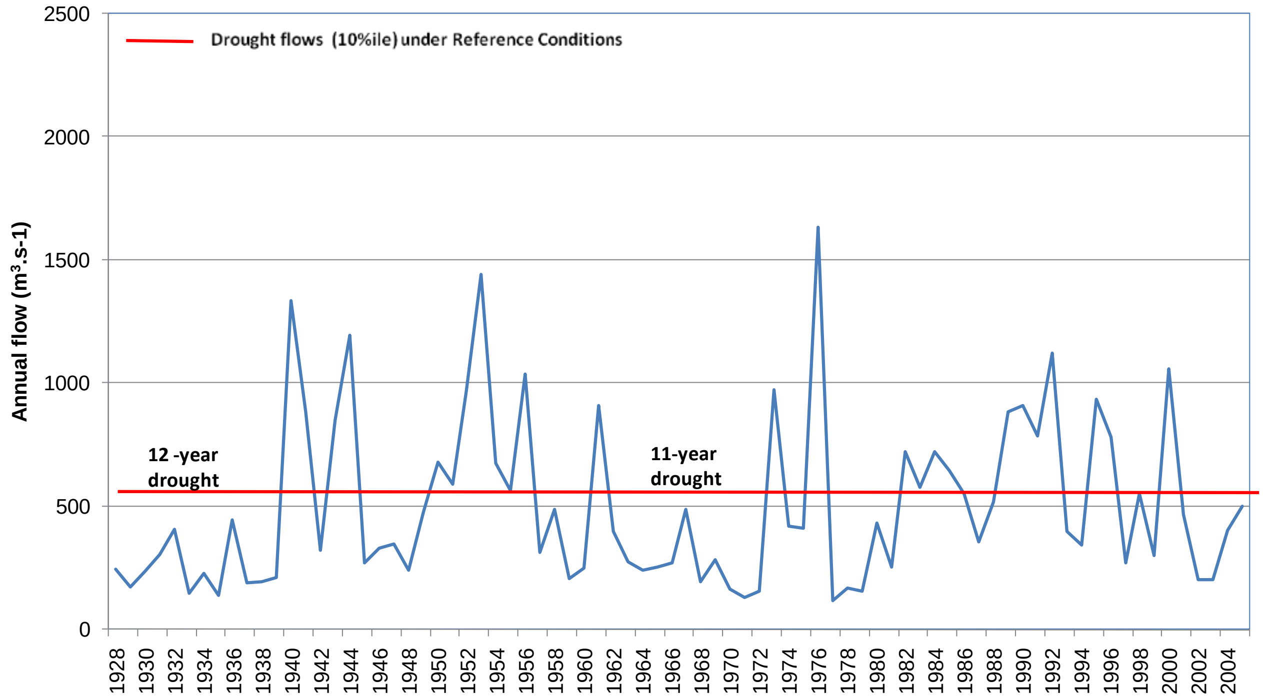


Figure 3-9 Drought conditions in the Berg River Estuary under the present state.

3.1.3.4 Present sediment processes

General

The Berg River Estuary is a river-dominated system and sediment dispersal occurs seaward of the river mouth; only two other South African estuaries are characterised by having offshore mud deposit centres, namely the Orange (Gariep) and the Thukela (Cooper 2001 in DWAF 2007). The Berg River differs from the Orange and Thukela in that the seaward mud deposition centre is more a result of the very low wave energy and surf zone currents off the mouth, which result in low sediment dispersal potential off the mouth (Figure 3-10) than a large sediment production. The low surf-zone sediment transport potential also means that one of the major drivers for mouth closure is low relative to other SA estuaries.

Figure 3-10 The low-energy St Helena Bay shoreline (Source: A Theron).

The very low gradient (i.e. slope) of the estuary and its great length, means that fluvial sediments entering the head of the estuary have a long residence time in the system before being exported to the sea. (Not all of the fluvial sediment necessarily reaches the sea; for example, some is deposited on the wide floodplains.) Even large river floods cannot easily move sediments right through the estuary and estuarine sediments tend to be moved along in pulses with a range of flood magnitudes (the relative amount of sediment and downstream transportation distance being related to the size and duration of the flood).

The long, low-gradient nature of the Berg River Estuary with its extensive floodplains, also has the effect of "regulating" the effect of river floods and in general progressively "buffering" the effects on sediments and morphology in a downstream direction, with this effect significant effect in the middle and especially the lower estuary. This flood "regulation/buffering" effect together with the large tidal prism of the estuary results in the lower estuary sediment regime and morphology being largely affected by the sea tides, particularly since the mouth was stabilised in a wide-open state (Figure 3-11).

Figure 3-11 The breakwaters and training walls ensure a wide-open mouth (Source: A. Theron).

The upper Berg River plays a critical role in contributing to both lowflows and small floods in the lower river, contributing on average 72% of the flood peak in the lower reaches, for floods <20 m^3s^{-1} and contributing disproportionally to all intra-annual flood events in the lower reaches (Ractliffe 2009). Thus, the pulsed re-suspension of fluvial sediments and deposition further downstream in the estuary associated with smaller floods has diminished as a result of the Berg River dam reducing such floods.

According to Rowntree and Macgregor (1996), most sediment production occurs downstream of the Berg River Dam. Thus, while the Berg River Dam has a significant effect on flows and floods into the estuary, and thus on estuarine sediment movement and flushing, it does not have a significant effect on sediment supply to the estuary.

The two older dams, Wemmershoek and Misverstand dams, have the potential to trap large proportions of the coarser sediments that would have reached the estuary. The effect of the more-downstream of the two, Misverstand Dam (45% trapping efficiency), on the hydrological regime of the river downstream is thought to be less pronounced than that of Wemmershoek Dam (90% trapping efficiency; Ractliffe *et al*. 2007). This, and the significant catchment area and sediment yield potential below Misverstand Dam, means that it does not greatly effect sediment supply to the estuary.

Overall, however, the reduced floods (both in number and magnitude) translate into reduced sediment transport and scouring capacity within the estuary, which results in a less dynamic sediment bottom and greater potential for consolidation of sediments. Furthermore, the reduced floods, and hence reduced sediment transport potential and scouring, potentially allow more marine sediment intrusion through the mouth, possibly longer residence of such sediments within the estuary before eventual flushing out due to occasional large floods, and further transgression of such sediments up the estuary.

Note: Confidence in the quantification of sediment dynamics and morphology and changes therein, is low as there are virtually no sediment or morphology data for the Reference condition, and a paucity of such data for the present.

Lower reaches of the estuary

In its natural state, the lower reaches of the estuary, especially near the mouth, were relatively shallow and highly dynamic with ongoing channel and mouth variations and transient mud/sand banks. Thus, the construction of the breakwater and training walls to achieve a fixed permanently open mouth channel in a new location represents a dramatic change in the physical nature of the estuary. The now blind arm leading to the former mouth has since become a partial sediment trap and consequently has been subject to significant sedimentation and shallowing. Since construction of the new mouth, maintenance dredging has also been conducted in the lower estuary channel to ensure safe passage of fishing vessels and boats (Figure 3-12). Sediments transported to and deposited in the lower estuary channel are therefore periodically removed (dredged) and dumped elsewhere. The relatively wide permanently open mouth and deeper channel result in greater tidal intrusion into the estuary and also higher velocity tidal flows. This could result in more ingress of marine sediments than in the Reference condition. On the other hand, the breakwaters and mouth training walls, which extend to beyond the surf zone are likely to be effective in limiting the potential for surf zone sediments to enter the mouth. The higher flow velocities probably remove relatively more of the finer sediments (or hinder deposition of such sediments).

Construction of the Port Owen Marina (Figure 3-12) would have led to a small increase in the tidal prism of the estuary, but also potentially to diversion of a part of the flow (tidal and river flood) from the main estuary channel through the marina. Flow velocities and therefore sediment transport in the main estuary channel are probably affected in a small way, but it is uncertain if there is any net effect. A slightly more direct effect is perhaps the reported periodic dredging of parts of the marina and dumping of these sediments in the main estuary channel.

Figure 3-12 Dredging is required to enable safe access for such large vessels (left) and the Port Owen Marina (right) (Source: A Theron).

Another significant modification of the tidal and supra-tidal sediment habitat was brought about by the construction of the saltpans and their impoundment/protective walls. In effect, the estuary channel bank adjacent to the salt works has been artificially fixed in place. In addition, fluvial sediments can no longer be deposited on the former flood plain during large river floods. The impacts to the sediments and morphology due to the salt works are not considered to extend to the sub-tidal sediments or morphology.

In the lower reaches numerous wharfs, jetties and embankments have been constructed (examples are shown in the figure below), especially at Laaiplek (Figure 3-13). Both bank stabilisation and construction of wharfs/quay walls represent direct replacement of the natural inter- and sub-tidal bank sediments. They also affect morphology in that the estuary bank profile is fixed, preventing natural erosion and variability of the channel bank configuration. If steep or vertical constructed embankments extend to deeper than the intertidal zone, they can also result in relatively high flow velocities near such embankments. The shallower, natural embankments, which would have been found in such locations, have lower edge flow velocities and thus lower sediment transport and less winnowing of finer sediments from the bed/surface.

Figure 3-13 Wharfs and quay walls (left) and jetties, wharfs and quays (right) (Source: A Theron).

The jetties, which are found mostly in the lower estuary with some in the middle estuary, are considered to have only a relatively small local disturbance impact on the estuarine sediments.

Thus, the sediments and morphology of the lower estuarine reaches have been largely modified by a number of local anthropogenic activities that are unrelated to landuse changes in the Berg River catchment or flows in the river itself. Nonetheless, the reductions in flow and flood size as a result of impoundments and water abstraction, have had some impacts on the estuarine sediments and morphology. In particular, there is less flushing of sediments, greater intrusion of marine sediments both in quantity and upstream extent.

Middle reaches

In the middle reaches, the construction of the Carinus Road bridge and the railway bridge, and their embankments, have resulted in significant modification of the estuarine morphology. The erstwhile variable channel has been fixed in place by the bridge openings. The flow concentration through the comparatively narrow openings results in higher velocities, sediment transport, and a relatively deeper channel in these locations. On the other hand, in the areas adjacent to the bridge embankments, longitudinal flow has been stopped, flow velocities are now lower and sediment deposition is enhanced. These sediment deposits are less dynamic than under natural conditions and the thicker sediment layers also mean that the sediment has become more consolidated and more resistant to scouring.

There are a fewer wharfs, jetties and embankments than in the lower reaches, but they have the same kinds of impacts on the sediments and morphology as described for these structures in the lower reaches.

It is believed that there is some trampling of inter- and supra tidal sediments by livestock in all reaches of the system.

As in the lower reaches, the reduction in the number and magnitude of river floods has reduced the sediment flushing potential in the middle reaches. This also implies less dynamic channel embankments and bottom, and consequently a greater potential for consolidation of the sediments.

Another consequence, but perhaps of lesser importance, is that on average it will now take a longer time for fluvial sediments to pass through the middle reaches of the estuary.

The possibility of siltation of the channel adjacent to the mudflats and of bank erosion has been reported in the "Green Report" (Morant *et al.* in prep.). While the modifications and impacts described here could motivate for such effects, there is no direct factual evidence (i.e. data/measurements) available suggest that these changes have indeed occurred.

Overall, for the middle reaches, it can be said that there are some noteworthy non-flow related anthropogenic impacts, as well as some impacts related to a reduction in river flow, although these are somewhat muted/buffered by the long upper reaches.

Upper reaches

There is at least one road bridge and one drift crossing the upper estuary. The effect of bridges and their embankments on estuarine morphology and sediments are similar to that described for the bridges in the middle reaches.

A large meander in the channel has been cut short artificially, but the effects of this are likely to be localised.

The floodplain of the upper estuary is the most developed in terms of farming; trampling of inter- and supra-tidal sediments by livestock is widespread in this region. There is significant invasion by alien tree species of the supra- and inter tidal zones of the upper portion of the upper estuary. Dense stands of such trees tend to bind and consolidate otherwise much looser sediments and also significantly increase the flow resistance over such stands. These effects result in the sediments being much less prone to scouring during all but the very largest of floods.

The effects of the reduction in river floods and sediment supply are greatest in this reach, as these are not attenuated as is the case for the middle and lower estuary. These effects can be summarised as:

1) The reduction of the sediment supply will be selective and much skewed towards less coarse sediment supply. Thus, the consequence will be relatively more fines in the estuarine sediment grading (with ecological consequences). This has further implications in that the finer sediments are more cohesive, which for example, allows more compaction and greater resistance to erosion/scouring. This in turn means less dynamic morphology and bed-forms, etc.
2) The above effects on consolidation will be further enhanced by the flood peak reduction (with enhanced non-linear effect on sediment scouring and transport); thus reinforcing the morphology and bed-form consequences.

3.1.4 Non-flow related impacts affecting abiotic components

The water resources of the Berg River have been developed increasingly during the last 60 years. This is both a product of its close proximity to Cape Town, its highly reliable run-off characteristics and its fertile catchment. Existing developments are summarised in Table 3.11.

Table 3.11 Existing water resource developments in the Berg River catchment

Development	CAPACITY	DESCRIPTION
Wemmershoek Dam	58.8 x 10^6 m^3	The dam is situated on the Wemmers tributary of the Berg and is owned by the City of Cape Town.
Voëlvlei Dam	170 x 10^6 m^3/y	An off-channel storage dam situated to the west of the Voëlvlei mountains near Gouda. The dam is supplied mainly from canals fed from diversion structures on the Klein Berg, 24-Rivers and Leeu tributaries of the Berg River. It supplies Cape Town and a number of smaller municipalities, as well as irrigators in summer. Note that this is an off-channel facility and its capacity is related to its operational rules and not just its surface area (capacity is thus listed as a per annum value).
Misverstand Dam	6.1 x 10^6 m^3	The dam is situated on the Berg River itself and supplies water to Saldanha/Vredenburg and vicinity.
Riviersonderend/Berg River Government Water Scheme	51 x 10^6 m^3 per annum (maximum diversion)	This scheme includes the Theewaterskloof Dam near Villiersdorp in the Riversonderend. This scheme is not operational at present, but in the past, winter run-off was abstracted from the Wolwekloof and Banhoek tributaries of the Berg River through a horizontal tunnel system, was stored in the Theewaterskloof Dam and, when required, was transferred back into the tunnel system and discharged into the upper Berg River. Water was also transferred to the Eerste River and Cape Town by this means.
Berg River Dam and supplement scheme	126.4 x 10^6 m^3	The Berg River Dam is located in the upper reaches of the Berg River above Franchoek and the supplement scheme comprises a diversion weir and balancing dam designed to augment storage in the Berg River Dam. The weir is situated a short distance downstream of the confluence with the Dwars River, and water is abstracted and pumped up to the Berg River Dam when flows in the river are higher than the volume required for the Reserve. Nominal abstraction capacity is 6 m^3s^{-1}.

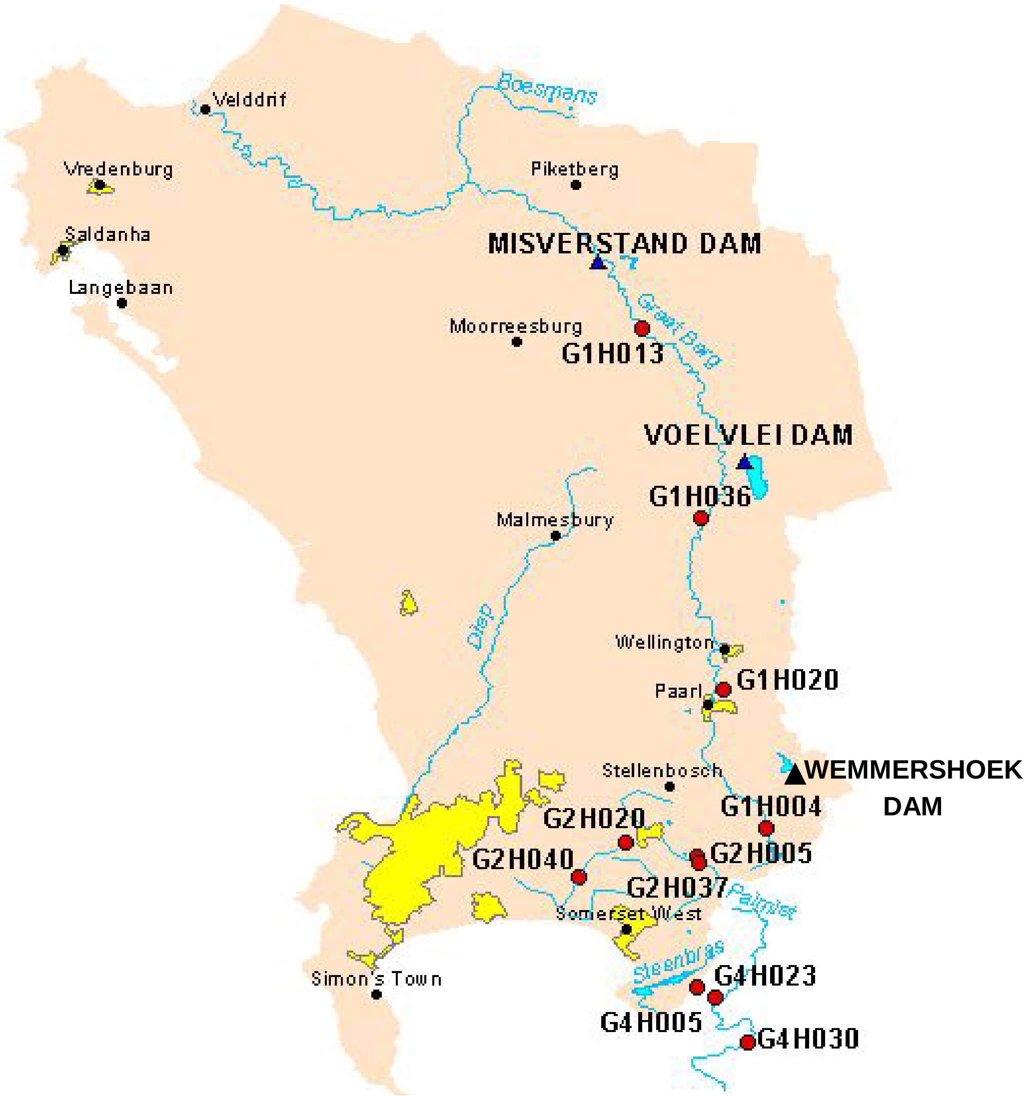


Figure 3-14 Locations of Misverstand, Voelvlei and Wemmershoek Dams. The new Berg Dam is located near G1H004 (Franschoek).

During the summer irrigation season, water released from the Berg River Dam is intended for use by riparian owners along the stretch of the Berg River from the tunnel to Riebeek-Kasteel. These releases include the compensation flow that would otherwise have to be released from Wemmershoek Dam.

Downstream of Riebeek-Kasteel the dry season flow is currently maintained by releases from Voëlvlei Dam, which are intended to meet the needs of the riparian owners along the remainder of the Berg River and the abstraction requirements at Misverstand Dam.

Anthropogenic influences, other than modification of river inflow, that are presently affecting abiotic characteristics in the estuary are described in Table 3.12. Many of these are depicted on the preceding pages as well.

Figure 3-15 Skuifraam Supplement scheme downstream of the Berg River Dam. Note problems with fish ladder and canoe access (Source: A. Theron).

Table 3.12 Non-flow related activities affecting the abiotic characteristics in the estuary

Type	Activity	Present	Describe impact
Land-use and development	Weirs	✓	Weir upstream prevents migration of fish
	Bridge(s)	✓	Downstream from the head of tidal effect the river is spanned by the minor road bridge at Kersefontein, the Sishen-Saldanha railway and the R27 (Carinus) road bridges. None of these impede summer (low) flow. However, both the Carinus and Sishen-Saldanha bridges have long approach embankments across the flood plain, which impede flood flows despite the culverts through them.
	Artificial breaching	✗	

Type	Activity	Present	Describe impact
	Mouth stabilization	✓	Shoaling of the Berg River mouth, particularly during the summer, caused problems for fishing boats attempting to enter the harbour. In 1958, the AIF factory had to close because the boats could no longer reach it. Many fishermen and factory workers lost their jobs as a result. Anecdotal information also indicates that the mouth may have periodically closed during drier periods in the 1960s. In 1966, the Government cut a new mouth about 1 km north of the natural mouth. The new mouth is controlled by means of training walls and provides safe access to the estuary throughout the year. The stabilization has increased the average tidal variation in the system, especially during summer when the mouth would have been constricted.
	Bank stabilisation and destabilisation	✓	Banks stabilised in mouth region (Laaiplek), adjacent to the salt works and immediately upstream of Carinus bridge. Leading to loss of intertidal area.
	Causeway	✓	Farmers construct causeways to dam the river for pumping and to cross the river. These temporary causeways have almost no effect in flood as they are overtopped or swept away. But, during summer when the river flow is low, these structures may have an effect on the salinity regime of the upper estuary.
	Marina development	✓	The Port Owen Marina was constructed along the northern boundary of the estuary resulting in loss of supratidal area and increased subtidal area. There are also some possible effects on the tidal prism of the estuary.
	Dredging	✓	Maintenance dredging is done to keep the lower estuary channel navigable.
	Mining (e.g. sand winning)	×	
	Poor agricultural practices (e.g. causing siltation)	✓	Poor agricultural practises in catchment are causing degradation off land cover and related sedimentation in estuary.
	Exceedance of carrying capacity from boating, bathers etc.	✓	Recreation has become an important activity on the Berg River Estuary particularly since the establishment of the Port Owen marina. Yachts based at Port Owen have easy access to St Helena Bay, which provides extensive sheltered sailing.
	Low-lying developments	✓	Velddrif, Laaiplek
	Lack of maintenance of infrastructure (e.g. roads and bridges)	×	
	Migration barrier in river	✓	Refer to discussions regarding causeways

Type	Activity	Present	Describe impact
	Salt works	✓	Extensive salt works occupy much of the south bank in the lower reaches. In 1986, the salt works was constructed on an area of moribund high saltmarsh immediately adjacent to the Carinus Bridge embankment. There is one small salt works immediately upstream of the railway bridge (Kliphoek Salt works). There is anecdotal evidence of the breaching of the retaining walls around the salt works and the flushing of the brine into the system.
Water Quality and Quantity	Agricultural and pastoral run-off containing fertilisers, pesticides and herbicides	✓	In the upper reaches of the estuary, there are agricultural activities along the banks that potentially could contribute to pesticides/ herbicides inputs to the system.
	Waste water treatment works	✗	There are no wastewater treatment works along the banks of the estuary (although there a several in the catchment).
	Municipal waste (including sewage disposal)	✗	There are no wastewater treatment works along the banks of the estuary (although there a several in the catchment).
	Industrial effluent (including cooling water) discharges	✓	Wastewater from a fish processing plant at Laaiplek is being discharged into the lower estuary (potentially adding to the DIN and DIP loading)
	Litter	✓	Although not considered a major issue, some littering does occur particularly in the lower reaches next to the town of Veldrif and Laaiplek.
	Mariculture waste products	✗	
	Pollution related to shipping activities in harbours	✓	The estuary supports a fishing harbour (near the mouth) where shipping activities are likely to contribute to waste inputs e.g. trace metals, hydrocarbons and ballast.
	Septic and conservancy tank seepage	✓	Seepage from properties close to the estuary is a potential concern although there are no measurements to confirm this.
	The inflow of contaminated storm-water or groundwater	✓	Seepage from properties close to the estuary is a potential concern although there are no measurements to confirm this.
	Lack of maintenance of infrastructure (e.g. sewage works)	✓	Seepage from properties close to the estuary is a potential concern although there are no measurements to confirm this.

A summary of non-flow related anthropogenic impacts to estuary morphology or sediment characteristics is presented Figure 3-16.

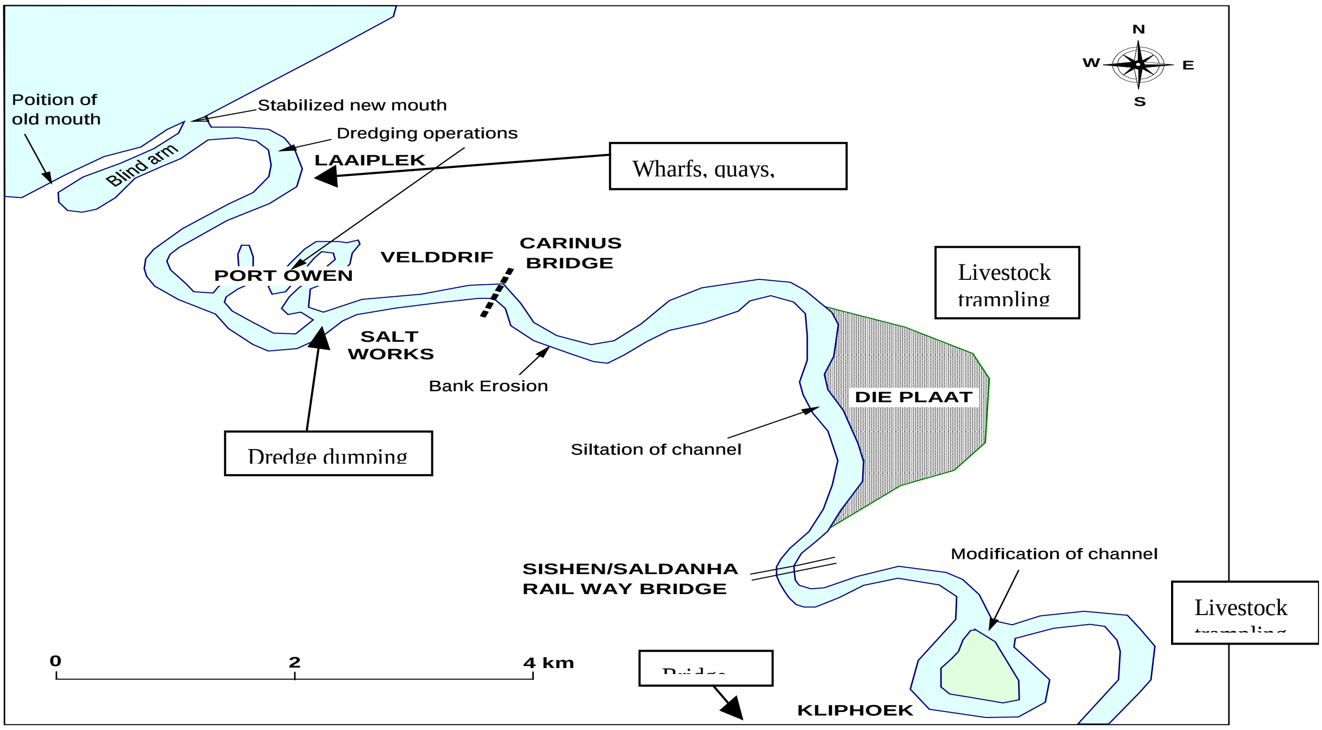


Figure 3-16 Location of non-flow related anthropogenic impacts on estuary morphology or sediment characteristics.

3.2 Biotic Components

3.2.1 Definition of biotic components

Five major biotic groups can be distinguished amongst estuarine biota: microalgae, macrophytes, invertebrates, fish and birds, along with a number of subgroups in each category. Major characteristics of each group and their subgroups are summarised below.

3.2.1.1 Microalgae

Major groups of microalgae in the Berg River Estuary include intertidal and subtidal benthic microalgae (otherwise known as microphytobenthos MPB) and phytoplankton, as well as several subgroups (Table 3.13).

Table 3.13 Major groups of microalgae considered in this study with their defining features

<table>
<tr><th></th><th>Microalgal groups</th><th>Defining features, typical/dominant species</th></tr>
<tr><td rowspan="2">Microalgae</td><td>Benthic microalgae (microphyto benthos – MPB); subtidal and intertidal</td><td>Epipelic: live freely on sediment surfaces
Episammic: live attached to sand grains
Epiphytic: live on other plants
Epilithic: live on stones and rocks
Epizoic: live on animals
MPB community generally consists of euglenophytes, cyanophytes and bacillariophytes (diatoms). Diatoms are generally dominant in the microphytobenthos. Sampling effort limited to soft sediment inhabiting microalgae (epipelic and episammic). Loss of partially submerged or fully submerged macrophytes and macroalgae will represent a loss of epiphyte habitat.

Dominant species (2006) include; Opephora minuta Cleve-Euler, Catenula adhaerens (Mereschk.) Mereschk, Navicula gregaria (Donkin), Bacillaria paxillifer var. paxillifer (O.F. Muller) Hendey, Amphora coffeaeformis (Agardh) Kützing, Amphora acutiscula Kützing, Navicula salinicola Hustedt and Fragilaria elliptica Schumann.</td></tr>
<tr><td>Phytoplankton</td><td>Flagellates, diatoms, dinoflagellates, cyanophytes, chlorophytes, euglenophytes and coccolithophorids.

A bloom of large flagellates (possibly Heterococcus viridis (Gerneck) Chodat) was present in the estuary (November 2006) from 6.0 to 16.5 km from the mouth.</td></tr>
</table>

3.2.1.2 Macrophytes

Macrophyte habitats and functional groups recorded in the Berg River Estuary include the open water surface area, macroalgae, submerged macrophytes, intertidal salt marsh, supratidal salt marsh, and reeds and sedges (Table 3.14).

Table 3.14 Macrophyte habitats and functional groups recorded in the Berg River Estuary.

Macrophyte habitat types	Mapping unit (Boucher and Jones 2007)	Dominant species	Cover (ha; Boucher and Jones 2007)	Cover (ha) within 5-m contour
Open water surface area	River		792.817	850.2
Macroalgae	Macroalgae	*Enteromorpha prolifera, E. flexuosa, Ectocarpus siliculosa* and *Caloglossa leprieuri*.		~ 200
Submerged macrophytes	Intertidal mudflats	*Zostera capensis* *Ruppia cirrhosa* *Potamogeton pectinatus*	205.656	206
Intertidal salt marsh	Halophytic salt marsh	*Sarcocornia perennis* *Spartina maritima* *Triglochin striata* *Salicornia meyeriana* *Bassia diffusa* *Cotula coronopifolia* *Leptochloa fusa*	128.860	123.9
	Sedge marsh	*Juncus kraussii*	375.975	375
	Open pan	*Triglochin striata* *Salicornia meyeriana*	1 161.668	1158.6
Supratidal salt marsh	Halophytic floodplain	*Sarcocornia pillansii*	1546.764	1520.7
	Xeric floodplain (transition habitat between halophytic floodplain and strandveld)	*Chrysanthemoides incana*	998.001	919.1
Reeds and sedges	Normal tall reed marsh	*Phragmites australis*	514.586	513.5
	Short reed marsh	*Schoenoplectus triquester* *Schoenoplectus scirpoideus* *Cyperus textilis*	73.059	73.1
	Sedge pan	*Juncus maritimus* *Aponogeton distachyos*	1 000.767	975.1

3.2.1.3 Invertebrates

Major invertebrate groups in the Berg River Estuary include copepods, mysids, carid shrimps, sandy subtidal benthos, and muddy subtidal benthos (Table 3.15).

Table 3.15 Major invertebrate groups found in estuaries with their defining features.

Invertebrate groups	Defining features, typical/dominant species
Copepods	Copepods contribute over 85% to total zooplankton abundance both during times of river dominance and dry summers (present day conditions). *Pseudodiaptomus hessei* is the most important species in the Berg River Estuary, making up at least 65% of the 14 species of copepods present during six of the seven visits (note: marine associated species grouped and not identified to the species level). *P. hessei* does not show any correlation to salinity patterns, reflecting its wide salinity tolerance range. Instead, this species responds to pulse events, and is flushed out of the estuary under freshwater dominant states in winter (State 5).
Mysids	Four species present in the Berg River Estuary, but only *Mesopodopsis wooldridgei* and *Rhopalophthalmus terranatalis* are important numerically. Both these mysid species attain high densities and because of the population turnover rates (estimated at approx 4-5 times per annum), they contribute significantly to biomass in the water column.
Carid shrimps	Unknown
Sandy subtidal benthos	*Callianassa kraussi* is extremely abundant in the subtidal benthos of the lower estuary (up to 12 km from the mouthm i.e., all of Zone A and *c*. 2 km of Zone B). Densities of over 800 ind.m^2 were sampled on a number of occasions. Sand prawns collected in grab samples were newly settled individuals (therefore, near-surface burrowers efficiently sampled with the grab down to 8-10 cm). Adults were not collected, but they were undoubtedly present in deeper sediments. Densities would therefore be greater than the data indicates. Highest densities were at the interface of Zones A and B, decreasing away from this area (about a 2-3 km stretch). Present-day conditions result in lower levels of abundance seawards of the 10-km chainage due to strong tidal currents and coarser sediments in the channel (current mouth condition and dredging activities that maintain the open mouth channel, even in summer when the mouth became constricted under natural conditions). The blind arm is currently composed of calm waters and fine muddy sediments not suitable for sand prawns). These fine sediments would not have been present under natural conditions
Muddy subtidal benthos	Like the benthos present in sandy sediments, those inhabiting muddy sediments (Zone B and Zone C) attain extremely high density levels, numerically dominated by amphipods (54% by number – particularly *Corophium triaenonyx* and *Gradiidierella lutosa*) and polychaetes (32% by number – (particularly *Boccardia* sp. and *Ceratonereis keiskama*). Species richness tended to be higher in the dry season, with little spatial shift in population distribution patterns between wet and dry seasons. This reflects the euryhalinty of the macrozoobenthic assemblage to salinity shifts. However, breeding activity is probably curtailed during winter because of low salinity throughout much of the estuary.

3.2.1.4 Fish

The classification for estuary-associated fishes in southern Africa developed by Whitfield (1994) is the most widely adopted system in the region. It recognises five major categories of estuary associated fish species and several subcategories based on their salinity tolerances and their use of the estuarine environment (Table 3.16).

Table 3.16 Major groups of fish found in estuaries classified in respect of their salinity tolerances (*sensu* Whitfield 1994).

Fish groups	Defining features, typical/dominant species
• Estuarine residents	Resident species not recorded spawning in marine or freshwater environment: Ia. Resident species not recorded spawning in marine or freshwater environment Ib. Resident species also having marine and/or freshwater breeding populations
• Estuary dependent marine species	Species usually breeding at sea with juveniles showing varying degrees of dependence on estuaries, further divided into: IIa. Juveniles dependent on estuaries as nursery areas IIb. Juveniles occurring mainly in estuaries, but also found at sea IIc. Juveniles occur mainly at sea, but also found in estuaries
• Marine migrants	Species that occur in estuaries in small numbers but are not dependent on estuaries
• Euryhaline freshwater species	Species whose penetration into estuaries is determined primarily by salinity tolerance. Includes some species which may breed in both freshwater and estuaries
• Catadromous species	Species which use estuaries as transit routes between the marine and freshwater environments but may also occupy estuaries in certain regions, further divided into: Va. Obligate catadromous species which require a freshwater phase in their development Vb. Facultative catadromous species which do not require a freshwater phase in their development but use estuaries as nursery areas

Fish species in estuaries can also be classified according to their mode of feeding (Table 3.17). This is particularly useful for describing trophic relations and biotic interactions in the estuary (as indicated in Figure 3-17), but less so in respect of changes in abiotic drivers such as freshwater flow.

Table 3.17 Major groups of fish found in estuaries classified in respect of their dietary guilds tolerances.

Groups	**Defining features, typical/dominant species**
Filter feeder	Feed by filtering water through gill rakers and extracting microscopic food particles (e.g. phytoplankton) from the water Dominant species in the Berg River Estuary: *Liza richardsonii, Atherina breviceps*
Active capture	Feed by capturing individual macroscopic prey items from the water column. Example *Gilchristella aestuaria*
Piscivore	Feed on other smaller fish species either as visually orienting (pursuit) predators or olfactory (ambush) predators
Benthic invertebrate forager	Feed on intertidal or subtidal benthic invertebrates either by selecting animals from the sediment surface or using some technique to extract them from the sediment
Herbivore	Feed on epiphytic microalgae living either on aquatic macrophyte, sediment surface or other hard substrata (e.g. rock). Feed by scraping epiphytic algae from the substratum or ingest the aquatic macrophytic vegetation but are usually only able to digest and assimilate the epiphytic algae.
Detritivore	Feed on detritus and digest and assimilate the organic material therein.

Table 3.18 Dominant fish species in the Berg River Estuary, their estuary association categories (*sensu* Whitfield 1994) and feeding guilds

Family	Species	Common name	Estuary association category	Mode of feeding[1]
Clupeidae	*Gilchristella aestuaria*	estuarine round herring	Ia	FF, AC
Gobiidae	*Caffrogobius multifasciatus*	prison goby	Ia	BI
Atherinidae	*Atherina breviceps*	silverside	Ib	FF
Clinidae	*Clinus superciliosus*	super klipvis	Ib	BI
Gobiidae	*Caffrogobius nudiceps*	nude goby	Ib	BI
Gobiidae	*Psammogobius knysnaensis*	Knysna sand gobi	Ib	BI
Syngnathidae	*Sygnathus temminkii*	pipefish	Ib	AC
Mugilidae	*Mugil cephalus*	flathead mullet	IIa	FF, D, H
Soleidae	*Solea bleekeri*	blackhand sole	IIb	BI
Scianidae	*Argyrosomus coronus*	Kob	IIb	P
Mugilidae	*Liza richardsonii*	harder	IIc	FF, D, H
Pomatomidae	*Pomatomus saltatrix*	elf	IIc	P
Carangidae	*Lichia amia*	Leervis, garrick	IIa	P
Galaxiidae	*Galxias zebratus*	Galaxias	IV	AC, BI
Sparidae	*Lithognathus lithognathus*	White steenbras	IIa	BI
Sparidae	*Rhabdosargus globiceps*	white stumpnose	IIc	BI

1. FF = Filter feeder, AC = active capture, BI = benthic invertebrate feeder, H = herbivore, P = piscivore

3.2.1.5 Birds

Birds were grouped into ten groups using a combination of factors, such as diet, feeding methods and use of habitats (Table 3.19). Though further subdivisions of some of these groups would have been possible, it was decided to restrict the subdivision to a manageable number of groups for the study.

Table 3.19 Major bird groups found in the Berg River Estuary, and their defining features.

	Bird groups	Defining features, typical/dominant species
Birds	Herbivorous waterfowl	This group is dominated by species that tend to occur in low salinity or freshwater habitats and are associated with the presence of aquatic plants such as *Potamageton* and *Phragmites*. The group includes some of the ducks (e.g. Southern Pochard), and all the rallids (e.g. Redknobbed Coot, African Purple Swamphen). Some herbivorous waterfowl such as Egyptian Goose, Spurwinged Goose and South African Shelduck probably feed in terrestrial areas away from the estuary and floodplain as well as in the estuary. Note, birds do not eat the algae found in the lower estuary.
	Omnivorous waterfowl	This group comprises ducks, which eat a mixture of plant material and invertebrate food such as small crustaceans - Yellow-billed Duck, African Black Duck, Cape Teal, Hottentot Teal, Red-billed Teal and Cape Shoveller. Although varying in tolerance, these species are fairly tolerant of more saline conditions, but African Black Duck tends to be restricted to areas of higher flow.
	Piscivorous waterfowl	This group comprises the grebes – Great Crested, Black-necked and Little Grebe. The first two tend to be restricted to lower salinities and deeper water, and Little Grebe tends to be found where there is abundant marginal vegetation.
	Wading/swimming piscivores	This group comprises the largest birds on the estuary – the wading and swimming birds (Ciconiiformes and Pelicaniformes), such as Reed Cormorant, Little Egret, Grey Heron. Loosely termed piscivores, their diet varies in plasticity, with fish usually dominating, but often also includes other vertebrates, such as frogs, and invertebrates. The ibises were included in this group, though their diet mainly comprises invertebrates and is fairly plastic. They tend to be tolerant of a wide range of salinities.
	Perching/aerial piscivores	This group comprises the kingfishers and birds of prey, such as African Fish Eagle and Marsh Harrier. They are not confined to a diet of fish, also taking other vertebrates and invertebrates. These species are tolerant of a wide range of salinities but require marginal vegetation, particularly trees or shrubs, or marsh in the case of Marsh Harrier and Marsh Owl.
	Lesser Flamingos	This species is unique in its diet (phytoplankton) and salinity tolerance, tolerating high salinity to hypersaline conditions.
	Greater Flamingos	Greater Flamingos feed on benthic invertebrates in a wide range of salinities.
	Macrobenthos-feeding waders	This group includes all the waders (e.g. Greenshank, Curlew Sandpiper). They are the smallest species and most numerous group on the estuary, and feed on benthic macroinvertebrates in exposed and shallow intertidal areas.
	Piscivorous gulls and terns	This group comprises the rest of the Charadriiformes, and includes all the gull and tern species using the estuary. These species are primarily piscivorous, but also take invertebrates. Most are euryhaline, but certain tern species on the estuary tend to be associated with low salinity environments.
	Marine cormorants	This group comprises cormorants that feed in marine environments and uses the estuary to roost – Cape, Bank and Crowned Cormorants. This group is neither directly nor indirectly sensitive to flow, and is thus not given much attention in this study.

3.2.2 The influence of flow on productivity, biomass and diversity

Figure 3-17 summarises the effects of abiotic characteristics and processes on the biota of the Berg River Estuary. Effects of the primary abiotic drivers on each biotic component are also summarised in Table 3.20 to Table 3.24.

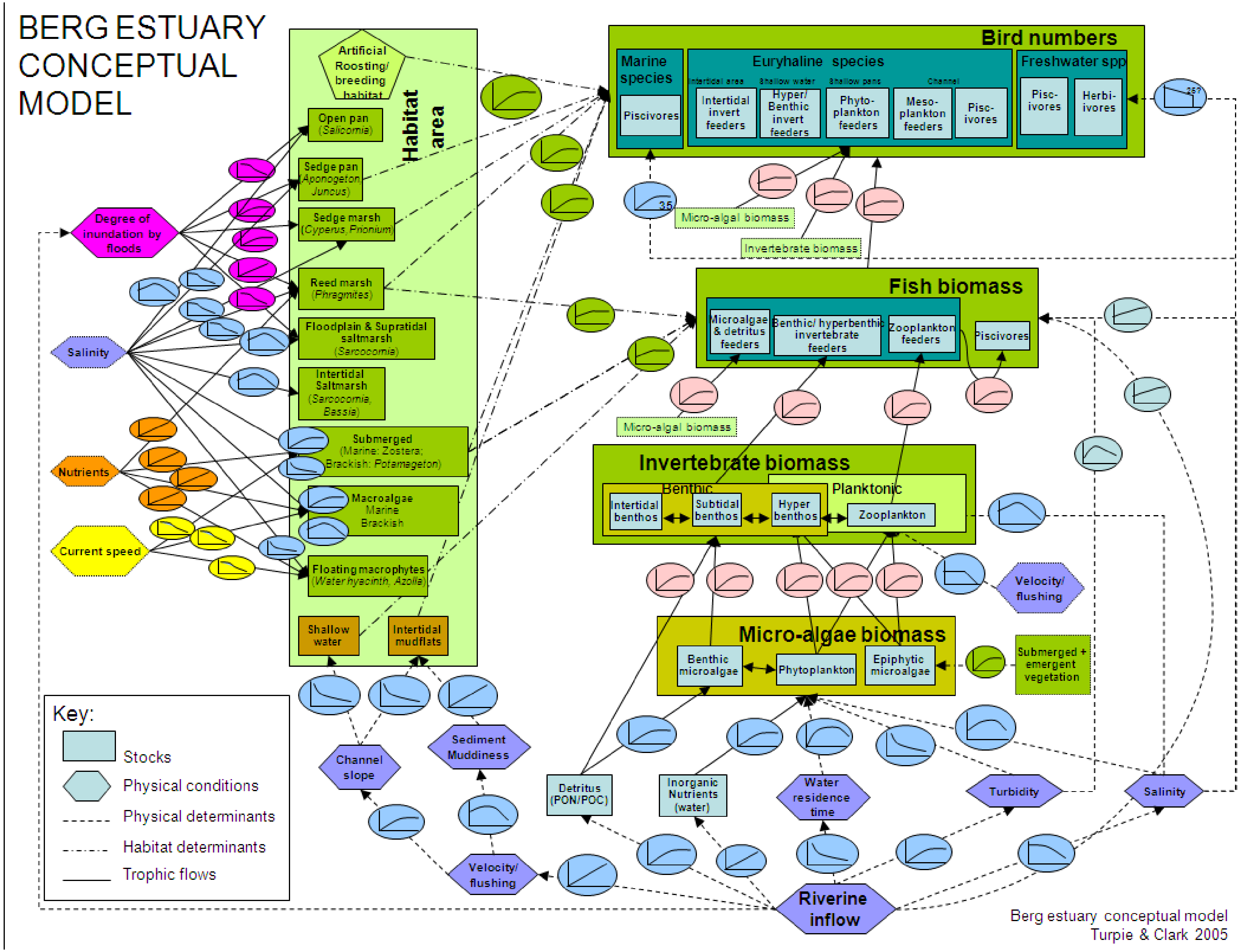


Figure 3-17. Conceptual model showing principal abiotic and biotic drivers and pathways for the Berg River Estuary (from DWAF 2007).

Table 3.20 The known effect of abiotic and biotic drivers on the microalgae of the Berg River Estuary

Driver	Cyanophytes	Dinoflagellates	Chlorophytes	Diatoms	Flagellates	MPB
Temperature	Positive					
% Fines (<63 µm)	Positive					Positive
Salinity	Negative	Positive	Negative			
External P input	Positive (capable of fixing N)	Positive (if combined with N ⇧)	Positive (if combined with N ⇧)	Positive (if combined with N ⇧)	Positive (if combined with N ⇧)	Positive (if combined with N ⇧)
Grazing	Negative	Negative	Negative	Negative	Negative	
[O_2]	Positive	Negative	Negative	Negative	Negative	
Stratification		Positive				
External N input		Positive (if combined with P ⇧)	Positive (if combined with P ⇧)	Positive (if combined with P ⇧)	Positive (if combined with P ⇧)	Positive (if combined with P ⇧)
Turbidity	Negative	Negative	Negative	Negative	Negative	Negative
Organic content	Positive					Positive

Table 3.21 The effect of abiotic and biotic drivers on the macrophytes of the Berg River Estuary

Macrophyte habitat types	Mapping unit (Boucher and Jones 2007)	Zone	Optimal salinity (ppt)	Inundation and flooding requirements
Macroalgae	Not mapped	A	35	Flushed out by high flows in winter.
Submerged macrophytes	Intertidal mudflats	A	35	Requires tidal flow.
Intertidal salt marsh	Halophytic salt marsh	A	35	Requires tidal flow.
	Sedge marsh (*Juncus kraussii*)	A, B, C	25	Tidal flow and baseflow from groundwater, one small winter flood per year to maintain moisture
	Open pan	C, D	<10 winter 45 summer	Type 1 permanently flooded close to water. Type 2 only flooded during winter at spring tides. Requires 2 small floods during winter for 5 months.
Supratidal salt marsh	Halophytic floodplain	B, C	45	Flooded at equinox spring high tide, dependent on groundwater. One medium flood during winter for 3 months duration.
	Xeric floodplain	B, C	45	Only flooded with large floods during equinox, dependent on groundwater. One large flood every 5 years during winter.
Reeds and sedges	Tall reed marsh	B, C	15	Winter flooding during high tide.
	Short reed marsh	B	15	Requires winter flooding.
	Sedge pan	C, D	<5	Flooded in wet season during spring tide and equinox spring tide during dry season. Requires 2 small floods during winter (May to Oct.) for 4-5 months.

Table 3.22 The effect of abiotic and biotic drivers on the *biomass and species composition* of invertebrates of the Berg River Estuary

Invertebrates	Copepods	Mysids	Carid shrimps	Intertidal benthos	Sandy Subtidal benthos (Caliannassa etc)	Muddy subtidal benthos
Salinity	Decreasing salinity values lead to a reduction in species richness. Salinity values between 5 and 28ppt are optimal and maintain or even increase biomass of typically estuarine species. Linked positively to phytoplankton standing stock. If salinity falls below about 5ppt, biomass rapidly decreases.	Only two species important in the estuary. Occasionally, marine associated species temporarily move in on the flood tide. Optimal salinity values between 10 and 35 ppt. Linked positively to phytoplankton standing stock. Values below 10 ppt lead to a significant reduction in biomass.	Only *Palaemon perengueyi* important. Optimal salinity values between 10 and 35 ppt. Values below 10 ppt lead to reduced biomass. Biomass linked positively to emergent macrophytes coverage. *Palaemon capensis* (5 – 10 ppt) probably important in low salinity areas, linked positively to *Phragmites* coverage.	Decreasing salinity values (below 10 ppt) will lead to a reduction in species richness and biomass (up to about 30-40%). The two species most affected will be *Boccardia* sp. and *Ceratonereis erythraeensis*, both ranked among the five most important species in intertidal habitats. At higher intertidal levels on the floodplain, reduced flooding and less frequent inundation will lead to increasing salt content of the sediment and greater compactness, both impacts leading to decreased invertebrate biomass. Part of the floodplain will also become completely barren of fauna in some areas.	Species richness will decrease below about 10 ppt. *Callianassa kraussi* is the most important species from a biomass perspective. Breeding ceases below about 17ppt and biomass will decline progressively as no new recruits enter the population. However, new recruits are able to colonize from downstream areas where salinity values remain suitable.	Species richness will decrease below about 10 ppt. *Corophium triaenonyx* and *Gradiidierella lutosa*) and polychaetes (32% by number – (particularly *Boccardia* sp. and *Ceratonereis keiskama*) particularly abundant. Adults adapted to low salinity values (mud prawns and amphipods), but breeding ceases temporarily if salinity falls below ca5-10ppt.
%fines (<63micron) in sediment	No influence	No influence	No influence	Species mix will shift as percentage fines decrease. Mud prawns will also disappear if sediment becomes too sandy. At the other extreme, increasing fines can lead to anoxic conditions developing and a decrease in species richness and biomass	Species mix will shift as percentage fines decrease. Increasing fines can lead to anoxic conditions developing and a decrease in species richness and biomass	Species mix will shift as percentage fines decrease. Increasing fines can lead to anoxic conditions developing and a decrease in species richness and biomass
% sands (180-350 micron) in sediment	No influence	No influence	No influence	Species mix will shift as percentage sand decreases – *Callianassa* is an example	Species such as *Callianassa*, *Urothoe* spp. (Amphipoda), *Iphinoe* sp. (Cumacea) will decrease or even disappear as this sand fraction decreases.	Species mix will shift as percentage sand increases – *Grandidierella* and *Corophium* (amphipods) are two examples of important species.
Water depth	Linked to volume – water depth provides habitat – greater biomass.	Linked to volume – water depth provides habitat – greater	Linked to volume – water depth provides habitat – greater	No influence	Provides a buffer against low salinity and strong water currents – biomass	Provides a buffer against low salinity and strong water currents – biomass

Invertebrates	Copepods	Mysids	Carid shrimps	Intertidal benthos	Sandy Subtidal benthos (Caliannassa etc)	Muddy subtidal benthos
		biomass.	biomass.		maintained.	maintained.
Phytoplankton abundance	Copepods utilize phytoplankton as a source of food and therefore respond positively to phytoplankton abundance. However, other food sources are also utilized so that it is only low concentrations of phytoplankton than begin to influence copepod abundance.	The two mysid species respond in a similar way to the copepods, although as *Rhopalophthalmus terranatalis* matures. It becomes more predatory, consuming a range of food sources.	Probably only the juveniles – late stage larvae are dependent to some extent on phytoplankton.	Overall, phytoplankton probably plays a minor role in the diet of the intertidal organisms.	Similar to the benthos.	Similar to the benthos.
Submerged macrophytes	Provision of detritus is a major source of food derived from the submerged macrophytes.	Same for the mysid juveniles, as well as for *Mesopodopsis wooldridgei*.	Provides a major habitat for carids, as well as a source of food via the detrital pool.	Detritus derived from the macrophytes is a major source of food for the intertidal group as a whole.	Detritus derived from the macrophytes is a major source of food for the intertidal group as a whole.	Detritus derived from the macrophytes is a major source of food for the intertidal group as a whole.
Emergent macrophytes	Provision of detritus is a major source of food derived from the submerged macrophytes.	Same for the mysid juveniles, as well as for *Mesopodopsis wooldridgei*.	Provides a major habitat for carids and other organisms such as amphipods, isopods, as well as a source of food via the detrital pool.	Detritus derived from the macrophytes is a major source of food for the intertidal group as a whole.	Detritus derived from the macrophytes is a major source of food for the intertidal group as a whole.	Detritus derived from the macrophytes is a major source of food for the intertidal group as a whole.
Intertidal saltmarsh	Limited influence	Limited influence	Limited influence	Detritus derived from the salt marshes provides a major source of food for intertidal organisms.	Limited influence	Detritus derived from the salt marshes provides a source of food for intertidal organisms.
Microalgal coverage and detritus derived from the microalgae	An important source of food for benthic copepods – harpacticoids for example.	Provision of a component of the food consumed by mysids.	Carids and other organisms (amphipods and isopods are examples) will utilize the microalgae extensively	Intertidal organisms (polychaete worms is an example) will utilize the microalgae extensively	The subtidal benthos (amphipods and isopods are examples) will utilize the microalgae and detritus associated with the microalgae extensively	The subtidal benthos (amphipods and isopods are examples) will utilize the microalgae and detritus associated with the microalgae extensively

Table 3.23 The effect of abiotic and biotic drivers on the fish of the Berg River Estuary

Fish	Ia. Estuarine residents (breed only in estuaries)	Ib. Estuarine residents (breed in estuaries and the sea)	IIa. Estuary dependent marine species	IIb and c. Estuary associated species	III. Marine migrants	IV. Euryhaline freshwater species
Freshwater inflow	Maintains salinity regime favourable for estuarine species	Maintains salinity regime favourable for estuarine species. Freshwater release from the mouth of the estuary provides an olfactory cue that assists these species to locate and recruit into estuaries	Freshwater release from the mouth of the estuary provides an olfactory cue that assists these species to locate and recruit into estuaries	Freshwater release from the mouth of the estuary provides an olfactory cue that assists these species to locate and recruit into estuaries	Reductions in freshwater inflow	Maintains salinity regime favourable for freshwater species
Salinity	Species in this category have wide salinity tolerances but mostly favour intermediate salinities typically found in the middle and lower reaches of the estuaries. These species breed in the upper reaches of estuaries where salinity is close to that of freshwater. Species in this category will be negatively affected by the loss of low salinity habitat at the head of the estuary.	Species in this category have wide salinity tolerances but mostly favour intermediate salinities typically found in the middle and lower reaches of the estuaries. Species in this category will be negatively affected by the loss of low salinity habitat at the head of the estuary.	Species in this category have wide salinity tolerances but mostly favour intermediate salinities typically found in the middle and lower reaches of estuaries.	Species in this category have wide salinity tolerances but mostly favour intermediate salinities typically found in the middle and lower reaches of estuaries.	Species in this category have a narrow salinity tolerance range, are likely to have benefited from reduced freshwater inflow to the estuary, and will benefit from any further reductions.	Species in this category have wide salinity tolerances but mostly favour low salinities typically found in the upper reaches of estuaries. Species in this category will be negatively affected by the loss of low salinity habitat at the head of the estuary.
Floods	Freshettes at the start of winter provide a cue for these species to undertake upstream spawning migrations. Floods scour the estuary, flush out accumulated sediments and organic material and shift the salt wedge back towards the mouth.	Floods scour the estuary, flush out accumulated sediments and organic material and shift the salt wedge back towards the mouth.	Floods scour the estuary, flush out accumulated sediments and organic material and shift the salt wedge back towards the mouth.	Floods scour the estuary, flush out accumulated sediments and organic material and shift the salt wedge back towards the mouth.	Reductions in flood magnitude and frequency will have had a positive impact on these species	Floods scour the estuary, flush out accumulated sediments and organic material and shift the salt wedge back towards the mouth.
Shallow water habitat	Species in this category are mostly small (<120 mm TL), benthic feeders, and favour shallow water habitat adjacent to the estuary	Species in this category are mostly small (<120 mm TL), benthic feeders, and favour shallow water habitat adjacent to the estuary banks where	Species in this category are mostly represented by juveniles that are small (<200 mm TL), and favour shallow water habitat	Species in this category are mostly represented by small juveniles (<200 mm TL) that favour shallow water habitat adjacent to the estuary banks		

Fish	Ia. Estuarine residents (breed only in estuaries)	Ib. Estuarine residents (breed in estuaries and the sea)	IIa. Estuary dependent marine species	IIb and c. Estuary associated species	III. Marine migrants	IV. Euryhaline freshwater species
	banks where food is abundant and piscivorous predators are rare. The loss of intertidal and shallow water subtidal habitat in the estuary has had a negative effect on most of these species. *G. aestuaria* is an exception in this respect.	food is abundant and piscivorous predators are rare. The loss of intertidal and shallow water subtidal habitat in the estuary has had a negative effect on most of these species.	adjacent to the estuary banks where food is abundant and piscivorous predators are rare. The loss of intertidal and shallow water subtidal habitat in the estuary has had a negative effect on most of these species.	where food is abundant and piscivorous predators are rare. The loss of intertidal and shallow water subtidal habitat in the estuary has had a negative effect on most of these species.		
Phytoplankton biomass	Filter feeding species in this category (viz. *G. aestuaria*) would respond positively to increased phytoplankton biomass in the estuary, their main food source.	Filter feeding species in this category (viz. *A. breviceps*) would respond positively to increased phytoplankton biomass in the estuary, their main food source.	Filter feeding species in this category (viz. *M. cephalus*) would respond positively to increased phytoplankton biomass in the estuary, their main food source.	Filter feeding species in this category (viz. *L. richardsonii*) would respond positively to increased phytoplankton biomass in the estuary, their main food source.	Filter feeding species in this category (e.g. *E. capensis, S. sagax*) would respond positively to increased phytoplankton biomass in the estuary, their main food source.	
Benthic micro-algae biomass	No herbivorous species in this category	No herbivorous species in this category	Herbivorous species in this category (viz. *M. cephalus*) would respond positively to increased microalgae biomass in the estuary.	Herbivorous species in this category (viz. *L. richardsonii*) would respond positively to increased microalgae biomass in the estuary.	No herbivorous species in this category	No herbivorous species in this category
Zooplankton biomass	Zooplanktivorous species in this category (viz. *G. aestuaria*) would respond positively to increased zooplankton biomass in the estuary and negatively to a reduction in biomass	Zooplanktivorous species in this category (viz. *A. breviceps*) would respond positively to increased zooplankton biomass in the estuary, and negatively to a reduction in biomass.	Zooplanktivorous species in this category (viz. *S. temminkii*) would respond positively to increased zooplankton biomass in the estuary, and negatively to a reduction in biomass.			
Benthic invertebrate biomass	Benthic invertebrate feeders in this category (viz. *C. multifasciatus*) would respond positively to increased zooplankton biomass in the estuary and negatively to a reduction in biomass.	Benthic invertebrate feeders in this category (viz. *C. nudiceps, P. knysnaensis, and C. superciliosus*) would respond positively to increased zooplankton biomass in the estuary and negatively to a reduction in biomass.	Benthic invertebrate feeders in this category (e.g. *L. lithognathus, R. globiceps*) would respond positively to increased zooplankton biomass in the estuary and negatively to a reduction in biomass.	Benthic invertebrate feeders in this category (e.g. Solea bleekeri, *R. globiceps*) would respond positively to increased zooplankton biomass in the estuary and negatively to a reduction in biomass.	Benthic invertebrate feeders in this category (e.g. *R. blochii, R. annulatus*) would respond positively to increased zooplankton biomass in the estuary and negatively to a reduction in biomass.	

Fish	**Ia. Estuarine residents (breed only in estuaries)**	**Ib. Estuarine residents (breed in estuaries and the sea)**	**IIa. Estuary dependent marine species**	**IIb and c. Estuary associated species**	**III. Marine migrants**	**IV. Euryhaline freshwater species**
Turbidity	Turbidity provides small (juvenile) fish with cover from visually orienting predators (birds and some fish) but high levels of turbidity can clog gills and compromise foraging ability. Estuarine species are typically adapted to relatively high turbidity levels.	Turbidity provides small (juvenile) fish with cover from visually orienting predators (birds and some fish) but high levels of turbidity can clog gills and compromise foraging ability. Estuarine species are typically adapted to relatively high turbidity levels.	Turbidity provides small (juvenile) fish with cover from visually orienting predators (birds and some fish) but high levels of turbidity can clog gills and compromise foraging ability. Estuary associated species are typically adapted to relatively high turbidity levels.	Turbidity provides small (juvenile) fish with cover from visually orienting predators (birds and some fish) but high levels of turbidity can clog gills and compromise foraging ability. Estuary associated species are typically adapted to relatively high turbidity levels. Olfactory orienting (ambush) predators (e.g. A. coronus) would benefit from increased turbidity while the reverse would be true for the visually orienting predators (e.g. *P. saltatrix*).	Turbidity provides small (juvenile) fish with cover from visually orienting predators (birds and some fish) but high levels of turbidity can clog gills and compromise foraging ability. Marine species that stray into estuaries are generally not well adapted to relatively high turbidity levels.	Turbidity provides small (juvenile) fish with cover from visually orienting predators (birds and some fish) but high levels of turbidity can clog gills and compromise foraging ability. Freshwater species found in estuaries are typically adapted to relatively high turbidity levels and would thus not be seriously affected by an increase in turbidity.
Aquatic macrophyte cover	Some species in this category utilise submerged aquatic macrophytes for cover (e.g. *C. multifasciatus*) attachment of eggs (e.g. *G. aestuaria*). Excessive macrophyte growth can lead to oxygen depletion which would adversely affect fish populations	Some species in this category associate strongly with submerged aquatic macrophytes (e.g. *S. temminkii*). Excessive macrophyte growth can lead to oxygen depletion which would adversely affect fish populations	Some species in this category associate strongly with submerged aquatic macrophytes (e.g. *R. holubi*). Excessive macrophyte growth can lead to oxygen depletion which would adversely affect fish populations	Excessive macrophyte growth can lead to oxygen depletion which would adversely affect fish populations	Excessive macrophyte growth can lead to oxygen depletion which would adversely affect fish populations	Excessive macrophyte growth can lead to oxygen depletion which would adversely affect fish populations
Dissolved oxygen	All fish species require oxygen for survival but most species in this category are tolerant of low oxygen levels, particularly *C. multifasciatus.* However, a significant reduction in levels of dissolved oxygen would have a negative effect on species in this group.	All fish species require oxygen for survival. Species in this category vary considerably in their tolerance of low oxygen levels – A. breviceps, for example is very intolerant of low oxygen while the gobies *C. nudiceps, P. knysnaensis* are highly tolerant. A significant reduction in levels of dissolved oxygen would have a negative effect on species in this group.	All fish species require oxygen for survival. Species in this category not tolerant of low oxygen levels and would be negatively affected by any reduced in dissolved oxygen. However, a significant reduction in levels of dissolved oxygen would have a negative effect on species in this group.	All fish species require oxygen for survival. Species in this category not tolerant of low oxygen levels and would be negatively affected by reduced oxygen levels.	All fish species require oxygen for survival. Species in this category not tolerant of low oxygen levels and would be negatively affected by reduced oxygen levels.	All fish species require oxygen for survival but most freshwater species are tolerant of low oxygen levels particularly *G. zebratus* (the only indigenous species in the estuary). A significant reduction in levels of dissolved oxygen would have a negative effect on species in this group.

Table 3.24 The effect of abiotic and biotic drivers on the birds of the Berg River Estuary

Birds	**Herbivorous Waterfowl**	**Omnivorous Waterfowl**	**Piscivorous waterfowl** (grebes)	**Wading/swimming Piscivores** (herons, egrets, reed corm, etc)	**Perching/aerial Piscivores** (kingfishers, birds of prey)	**Greater flamingo**	**Lesser flamingo**	**Macrobenthic feeding waders**	**Piscivorous gulls and terns**
Size of intertidal area	Positive as roosting area			Slightly Positive as roosting area				Major Positive	
Size of shallow water area				Positive		Positive	Positive	Positive	
Sandiness of intertidal areas								Negative	
Flow velocities (tidal or river inflow)	Negative	Negative	Negative	Negative					
Salinity:	Negative	Uncommon at high salinity	Negative				Positive – hypersaline		
Microalgae abundance							Positive, but limited since at Berg River Estuary feeding is mainly in artificial habitat		
Aquatic plant abundance	Positive	Positive							
Emergent and marginal vegetation	Positive	Positive	Positive influence on Little Grebe	Positive	Positive if adds suitable perching sites				
Macrozooplankton abundance		Positive							
Intertidal invertebrate abundance						Positive		Positive	
Abundance of fish in small-med size classes			Positive	Positive	Positive				Positive

Freshwater enters the estuary in the form of lowflows and floods. Baseflows affect salinity structure, water residence time, turbidity and sediment deposition in the system, as well as influencing the amount of nutrients introduced into the system by determining the ratio of inputs from the catchments versus from the sea. Floods affect the degree of inundation of the floodplain and sediment scouring, and also the salinity structure and the total nutrient input into the estuary.

Baseflow and flood velocities affect the nature and amount of physical habitats (sand and mud) while salinity and the degree of inundation affect the nature and amount of biotic habitat (e.g. mudflats, reedbeds, salt marshes).

Salinity affects the species composition of all of the biotic components, with different species having different salinity tolerance ranges. Abundance and productivity are largely influenced by availability of food. Freshwater flows bring the bulk of the nutrients into the system, which directly or indirectly feed all of the biotic components, and lowflows and tidal state determine the water residence time, which allows the nutrients to be used in micro- and macrophytic production. It is hypothesised that there is an optimal lowflow, which maximises microalgal productivity, all else being equal. Microalgal productivity is the most important determinant of overall biomass of estuarine biota, with most trophic pathways originating in microalgal rather than macrophyte (plant) productivity.

The temporal patterns of flow are also an important factor shaping the nature of the system. For example, aseasonal flooding may not benefit floodplain birds or facilitate fish recruitment into the estuary.

The biomass of all consumer groups is determined by a combination of food and habitat, either of which may be limiting, but both of which are influenced by some aspect of flow. Given the artificially high nutrient inputs into the system, it is likely that habitats requiring higher levels of inundation or scouring constitute the most significant limiting factor in the system, or might become so. Any reduction in flow will have a greater impact on the fauna and flora of the system through loss of habitat rather than reduction in food supply.

Species diversity is primarily determined by habitat but is also a function of overall system productivity and stability. While variable habitats may support high instantaneous diversity at times, when conditions attract opportunistic species, specialist resident species will only occur when specific habitats or conditions are permanently available.

Table 3.25 summarises the living resources utilisation and its direct affect on the estuarine biota.

Table 3.25 Summary of the living resources utilisation in the Berg River Estuary

Activity	Present	Describe impact
Recreational fishing	Yes	An increasingly popular destination for recreational fishers. Catch rates are currently higher than those experienced in other estuaries in the country and are driving further increases in effort. Catches include large numbers of juvenile fish under the minimum size, particularly white steenbras and elf and are contributing to the decline in abundance of these species in the system
Commercial/Subsistence fishing (e.g. gillnet fishery)	Yes	Historically, commercial gill and beach seine net fishers operating in the Berg River Estuary and St Helena Bay have had an enormous impact on fish populations in the estuary through overfishing of adult stocks. All commercial gill net permits on the Berg River Estuary were withdrawn in 2003 and numbers of permit holders in St Helena Bay were dramatically reduced. A dramatic recovery was evident in the abundance of the main target species Liza richardsonii as well as many of the bycatch species (*P. saltatrix* and *L. lithognathus*) in the years immediately following the ban largely thanks to active enforcement and good compliance.
Traditional fish traps	No	
Illegal fishing (Poaching)	Yes	Illegal gill net operations have escalated in recent years and now reportedly approaches level seen prior to the ban. Fish populations particularly the marine migrant species, are expected to decline again as a result.
Bait collection	Yes	Localized disturbance of sediments during the collection process.
Aquarium fish collecting	Negligible	
Inappropriate levels of recreational activities (e.g. fishing competitions)	Yes	One marine has been constructed on the estuary and another has been proposed. Recreational boat traffic on the estuary is currently low but is escalating. There is some erosion of banks due to boating and loss of habitat.
Mariculture	No	
Harvesting of mangroves and reeds / sedges	No	
Grazing and trampling of salt mashes	Yes	This has had a severe impact on the salt marsh, xeric floodplain and reed and sedge habitats. Floodplain vegetation is heavily utilised by cattle for grazing during the dry summer months. This has resulted in loss of vegetation cover, erosion and barren windswept areas. The situation will be exacerbated by a decrease in flooding and increase in drought conditions due to freshwater abstraction as well as climate change.
Translocated or alien fauna and flora	Yes	Water hyacinth (*Eichhornia crassipes*) occurs in the upper reaches of the estuary and is indicative of eutrophication. Thick mats of these plants are deposited after flooding on the inundated mudflats, causing die-back of the salt marsh and severely influencing the benthic invertebrate biomass and therefore bird numbers. *Enteromorpha flexuosa,* an alien species native to Europe, is one of several *Enteromorpha* species that is found on intertidal mudflats in the lower reaches of the estuary.
Bait collection	Yes	Reduction in biomass and destruction of habitat through trampling. Smaller organisms and newly settled prawns most vulnerable to trampling as they burrow in close proximity to the surface.

3.2.3 Present state

MICROALGAE
Microalgal data were based on a 2005 study, prior to the completion of the Berg River Dam. However, the difference in flow is not likely to be significant as there is little difference in flow states between the present state and Scenario 1. August 2005 (flow state 5; <5 ‰ throughout): Phytoplankton Chl-a ranged from 6.3 to 10 µg/L with a distinct peak measured at and immediately downstream of De Plaat. Flagellates (80.8%) and diatoms (17.4%) dominated the phytoplankton. Flagellates (bloom densities of ~85 000 cell/ml) and diatoms (bloom densities of ~34 000 cells/ml) and Cyanophyte (~4200 cells/ml) densities were highest 10.1 km from the mouth at De Plaat. Dinoflagellates were present in low density (<2000 cells/ml) and restricted to the upper reaches and 3.2 km from the mouth. Benthic Chl a ranged from 2.6 to 31.5 µg/g in the intertidal zone and 2.1 to 12.6 µg/g subtidally. The intertidal Chl a measured in the soft sediment of the blind arm near to the mouth of the estuary was significantly higher than the rest of the estuary. The subtidal Chl a at sites 0.7 km, 0.8 km, 3.2 km and 10.1 km were significantly higher than in the rest of the estuary. November 2005 (flow state 3; Zone A = 23-35‰ and Zone B = 0.4-7.0‰): Phytoplankton Chl-a was surprisingly low ranging from 0.3 to 6.6 µg/L (values of 5-20 µg/L punctuated with bloom concentrations - >20 µg/L – were expected). Chl-a increased with distance reaching a maximum 43 km from the mouth of the estuary. Diatoms (50.3%) and flagellates (47.6%) dominated the phytoplankton. Dinoflagellates were present throughout most of the estuary (cell density up to ~8500 cells/ml) and were expected to reach bloom densities (>10 000 cells/ml) in late summer, particularly if flow state 2 persists for 2-3 months. In November the benthic Chl-a concentration ranged from 1.5 to 3.9 µg/g in the intertidal zone and 0.8 to 14.9 µg/g in the subtidal zone. The intertidal Chl a was significantly higher at sites 0.8 km and 16.5 km than all other sites. Subtidal Chl a in November was separated into three groups based on statistical analyses. Chl a at sites 0.8 km, 10.1 km, 28 km and 43.2 km were significantly higher than all other sites, and Chl a at sites 15 km and 16.5 km were significantly higher than sites 0.7 km, 3.2 km and 6 km. The average intertidal and subtidal Chl a concentrations were significantly lower in November compared to August. This was surprising as flow was substantially lower creating a more stable benthic environment. Slinger and Taljaard (1994) measured phytoplankton Chl-a in September 1989 (~1.7 µg/L) and January/February 1990 (~0.2 µg/L). The averages were much lower than in 2006 and are more typical of oligotrophic systems. Confidence: High
MACROPHYTES
The Berg River Estuary has by far the largest and most diverse associated saline and freshwater wetlands compared to all other permanently open estuaries in South Africa. It is therefore a unique system worthy of conservation. Large areas are occupied by halophytic floodplain, open pan, sedge pan and xeric floodplain. By comparison, the supratidal and floodplain habitats of the Olifants Estuary occupy 143 and 797 ha respectively. The habitats in the Berg River Estuary are degraded and 26% of total estuarine area has been lost due to agricultural, urban and other activities. All habitats are dependent on flooding (both tidal and riverine) and suitable salinity. Any changes in these drivers will reduce the species richness, growth, cover, distribution and community composition. An estimate is provided below of the area lost for the different macrophyte habitat types. Anthropogenic activities would have resulted in a greater loss of habitats situated further from the water's edge i.e. more terrestrial habitats.

Estimated loss of specific area of macrophyte habitat type as a result of anthropogenic impacts.

Macrophyte habitat type	Mapping unit (Boucher and Jones 2007)	Area cover (ha)	Area lost (ha)	%
Submerged macrophytes	Intertidal mudflats	206	8.24	5
Intertidal salt marsh	Halophytic salt marsh	124	6.2	5
	Sedge marsh	375	37.5	10
	Open pan	1159	173.9	15
Supratidal salt marsh	Halophytic floodplain	1521	912.6	60
	Xeric floodplain	919.1	551.5	60
Reeds and sedges	Normal tall reed marsh	513.5	102.7	20
	Short reed marsh	73.1	14.6	20
	Sedge pan	975.1	292.5	30
	Total	**5866**	**2100**	
			26%	

Confidence: M

INVERTEBRATES

The invertebrate fauna in the Berg River Estuary under present-day conditions is extremely rich in terms of biomass. The water column (zooplankton), intertidal and subtidal benthic habitats in the Berg River Estuary support biomass levels (per unit volume or area) that rank among the highest recorded for these invertebrate groups in South African estuaries in general. The size of the estuary further underscores exceptionally high biomass levels. This is a relatively unique situation and the estuary provides wide and rich foraging opportunities for higher trophic levels, both in the water column and benthos. A comparison with the natural state when freshwater conditions persisted for longer is replicated under present-day seasonal comparisons. All three major groups of invertebrates reflect fewer species and lower biomass during high-flow winter periods compared to summer (by approximately 40%). However, under present day conditions, approximately 40% of the estuarine vegetation has been lost and this transforms in to a major decline in available habitat utilized by intertidal invertebrates on intertidal mudflats (5% lost), open pans (73% lost) and other vegetated areas (approximately 50% lost).

Confidence: M

FISH

The Berg River Estuary under present day conditions provides an extremely important habitat for fish. Compared to the adjacent marine coastal waters of the West Coast, the Berg River Estuary is highly productive, and includes a significant amount (~30%) of the available calm, shallow, and warm water habitat that is important as a nursery and feeding ground for many fish species. These attributes promote rapid growth and/or reduced mortality for fish species, hence making them ideal environments for colonisation by juveniles of marine species. Under present day conditions, the fish fauna of the Berg River Estuary includes significant population of 12 fish species, down from an estimated 17 species under Reference conditions (see Table 3.18, first 12 species on the table). Of the remaining five specie, four (white stumpnose, white steenbras, kob, leervis) are still represented in the system but such low numbers of individuals that they cannot be considered viable populations of these species. At least one species has been lost from the system entirely (witvis). Reasons for the loss of these species is primarily non-flow related (due to overexploitation of adult stocks nationally – the former) and introduction of alien invasive freshwater fish to the Berg system (the latter). Overall abundance of fish under present day conditions is estimated to be higher than under natural conditions and is mostly related to increased abundance of the two dominant species in the system – *Liza richardsonii* and *Gilchristella aestuaria*. These two species are both filter feeders, have benefitted from the increase in productivity, and hence amount of food available in the system. Abundance of Liza richardsonii is considered only marginally elevated above the Reference condition (~30%) but would be very much higher than this in the absence of historical legal gill net fishing in the estuary and the sea, and current illegal fishing activity in the estuary. Abundance of most of the marine migrant species (aside from *L. richardsonii*) are estimated to be severely depressed (mostly <10% of Reference) due to impacts of legal and illegal fishing. Their numbers make up a very small proportion of total abundance and hence their loss contributes little to the change in abundance score. The reduction in low salinity habitat at the head of the estuary (i.e. between 35 and 45 km upstream of the mouth) will also have negatively affected the abundance of many fish species in the estuary, particularly the estuarine resident species (e.g. *Caffrogobius multifasciatus*).

Confidence: M

BIRDS

The Berg River Estuary under present day conditions is one of the most important estuaries in the country in terms of the numbers and diversity of birds. Excluding exotic and vagrant species, some 93 non-passerine waterbird species have been recorded in seasonal counts of the estuary. Charadriiformes (waders, gulls and terns) account for 41% of the species recorded, with most of these being wader species. More than half of the 27 wader species are Palaearctic migrants. An average of 62.6 (± 4.5) and 60.5 (± 15.7) species have been recorded in summer and winter CWAC counts, respectively (1994 – 2006), with an average number of 13 700 and 12 300 non-passerine waterbirds recorded in summer and winter CWAC counts, respectively. Waders are the dominant (and most diverse) group, followed by herbivorous waterfowl, which are dominated by Redknobbed Coot.

Group	Average summer numbers	Composition
Herbivorous waterfowl	3 574	23%
Piscivorous waterfowl	262	2%
Omnivorous waterfowl	668	4%
Piscivores	1 863	12%
Greater Flamingo (Invertebrate feeders)	632	4%
Lesser Flamingo (Phytoplankton)	336	2%
Waders (Invertebrate feeders)	6 314	41%
Gulls and terns (Piscivores)	1 658	11%

Although the waders of the lower estuary constitute the largest group, the floodplain wetlands account for much of the diversity and numbers of the estuary as a whole, containing a large proportion of the waterfowl and piscivorous birds. Flamingos mainly occur in the artificial saltpans.

Note that the data describe the situation up to 2006, thus describing a recent baseline condition rather than the state that will develop under present flow conditions, which have changed since then. This has been taken into account in the assessments of PES and the Scenarios. See Appendix H for a detailed baseline description of birds.

Confidence: H

3.2.4 Changes in biotic characteristics relative to the Reference Condition

MICROALGAE

River flow would have exceeded 1 m^3s^{-1} with frequent flooding and combined with low nutrient loads would have supported low average microalgal biomass; phytoplankton (<2 µg/L) and MPB (<5 µg/g). The phytoplankton would have been dominated by freshwater taxa (predominantly diatoms and chlorophytes) and diatoms – a mix of epipelic and episammic forms – would have dominated the sediment.

Confidence: M

MACROPHYTES

The same mix of habitat types would have been present but with a higher overall plant cover i.e. 7966 ha compared to 5866 ha (present). The fresher habitats would have been more abundant. Due to strong river and tidal flow, macroalgae in the lower reaches of the estuary would have been scarce. No aquatic invasives such as *Eicchornia crassipes* in the upper reaches or disturbance on the marshes and floodplain. No exotic trees invasive in the riparian zone. Possibly higher overall species richness. Presently *Phragmites australis* spreads into areas after disturbance such as fire displacing species rich wetland habitats. The open pan and floodplain areas would have been less saline and stayed inundated and moist for a longer period. Bare areas because of hypersaline conditions and leaching of salt from the salt works would have been vegetated. Reeds and sedges would have lined the banks closer to the mouth under Reference conditions.

Confidence: M

INVERTEBRATES

Because of greater river dominance within years, biomass levels of the zooplankton and subtidal benthos under natural conditions were probably 30-40% lower compared to present day conditions. Much of the estuary experienced salinity values of <5ppt (Zones B, C, D) on average under natural conditions. River dominance therefore persisted for longer within years.

Intertidal biomass levels however, were significantly greater under natural conditions because of the greater availability of habitat, particularly in Zone A. Much of this area now altered – roads, buildings, wharfs, embankments etc. The frequency of flooding and the persistence of freshwater inundating the floodplain would have maintained relatively low salinities (removal of accumulated salts in the sediment) more suitable for invertebrates. In addition, the presence of commercial saltpans has lead to a significant decrease in available habitat for colonization. Parts of the floodplain would also dry out completely during dry years, particularly during droughts that persist for up to 8 years at a time.

Intertidal and subtidal sandbanks in the former channel near the mouth (running south and parallel to the coast for about 1 km – present day blind arm) would have provided extensive habitat for the sand infauna. Currently, the mouth and lower estuary are dredged to maintain a deep channel. Because of managed mouth conditions (present day), tidal currents are stronger leading to more course sediments that are less suitable for benthic invertebrates in the lower estuary – under natural conditions the choked mouth during summer would have resulted in finer sediments in the lower estuary. The present blind arm at the mouth has now become fine mud, compared to its previous sandy character, leading to a complete switch in species composition.

The persistence of *Phragmites* nearer the mouth provided additional habitat for carid shrimps such as *Palaemon capensis*. Because of greater marine influence, *Phragmites* beds have disappeared from the lower estuary

Confidence: Medium

FISH
Under Reference conditions the Berg River Estuary was a less productive system with lower phytoplankton and invertebrate biomass and hence less food available for fish. However, national populations of many of the fish species in the system were much greater under Reference conditions due to severe overexploitation of adult stocks (and in some cases juvenile stocks as well) in the intervening years. Thus, populations of some fish species are estimated to be have been smaller under Reference conditions (viz. *L. richardsonii* and *G. aestuaria*) due to their being less food available for them at this time, but populations of most species would have been very much larger under Reference conditions, particularly the juveniles of the larger marine migrant species (white stumpnose, white steenbras, kob, leervis). Given that the former two species are estimated to be overwhelmingly dominant in the system under both Reference but particularly present day conditions, the lower abundance of these species under Reference condition implies that overall abundance of fish in the system would have been lower than under present day conditions. Instantaneous specie richness (i.e. the number of species that would be recorded from a single comprehensive survey of the system) would have been considerably higher under Reference conditions (estimated 17 species versus the present 12). The increased amount of freshwater habitat available at the head of the estuary under Reference conditions would have supported higher numbers of some of the estuarine resident species (e.g. *Caffrogobius multifasciatus*). Confidence: Medium
BIRDS
Analysis of count data for the past 12 years as well as a couple of earlier counts, suggests that there have not been any major trends in terms of avifauna, with numbers of component groups exhibiting high inter-annual variability. However, three observations are important in this regard. 1. Numbers of certain species have increased due to expansions in their regional populations (e.g. Egyptian Goose, Glossy Ibis). 2. Numbers of certain migratory wader species have decreased probably due to deteriorating conditions on their breeding grounds. 3. Numbers of certain species are positively correlated with flow. The first two trends may cancel one another out to some extent in terms of overall numbers, but have also led to a change in species composition, though this is not easy to detect statistically. The third trend suggests that had counts been carried out over the longer term, a gradual decline in numbers of certain groups might have been detected due to reductions in river flow. In addition, there has been major losses of habitat, particularly in the lower reaches. Given these factors, and the increase in disturbance on the system, average species richness and numbers might be expected to have declined. Thus average instantaneous species richness would have been slightly higher in the Reference condition, and the community would have contained a slightly higher proportion of migratory waders, more coots and omnivorous waterfowl on average due to more vegetated habitats and flooding of the floodplain, and a lower proportion of wading birds. See Appendix H for a detailed baseline description of changes in bird fauna over the period 1994-2006. Confidence: Medium

3.3 Economic value of the Berg estuary

3.3.1 Introduction

South Africa has roughly 258 functioning estuaries along its approximately 3 100 km coastline. Many human activities undertaken in estuaries and their catchment areas impact directly on estuarine biodiversity and resource stocks, and different activities often conflict with one another through such impacts. If estuaries and their catchments are to be managed in an optimal sustainable way, it is necessary to understand the full economic value of the goods and services that they provide. This is generally assessed within a modified Total Economic Value Framework, which includes subsistence, property, tourism, nursery, and existence value of estuaries (Turpie and Clark 2007).

Subsistence value is the value derived from subsistence fishers who harvest resources (e.g. fish, reeds, building material) from an estuary. Property value of estuaries is the premium paid for access to or views of estuaries and represents the value or willingness to pay for that amenity. Tourism value of an estuary is reflected in visitors' expenditure on travel to get to the estuary and accommodation at the site. The nursery value of an estuary is the value that a system contributes to marine fishery production through the provision of nursery habitat for commercially or recreationally valuable species. The existence value of estuaries is the feeling of satisfaction that their existence generates. People are willing to pay to maintain that feeling and this willingness to pay is used to reflect this value in monetary terms. This is extremely difficult to quantify accurately and was not attempted in this study.

The recreational use value of an estuary includes its aesthetic value, and is expressed in terms of (i) expenditure by visitors on trips to the estuary, and (ii) by investment in property with access to or views of the estuary, in the case of residents and holiday homeowners. This expenditure impacts on the broader economy, creating income for the tourism industry, the real-estate sector and other knock-on effects. Moreover, the existing expenditure may be less than users' actual willingness to pay for access to the estuary, with the differential being expressed as the aggregate consumers' surplus. From the users' perspective, total recreational use value in the sense of the total utility or wellbeing derived from the estuary includes this consumer surplus.

This section of the report presents information on subsistence value, property value, visitor expenditure, nursery value of the system for fish, and existence value of the Berg estuary. Details on methods used to assess these values are provided in Appendix I.

3.3.2 Subsistence value of the Berg estuary

Information on subsistence fishing effort on the Berg estuary is available from two sources. Subsistence use of all estuaries between the Orange and the Mdumbe were evaluated by Turpie and Clark (2007) using survey data collected as part of the Subsistence Fisheries Task Group assessment (Clark *et al.* 2002, Branch *et al.* 2002). These data were collected by a team of enumerators who were tasked with interviewing key informants knowledgeable regarding subsistence fishing activities in a series of eight regions spanning the South African coastline. Estimates of the total number of subsistence fishers in the area around the Berg estuary was available from Clark *et al.* 2002, while an estimate of the value of the annual subsistence catch from the estuary was derived by multiplying the average catch per resource (invertebrates and fish) caught fisher per annum by an estimate of the value for each as proffered by the fishermen themselves (data from Branch *et al.* 2002). Based on these data, Turpie and Clark (2009) estimated the subsistence value of the Berg estuary to be in the order of R600 000 per annum.

The second source of data is from the work of Hutchings *et al.* (2008) who undertook a survey of linefishing effort on the Berg estuary in the period December 2002 to November 2005. Recreational and subsistence anglers were differentiated through the gear that they used – recreational anglers generally fished with a rod and reel while subsistence fishers generally used handlines – and from information supplied by the anglers themselves. This study was concerned with linefish catch only, and did not include surveys of invertebrate (bait fisheries) or net (illegal gill netting). The total value of the subsistence fishery derived from this study can thus be considered a minimum estimate only. Hutchings *et al.* (2008) authors estimated that average annual subsistence line fishing effort (estimated by extrapolating from instantaneous counts of the number of fishers in each survey section) was in the order of 1 448 shore angler days for the period 2003-2005. Fishing effort was not consistent across all months, and peaked in summer, although fishers remained active for much of the year with low effort only observed during late winter (August-October). Catch-per-unit-effort (CPUE), catch (total number of fish per year), and catch value was estimated separately for the dominant species caught (Table 3.26). Catch value was calculated by multiplying the replacement value of the protein derived from the fish (assumed to be a constant R20/kg for all species) by the average mass of an individual fish in each species by the estimated total annual catch from Hutchings *et al*. (2008). Total value of the subsistence linefish catch from the Berg estuary was estimated at R228 048 per annum. Given that this is a minimum estimate for the fishery as it include only line fishing effort (i.e. does not take account of net fish catch or invertebrates catches) it is likely that the true value lies somewhere between this and the value provided by Turpie and Clark (2008) – i.e. between R2228 000 and R600 000.

Table 3.26. Catch-per-unit-effort (fish.angler^{-1}.hour^{-1}) and total annual catch by species for subsistence fishers on the Berg estuary, December 2002-November 2005 (from Hutchings *et al.* 2008).

Species	CPUE	Annual catch	Value per fish	Total catch value
Elf	1.158	7 846	R 6.00	R 47,076.00
Harder **	1.711	11 237	R 6.00	R 67,422.00
Carp **	0.296	2 688	R 40.00	R107,520.00
Barbel	0.017	158	R 30.00	R 4,740.00
White stump	0.017	109	R 8.00	R 872.00
Gurnard *	0.002	13	R 10.00	R 130.00
Other sp *.	0.006	48	R 6.00	R 288.00
All species	3.207	22 100		R228,048.00

3.3.3 Contribution of the estuary to property value in Veldrif

Veldrif is situated at the mouth of the Berg estuary, and is the only major settlement near the estuary. The recreational value of the Veldrif area is dominated by use of the estuary. The value of property in Veldrif attributable to the presence of the Berg estuary was determined through a Hedonic Pricing Analysis, which is a multivariate statistical technique that allows non-market valuation of the characteristics of a commodity rather than of the entire commodity itself (UNEP 1995).

Information for a total of 264 properties was included in the analysis. Properties were split into those that bordered on the estuary and/or had estuary views (44%), had sea views (14%) or had no view of either (42%). The value of these properties was found to be linked to both the erf size (Figure 3-18) and location (view) (Table 3.27). .

The presence of water frontage or water view made a significant difference to the property value in the area, and houses with canal and estuary frontage had the highest average price (Table 3.27). Houses with canal and estuary frontage were worth about R1.7 million and R1.6 million on average respectively, more than double the average price of properties with no water frontage or view.

There was also a significant positive correlation between house price and distance to the estuary (Figure 3-19).

Table 3.27 Average prices of properties with canal or estuary frontage, sea views and with no water views (2009 Rands).

	Average	SD	Max	Min	n
Canal frontage	1,673,913	639,579	3,500,000	350,000	23
Estuary frontage	1,580,924	1,038,355	6,000,000	10,000	92
Sea view	1,426,838	967,393	4,000,000	10,000	37
No water view	731,717	731,717	6,000,000	8,000	112

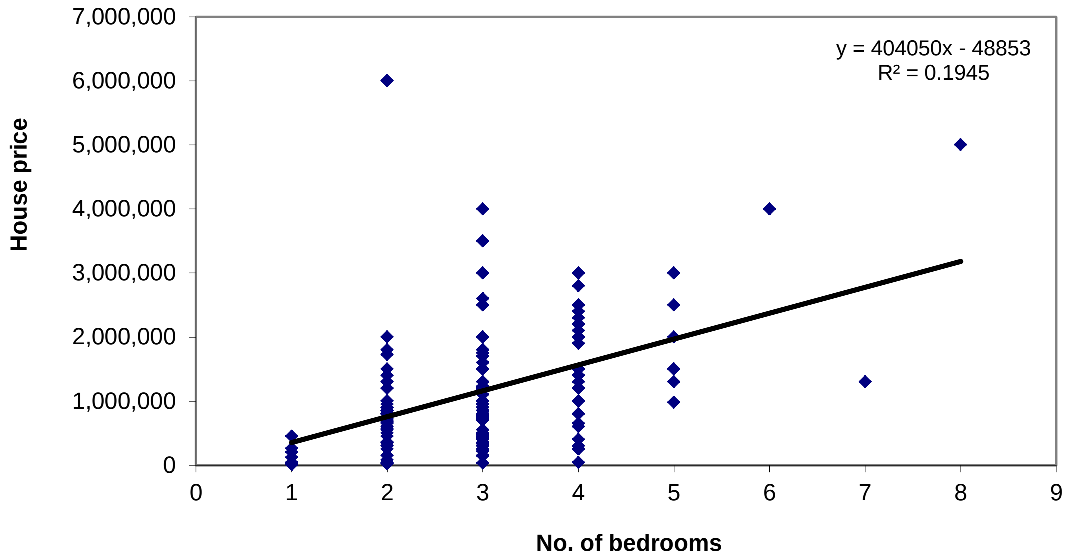


Figure 3-18 Variation of house price in relation to number of bedrooms

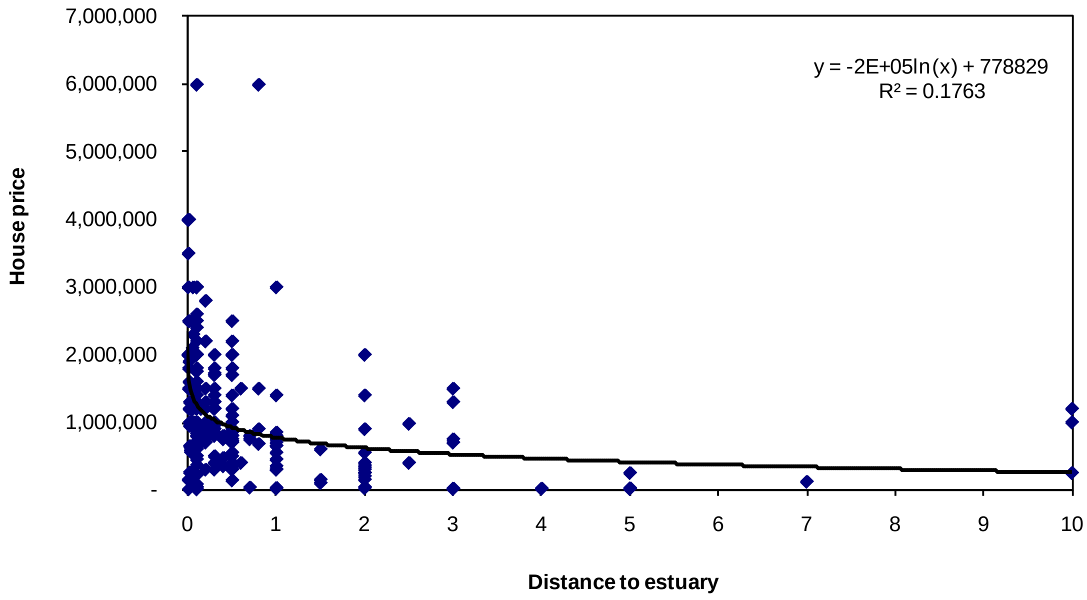


Figure 3-19 Relationship between house price and distance to the Berg Estuary

The hedonic pricing method was applied to determine the overall relationship between property values and a range of other variables. This provided a far stronger relationship than the individual relationships described above. The best-fit regression was obtained with the property size and property area, however the property areas is relative to its position in relation to the estuary and therefore distance to the estuary (km) was used instead.

Property value was modelled as follows (n = 318, $r^2 = 0.24$, $P < 0.001$):

Value = 83 115 + 394 248*B – 129 445*D……………………………………………1

Where B = number of bedrooms and D = distance from the coast in kilometres. Based on this model, property in the Veldrif area was estimated to have a total capital value in the order of R1.8 billion, and the total premium associated with proximity to the Berg estuary was estimated to be just under R900 million. This translates to an annual turnover of about R49 million in the financial and property sectors (Table 3.28).

Table 3.28 Estimated contribution of the estuary to economic output in the financial and property sectors

Suburb	Total Property Value (R millions)	Premium (R millions)	Cost of capital (R millions)	Annual inc to property sector (R millions)	Total turnover (R millions)
Farms	29	11	0.6	0.1	0.6
Laaiplek	376	160	8.0	1.1	9.1
Noordhoek	429	202	10.1	1.4	11.5
Port Owen	327	165	8.3	1.2	9.4
Veldrif	629	315	15.7	2.2	17.9
Total	1 791	853	42.7	6.0	48.6

3.3.4 Expenditure by visitors and residents in Veldrif

The expenditure by visitors to, and residents in the Veldrif area was estimated based on the average expenditure reported in the questionnaire survey and estimated numbers of visitors and residents. Respondents were asked to indicate the total amount their group budgeted to spend during the entire trip, and were reminded to think about their expenditure on accommodation, tours, restaurants, entertainment and shops. They were also asked to indicate the degree to which visiting the Veldrif area was the reason for the trip, expressed as a percentage. Interviewees from the survey were split into permanent residents and visitors. Total number of visitors was estimated on the basis of the ratio between visitors and residents in the survey, where total number of residents was a known value.

Development around the Berg Estuary comprises of four main suburbs (Veldrif, Laaiplek, Noordhoek and Port Owen). Laaiplek is situated near the mouth of the estuary, closest to the beach, and has 353 properties. Port Owen, which is found on the estuary near the marina, has 270 properties, a large proportion of which are found on the marina system. Veldrif, which has 550 properties, is east of Laaiplek and Port Owen, further from the mouth but adjacent to the estuary. North of Veldrif is Noordhoek, the suburb furthest from the estuary, which has 820 properties. This gives a total of 2 017 properties, whose permanent or temporary residents may utilise the estuary to some degree.

The coastal area (coast, beach, and ocean) contributes 30% of people's enjoyment of the Veldrif area, while the estuary alone contributes more than one third (35%), or as much as the other five attractions/amenities combined (Figure 3-20). A variety of activities are carried out on the estuary, with relaxing, walking and swimming being the most important (35%; Figure 3-21). Fishing, bird watching and boating, all of which are potentially affected by changes in flow, make up 19%, 15% and 14% of estuary value, respectively.

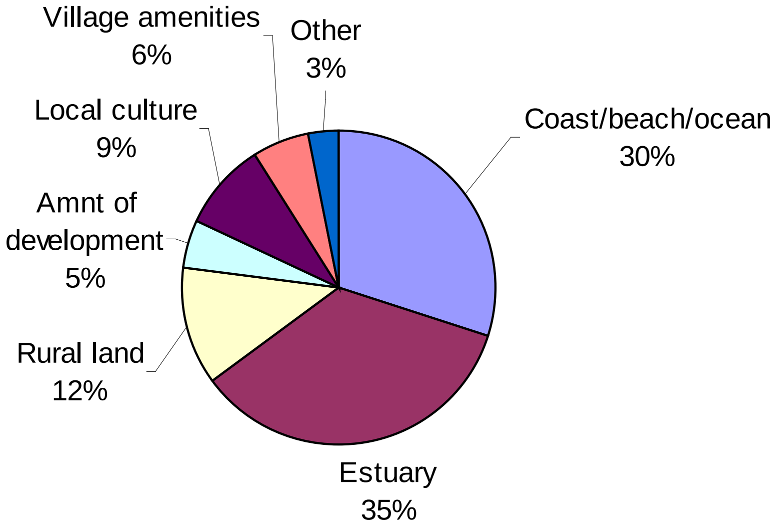


Figure 3-20 Average percentage contribution of different amenities to enjoyment of the area.

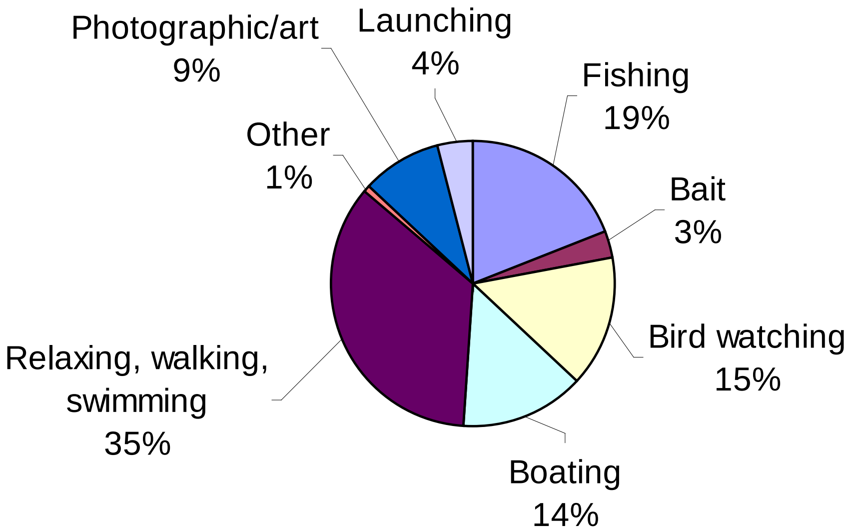


Figure 3-21 Average percentage contribution of different activities to enjoyment of the estuary. Launching means using the estuary to get out to sea.

A high proportion of households have boats, with more than 50% of residents and holiday home owners using boats (Table 3.29), reflecting the high level of use of the estuary. Most of the boats are used either on the estuary or launched from the estuary.

Table 3.29 Average number of boat days per year and the percentage of households/groups with boats

	Avg. boat days per year		Percentage households/groups with boats	
	Non-powered	**Powered**	**Non-powered**	**Powered**
Residents	61.4	37.9	16.2	42.7
Holiday home owners	43.4	86.2	24.5	65.3
Visitors	2.2	16.4	8.5	17

Table 3.30 shows the average length of trip for visitors staying in the Veldrif area, the average expenditure per person per day (pppd) for the trip, and the percentage reason for the whole trip away to come to the Veldrif area. The main types of accommodation for visitors were camping (23%), staying with friends (19%), cottages (19%) and bed and breakfasts (10%).

Table 3.30. Average length of trip to the Veldrif area, average expenditure (pppd) for total trip, and percentage reason for trip to come to the Veldrif area.

	Trip Length (days)	Veldrif area as % reason for trip	Average Spent (R pppd)	
			Accommodation	**Expenses**
Visitors	6.9	89%	R53	R85

Questionnaire surveys revealed that holiday homeowners spend on average 73 days in the area and spend an average of R85 per person per day on expenses. Visitors to the area spend on average R138 per person per day on expenses and accommodation. This estimated total expenditure by holiday home owners and visitors to the area is some R52 million per annum. Given that the estuary contributes 35% of the value to the area, a total of R18.3 million of this visitor expenditure can be attributed to the estuary.

3.3.5 Nursery value of the Berg estuary

One of the most important values of estuarine systems is their contribution to fisheries. Resident fish populations are exploited directly in estuarine recreational and subsistence fisheries. More importantly, though, estuaries provide nursery areas for numerous species of fishes that are exploited by recreational and commercial fishers operating in the inshore marine environment. These species are dependent on estuaries for the early stages of their growth.

The Berg Estuary acts as a very important nursery area for inshore marine fish along the West coast. The affected fisheries in this region are primarily the recreational line fisheries, inshore commercial line and net fisheries, and inshore and estuarine subsistence fisheries. Recreational shore and boat anglers on the West coast take an estimated annual catch of 115 and 407 tons of fish per annum, respectively (Turpie and Lamberth 2003). Spear fishers take an estimated 19 tons. Commercial line and net fishers take a further 10 191 and 4 303 tons, respectively Fish that spend at least part of their life cycle in estuaries contribute up to 83% of the catch weight of these fisheries.

Along the West coast, the recreational fisheries are estimated to be worth R6.2 million per annum and commercial fisheries some R26.1 million (Turpie and Lamberth 2003). Fish that spend at least part of their life cycle in estuaries make up 52.3% of the combined value of these fisheries. Taking into account the degree to which different categories of fish depend on estuaries, the value attributed to estuaries is more conservatively estimated at about 21.3% of overall value, or R745 million for the West coast

The above value is attributed to the combined nursery function of all the estuaries along the West coast. The relative contribution of the different estuaries is unknown, but the yields of the each estuary have been estimated on the basis of catch data (Turpie and Lamberth 2003). Based on the yields of the Berg relative to other West coast estuaries, which contributes about 79.7% of the total, Turpie and Lamberth (2003) estimate the nursery value of the Berg estuary to be in the order of R8.1 million per annum.

3.3.6 Existence value of the Berg estuary

Existence value (otherwise known as non-use value) is typically estimated using the Contingent Valuation Method (CVM). CVM is used to estimate the values associated with resources or products that do not currently fall under existing markets, and thus utilise a simulated market approach (Mitchell and Carson 1989, Garrod and Willis 1999). A 'stated preference' method, CVM elicits a stated willingness-to-pay (WTP) from respondents which is contingent on a hypothetical scenario coming about (Arrow *et al.* 1993). Turpie and Clark (2008) attempted develop estimates of existence values of all temperate estuaries in South Africa (Orange to the Mdumbi) using a combination of contingent valuation and conjoint valuation (choice modelling) methodology. Their estimates are based on a questionnaire survey of 605 respondents in the Western Cape from which overall willingness to pay for estuaries was estimated by extrapolating the above results (WTP for conservation x % allocation to estuaries) to the South African population. Results from this survey and earlier estimates of aggregate WTP for estuarine biodiversity, was disaggregated using a relationship between value and estuary characteristics based on a second survey of 125 respondents who were asked to score the 14 different estuaries used in the first survey in terms of their scenic beauty, independent estimates of which were available for all estuaries in the country. Existence value of the Berg estuary calculated using this approach was estimated to be R176,452 per annum, which places it on the upper end of the spectrum of existence values for temperate estuaries in South Africa.

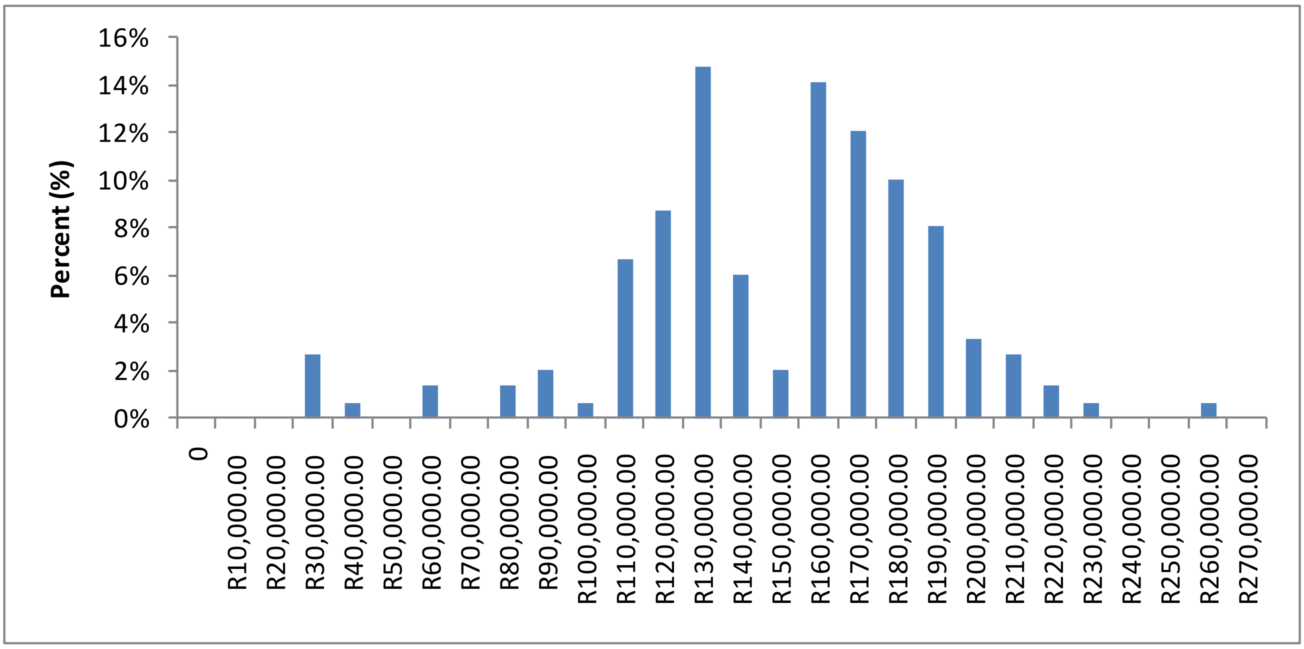


Figure 3-22 Frequency distribution for existence value of temperate estuaries in South Africa (Orange to Mdumbi) (Data from Turpie and Clark 2008).

3.3.7 Total economic value of the Berg estuary

Adding up all the components of value for the Berg estuary, as described above, allows for an estimate of total economic value of the system under present day conditions to be generated. The various components of value are summarised in Table 3.31 along with the estimate of total economic value. Total economic value of the Berg estuary is estimated to be R75.6 million, with by far the largest component of this value being derived from turnover in the property sector (R48.6 million), followed closely by visitor expenditure (R18.3 million) and nursery value (R8.1 million). Subsistence and existence value make relatively small contributions to total economic value. This places the Berg estuary firmly on the upper end of the value spectrum for temperate estuaries in South Africa (Figure 3-23).

Table 3.31. Summary of economic value of the Berg estuary

Component of value	Value
Subsistence value[1]	R 414,000
Property sector turnover	R 48,600,000
Visitor expenditure	R 18,300,000
Nursery value	R 8,100,000
Existence value	R 176,452
Total value	**R 75,590,452**

1. Average of the values derived from Hutchings *et al*. (2008) and Turpie and Clark (2008)

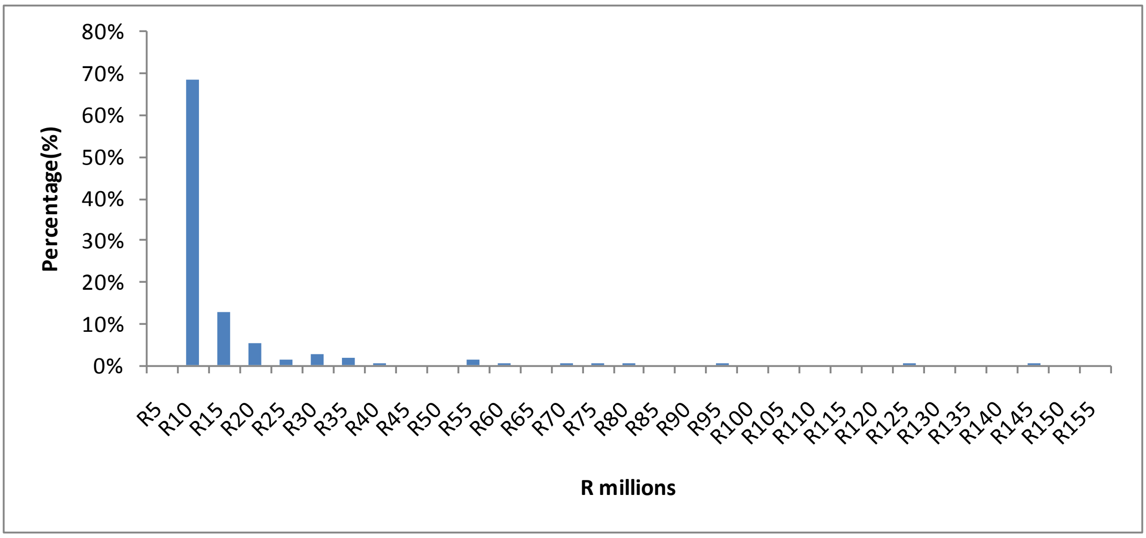


Figure 3-23 Frequency distribution of Total Economic Value for temperate estuaries in South Africa (after Turpie and Clark 2008).

3.4 Present Ecological Status of the Berg River Estuary

3.4.1 Abiotic Components

3.4.1.1 Hydrology

Low flow Scoring Formula: (100 – (% Reference -% Present)) (DWAF 2008). Floods Scoring Formula: % Change in occurrence (2/3) +% Change in magnitude (1/3).

<table>
<tr><th>Variable</th><th>Score</th><th>Motivation</th><th>Confidence</th></tr>
<tr><td>a.% Similarity in period of lowflows OR present MAR as a % of MAR in the Reference condition</td><td>68</td><td>Changes in hydrology are calculated from changes in the relative occurrence of States 1 to 5:
$Similarity_{State} = \sum \min(Fraction_{Ci,Zi\ in\ Ref}, Fraction_{Ci,Zi\ in\ Present})$
Where Ci represent the % occurrence of the *ith* state over the duration of the flow record (Z = 77-years).
<table>
<tr><th>State</th><th>Reference</th><th>Present</th></tr>
<tr><td>1</td><td>0.5</td><td>28.4</td></tr>
<tr><td>2</td><td>3.1</td><td>3.7</td></tr>
<tr><td>3</td><td>28.0</td><td>15.5</td></tr>
<tr><td>4</td><td>31.3</td><td>34.8</td></tr>
<tr><td>5</td><td>37.0</td><td>17.6</td></tr>
</table></td><td>High</td></tr>
<tr><td>b.% Similarity in mean annual frequency of floods</td><td>79</td><td>Reduction in floods are calculated from changes in relative occurrence of the various size classes of floods:
$Similarity_{Floods} = \sum \min(Fraction_{Ci,Zi\ in\ Ref}, Fraction_{Ci,Zi\ in\ Present})$
Where Ci represent the % occurrence of the *ith* flood class over the duration of the flow record (Z = 77-years).
<table>
<tr><th>Flood size (Daily average flow in m^3s^{-1})</th><th>% inundation</th><th>Reference %Occurrence/</th><th>Present % Occurrence/</th></tr>
<tr><td>100-200</td><td rowspan="2">50-70</td><td rowspan="2">13</td><td rowspan="2">16</td></tr>
<tr><td>200-300</td></tr>
<tr><td>300-500</td><td>70-80</td><td>9</td><td>7</td></tr>
<tr><td>500-800</td><td>80-90</td><td>6</td><td>3</td></tr>
<tr><td>800->1000</td><td>>90%</td><td>6</td><td>4</td></tr>
<tr><td>No Floods</td><td></td><td>0</td><td>4</td></tr>
<tr><td>Annual % occurrence</td><td></td><td>34</td><td>30</td></tr>
</table></td><td>Medium</td></tr>
<tr><td>[1]Hydrology score</td><td>72</td><td></td><td></td></tr>
</table>

[1] Hydrology score is the weighted mean of a (60%) and b (40%).

3.4.1.2 Hydrodynamics and mouth condition

Variable	Score	Motivation	Confidence
Change in mean duration of closure, e.g. over a 5 or 10 year period	90	Under Reference conditions the system would have been significantly more constricted during the summer months before mouth stabilisation – allow 5 %. There is anecdotal information that indicates that the Berg might have closed for short periods during drought conditions under the Reference conditions - allow 5 %.	High
Hydrodynamics and mouth conditions score	90		

3.4.1.3 Water quality

<table>
<tr><td>Salinity</td><td>The change in salinity was evaluated on change in the average salinity. Change in the average salinity was calculated as the average salinity per state for a zone (A to D) multiplied by the % occurrence of the state.
<table>
<tr><th></th><th>Reference:</th><th>Present:</th></tr>
<tr><td>Average Salinity over 12 months</td><td><table><tr><td>Zone</td><td>A</td><td>B</td><td>C</td><td>D</td></tr><tr><td>Salinity</td><td>18</td><td>5</td><td>0</td><td>0</td></tr></table></td><td><table><tr><td>Zone</td><td>A</td><td>B</td><td>C</td><td>D</td></tr><tr><td>Salinity</td><td>24</td><td>12</td><td>5</td><td>1</td></tr></table></td></tr>
<tr><td>Average Salinity for 6 summer months (October to March)</td><td><table><tr><td>Zone</td><td>A</td><td>B</td><td>C</td><td>D</td></tr><tr><td>Salinity</td><td>25</td><td>9</td><td>0</td><td>0</td></tr></table></td><td><table><tr><td>Zone</td><td>A</td><td>B</td><td>C</td><td>D</td></tr><tr><td>Salinity</td><td>30</td><td>18</td><td>8</td><td>2</td></tr></table></td></tr>
</table>
There was an average change in salinity of about 63%.</td></tr>
<tr><td>DIN</td><td>DIN concentrations in river inflow during higher flows (winter) increased markedly from Reference (<100 µg.l^{-1}) to Present (> 800 µg.l^{-1}) due to anthropogenic inputs from agriculture and other activities in the catchment. This affects the estuary particularly during the occurrence of States 3-5 (typically of high flow periods). Thus, when any of these states occur under the present state (or any scenario), DIN concentrations will markedly increase compared with Reference, affecting the system as follows (referring to Table 3.5 and Figure 3.2):
Entire estuary (during State 5)
Zones B-D (during State 4)
Part of Zone B, C and D (during State 3)

During summer, the sea is a major source of DIN to the estuary, in particular during States 1 and 2. Thus, an increase in the occurrence of States 1 and 2 under the present state (or any scenario) - specifically during summer when upwelling is frequent along this coast - would result in higher DIN inputs to the lower zones compared with Reference, affecting the system as follows (referring to Table 3.5 and Figure 3.2):
Zones A and B (increase in State 1)
Zone A (increase in State 2)</td></tr>
</table>

	To score similarity to Reference condition the following approach was followed: Estuary has *n* DIN conditions (C_1 *to* C_n), e.g. low (<100 µg.l^{-1}), medium (~300 µg.l^{-1}) and high (>800 µg.l^{-1}) Estuary is sub-divided into *n* zones (Z_1 *to* Z_n), e.g. Zone A (44% of total volume), Zone B (43%), Zone C (9%) and Zone D (4%) Estuary has *n* abiotic states (S_1 *to* S_n) each with a specific DIN condition (C_1 *to* C_n) occurring in a specific zone (Z_1 *to* Z_n) (see Table 3.2) For a particular flow scenario (e.g. Reference, Present, etc.) each abiotic state (S_1 *to* S_n) has a specific %occurrence *(%S_1 to %S_n)* For a specific flow scenario the fraction of occurrence of *a specific DIN Condition (Ci) in a specific zone (Zi)* is determined by: $Fraction_{Ci,Zi} = C_i*\%S_1*Vol_{Zi} + C_i*\%S_2Vol_{Zi} + ...+ C_i*\%S_nVol_{Zi}$ *(considering only* S_1 *to* S_n *in which* C_i *occurs in* Z_i*)* Similarity of DIN in Present or any Scenarios relative to Reference is calculated as follows: $Similarity_{DIN} = \sum min(Fraction_{Ci,Zi\ in\ Ref}, Fraction_{Ci,Zi\ in\ Present/Future\ scenario})$
DIP	Presently, anthropogenic inputs (fishing harbour and fish processing industry) have elevated DIP in the lower zones (Zones A and B) substantially compared to reference (from ~60 µg.l^{-1} to (> 120 µg.l^{-1}) particularly during summer. Thus, during the occurrence of States 1 and 2 DIP concentrations in Zone A are markedly higher under the present (or any scenario) compared with the Reference (upwelling contributes to some extent, but is masked by anthropogenic inputs). DIP concentrations in river inflow have increased to some extent from the Reference (~30 µg.l^{-1}) to the present state (~80 µg.l^{-1}) specifically during winter (States 3-5). Thus, an increase in the occurrence of States 3-5 under the Present (or any scenario) would result in a slight increase in DIP concentrations compared with Reference, affecting the system as follows (referring to Table 3.5 and Figure 3.2): Entire estuary (during State 5) Zones B-D (during State 4) Part of Zone B, C and D (during State 3) To score similarity to Reference condition the following approach was followed: Estuary has *n* DIP conditions (C_1 *to* C_n), e.g. low (<30 µg.l^{-1}), medium (~60 µg.l^{-1}) and high (>100 µg.l^{-1}) Estuary is sub-divided into *n* zones (Z_1 *to* Z_n), e.g. Zone A (44% of total volume), Zone B (43%), Zone C (9%) and Zone D (4%) Estuary has *n* abiotic states (S_1 *to* S_n) each with a specific DIP condition (C_1 *to* C_n) occurring in a specific zone (Z_1 *to* Z_n) (see Table 3.2) For a particular flow scenario (e.g. Reference, Present, etc.) each abiotic state (S_1 *to* S_n) has a specific %occurrence *(%S_1 to %S_n)* For a specific flow scenario the fraction occurrence of *a specific DIP Condition (Ci) in a specific zone (Zi)* is determined by:

	$Fraction_{Ci,Zi} = C_i{*}\%S_1{*}Vol_{Zi} + C_i{*}\%S_2Vol_{Zi} + \ldots\ldots + C_i{*}\%S_nVol_{Zi}$ *(considering only* S_1 *to* S_n *in which* C_i *occurs in* Z_i*)* Similarity of DIP in Present or any Scenarios relative to Reference is then calculated as follows: $Similarity_{DIP} = \sum \min(Fraction_{Ci,Zi\ in\ Ref}, Fraction_{Ci,Zi\ in\ Present/Future\ scenario})$
DIN/DIP	Overall nutrient score = Average [$Similarity_{DIN}$, $Similarity_{DIP}$]
Transparency	River inflow to the Berg River Estuary is referred to as "murky" brown waters. Agricultural development in the catchment may have contributed to silt loading in river inflow. However, river inflow would have been turbid in the natural condition, in anyway making the incremental effect of agricultural activities on transparency less significant. As a result, zones with strong freshwater influence will have markedly lower transparency compared with the zones experiencing strong marine influence. Therefore, an increase in the occurrence of States 1 and 2 (i.e. strong marine influence) will result in an increased in transparency in the estuary from Reference to Present (or any Scenario), specifically in Zones A and B (referring to Table 3.5 and Figure 3.2). To score similarity to Reference condition the following approach was followed: Estuary has *n* Transparency conditions (C_1 *to* C_n), e.g. low (<0.2 m Secchi depth), medium (~1 m) and high (>1.2 m) Estuary is sub-divided into *n* zones (Z_1 *to* Z_n), e.g. Zone A (44% of total volume), Zone B (43%), Zone C (9%) and Zone D (4%) Estuary has *n* abiotic states (S_1 *to* S_n) each with a specific Transparency condition (C_1 *to* C_n) occurring in a specific zone (Z_1 *to* Z_n) (see Table 3.2) For a particular flow scenario (e.g. Reference, Present, etc.) each abiotic state (S_1 *to* S_n) has a specific %occurrence *(*$\%S_1$ *to* $\%S_n$) For a specific flow scenario the fraction occurrence of *a specific Transparency Condition (Ci) in a specific zone (Zi)* is determined by: $Fraction_{Ci,Zi} = C_i{*}\%S_1{*}Vol_{Zi} + C_i{*}\%S_2Vol_{Zi} + \ldots\ldots + C_i{*}\%S_nVol_{Zi}$ *(considering only* S_1 *to* S_n *in which* C_i *occurs in* Z_i*)* Similarity of DIP in Present or any Scenarios relative to Reference is then calculated as follows: $Similarity_{Transparency} = \sum \min(Fraction_{Ci,Zi\ in\ Ref}, Fraction_{Ci,Zi\ in\ Present/Future\ scenario})$
DO	The Berg River Estuary is generally oxygenated (>4 $mg.l^{-1}$). However, lower DO concentrations can occur near the mouth associated with seawater intrusion (St Helena Bay has been identified as a zone for the formation of oxygen-deficient waters). Also in the middle reaches (particularly zone C), lower DO concentrations occasionally occur during summer owing to high organic loading and long residence times. An increase in occurrence of States 1 and 2 from Reference to Present (or any Scenario) would therefore result in an overall reduction of DO, albeit only mildly (referring to Table 3.5 and Figure 3.2). To score similarity to Reference condition the following approach was followed:

	Estuary has *n* Oxygen conditions (C_1 *to* C_n), e.g. low (<2 mg.l^{-1}), medium (~4 mg.l^{-1}) and high (>6 mg.l^{-1}) Estuary is sub-divided into *n* zones (Z_1 *to* Z_n), e.g. Zone A (44% of total volume), Zone B (43%), Zone C (9%) and Zone D (4%) Estuary has *n* abiotic states (S_1 *to* S_n) each with a specific Oxygen condition (C_1 *to* C_n) occurring in a specific zone (Z_1 *to* Z_n) (see Table 3.2) For a particular flow scenario (e.g. Reference, Present, etc.) each abiotic state (S_1 *to* S_n) has a specific %occurrence *(*$\%S_1$ *to* $\%S_n$*)* For a specific flow scenario the fraction occurrence of *a specific Oxygen Condition (Ci) in a specific zone (Zi)* is determined by: $Fraction_{Ci,Zi} = C_i*\%S_1*Vol_{Zi} + C_i*\%S_2Vol_{Zi} + \ldots\ldots + C_i*\%S_nVol_{Zi}$ *(considering only* S_1 *to* S_n *in which* C_i *occurs in* Z_i*)* Similarity of DIP in Present or any Scenarios relative to Reference is then calculated as follows: $Similarity_{DO} = \sum \min(Fraction_{Ci,Zi\ in\ Ref}, Fraction_{Ci,Zi\ in\ Present/Future\ scenario})$
Toxic substances	Agricultural activities in the catchment (and along the banks of the estuary) as well as the fishing harbour and marina near the mouth have most likely contributed to toxic loading of the system, e.g. pesticide/herbicide (agriculture) and trace metal/hydrocarbon (harbour). There are no data to confirm the extent of pollutant accumulation. Assume similarity to Reference as 80% for Present and all future Scenarios.

Scenario	**1. Changes in longitudinal salinity gradient and vertical stratification**		**2a. DIN/DIP in estuary**		**2b. SS/Turbidity/ Transparency in estuary**		**2c. DO in estuary**		**2d. Toxic substances in estuary**		**Overall score**
	Score L/M/H	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**	
Present	63 H	⇧ Saline	25 M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	85 M/H	⇧ Summer (lower zones)	85 M/H	⇩ Summer (middle zones)	80 L	⇧Overall accumulation	40

3.4.1.4 Physical habitat alteration (including Berg Dam)

Variable		Score	Motivation	Confidence
1. Resemblance of intertidal sediment structure and distribution to Reference condition				
1a	% Similarity in intertidal area exposed	61%	Lower reaches : 25% (mouth structures, moved and fixed, deeper channel, greater tidal Δ thus more marine sediment intrusion; channel dredging; wharfs, jetties, embankments; marina and dredging + dumping; salt works; fewer and smaller floods – thus less sediment flushing and more marine	L (virtually no sediment or morphology

			sediment intrusion) Middle reaches : 50% (Carinus and Railway bridges and embankments; siltation of channel; bank erosion; livestock trampling of inter and supra tidal sediments; a few wharfs, jetties, embankments; less and smaller floods – thus less sediment flushing, less dynamic bottom (also greater potential for consolidation) and longer time for fluvial sediments to pass through middle reaches.) Upper reaches : 75% (one bridge, drift?; channel modified – shortcut; livestock trampling of inter and supra tidal sediments; less and smaller floods – thus less sediment flushing, less dynamic bottom (also greater potential for consolidation) and longer time for fluvial sediments to pass through upper reaches; less fluvial coarse sediment deposition due to dam trapping) The 3 zones represent 21%, 13% and 66% of the total intertidal area of the total estuary. Weighted (based on intertidal areas) mathematical average for all 3 zones = 61%	data for Reference condition; paucity of such data for present)
1b	% Similarity in sand fraction relative to total sand and mud	75%	Lower reaches : More marine sediment intrusion through permanently open mouth and greater tidal Δ – 10% Upper reaches : dams trapping some coarse fluvial sediments – 5 % Whole estuary : reduced sediment transport and scouring capacity through reduced floods, thus more marine sediment intrusion; also less dynamic sediment bottom and greater potential for consolidation – 10% Cumulative impact = 25%, thus score = 75%	L (virtually no sediment data for Reference condition; paucity of such data for present; big uncertainty about net 50yr+ effects)

2	Resemblance of subtidal estuary to Reference condition: depth, bed or channel morphology	64%	Most of impacts listed in 1a are considered to have effects through intertidal into subtidal area. Thus practically same total score. Detail, with differences from 1a – double strike-through: Lower reaches : 25% (mouth structures, moved and fixed, deeper channel, greater tidal ∆ thus more marine sediment intrusion; channel dredging; wharfs, jetties, embankments; marina and dredging + dumping; salt works; less and smaller floods – thus less sediment flushing and more marine sediment intrusion.) Middle reaches : 50% (Carinus and Railway bridges and embankments; siltation of channel?; bank erosion; a few wharfs, jetties, embankments; less and smaller floods – thus less sediment flushing, less dynamic bottom (also greater potential for consolidation) and longer time for fluvial sediments to pass through middle reaches.) Upper reaches : 75% (one bridge, drift?; channel modified – shortcut; less and smaller floods – thus less sediment flushing, less dynamic bottom (also greater potential for consolidation) and longer time for fluvial sediments to pass through upper reaches; less fluvial coarse sediment deposition due to dam trapping.) The 3 zones represent 15%, 29% and 56% of the total subtidal area of the total estuary. Weighted (based on subtidal areas) mathematical average for all 3 zones = 64%	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)
	Physical habitat score	66%		

3.4.2 Biotic Components

3.4.2.1 Microalgae

Variable	Score	Motivation	Confidence
1. Species richness	100%	Full range of conditions still exists in the estuary. Unlikely that there has been any gain or loss of species.	M
2a. Abundance	81%	*Phytoplankton*: expected ⇧ average Chl-a from 2.2 µg/L (Reference) to 6.3 µg/L = 19% change (assuming a maximum of 20 µg/L). *Benthic microalgae*: highest Chl-a (>10 µg/g) found in soft sediment (high fines and organic content) in blind arm near mouth, Die Plaat and in subtidal sediment in upper half of estuary (elevated chlorophyll a in 50% of estuary). Increase associated with reduction in flow (more stable environment) and elevated nutrients. Assuming a 37% ⇩ in biomass (related to change in intertidal and subtidal zones), which is mitigated by an increase in nutrients (DIN/DIP score was 25); 12% loss of biomass.	L
2b. Community composition	75%	*Phytoplankton*: Based on evenness between groups (assuming Reference composition was flagellates 49%, diatoms 49%, chlorophytes 1%, dinoflagellates 1% and cyanophytes 0%) then there has been a 13% change. *Benthic microalgae*:25% similarity in sand fraction relative to total sand and mud ➔ 25% shift from epipelic to episammic diatom taxa.	L
Microalgae score	75%		

3.4.2.2 Macrophytes

Variable	Score	Motivation	Confidence
1. Species richness	80%	Loss of species in the sedge marsh and sedge pans due to increase in salinity and reduced flooding. Loss of species due to invasion of riparian zone by exotic trees.	L
2a. Abundance/ Biomass	54%	Tables 2 and 3 indicate the area (26%) lost due to anthropogenic impacts such as development and agriculture. In addition to these non-flow related impacts, flow related changes listed below have also most likely occurred. Flow related changes would have reduced macrophyte habitat by a further 20%, therefore overall change of 46%. Reduced flooding and increase in salinity results in open pans, halophytic and xeric floodplain become drier with less biomass and vegetation cover. Drought periods occur for up to 8 years at a time, which would result in extensive dieback of floodplain habitats. Saline intrusion during summer causes dieback of the fringing reeds and sedges, which grow best in a salinity of less than 15 ppt. Mats of decaying water hyacinth washed downstream cause dieback of salt marsh and subsequent erosion (e.g. at De Plaat).	M
2b. Community composition	60	Macroalgae, particularly the filamentous species, form extensive mats in the lower reaches, which displace the eelgrass, (*Zostera capensis*) beds. Water hyacinth (*Eichhornia crassipes*) displaces pondweed (*Potamageton pectintus*) in the upper reaches of the estuary. Overall, there would have been change in community composition from the freshwater brackish wetlands to halophytic floodplain and salt marsh and from sedge pans to open saline pans.	M
Macrophyte score	54		

3.4.2.3 Invertebrates

Variable	Score	Motivation	Confidence
1. Species richness	100	Full range of condition in terms of salinity, sediment type, intertidal banks, intertidal vegetated areas still present.	M
2a. Abundance	50	There has been a significant increase in average salinity distribution in the estuary (68%). Floods are now less frequent (less frequent flushing) and this would enable a more permanent zooplankton community to maintain itself and extend further upstream (salinity intrusion into the upper estuary – extension of habitat). On average, a 30 - 40% increase in average biomass predicted under present day conditions. The subtidal benthic fauna would reflect similar changes in biomass for similar reasons. Intertidally, habitat available for colonization by the burrowing infauna (exposed mud and sandbanks) has declined by about 50% (particularly in Zone A) and the area that is now non-vegetated has increased by 40% compared to natural.. *Phragmites* beds along the estuary margins have also declined (less habitat available for carids such as *Palaemon*. Invertebrates colonizing the floodplain will have decreased significantly in biomass, due to increased salt content of the sediment and greater compactness of the sediment as flood magnitude and frequency decreased.	M
2b. Community composition	50	There has been a significant change in the mix of species because of changes in salinity structures and intertidal habitat, as well as less frequent flooding. This will affect food web structures. Loss of vegetated areas in the intertidal by approx 40% will lead to a different faunal mix. The blind arm near the mouth is now replaced by mud – previously this part of the channel would have been sand. Other reasons indicated in section 2a also apply.	M
Invertebrates score	**50**		

3.4.2.4 Fish

Variable	Score	Motivation	Confidence
1. Species richness	56	Instantaneous species richness has declined from an estimated 17 species under the Reference condition to 12 species presently. Only one species (witvis) has been lost from the system entirely, populations of other species have simple been reduced to levels where they are no longer able to sustain themselves and probability of capture in a single survey is low.	M
2a. Abundance	85	Abundance of two dominant species in the system (*Liza richardsonii* and *Gilchristella aestuaria*) has increased significantly due to increased productivity and food availability (phytoplankton and zooplankton). Most other species have declined in abundance, some by >90%. Net effect is an increase in overall abundance of ~30%.	M

2b. Community composition	87	Significant changes are evident in community structure with overall abundance of estuarine residents having increased (due to an increase in abundance of the *G. aestuaria*) and the same for marine migrants (due to increase in the abundance of the co-dominant *L. richardsonii*). Abundance of most other estuarine resident and marine migrant species is substantially lower than under the Reference condition but their contribution to overall abundance is low and hence they make a small contribution to the overall score change.	M
Fish score	**56**		

3.4.2.5 Birds

Variable	Score	Motivation	Confidence
1. Species richness	82	Average instantaneous species richness is assumed to be about 90 - 95% of natural. Certain species will be less common as a result of reduced flooding, reduced breeding populations elsewhere, and increased disturbance on the estuary. This does not include the tendency for certain species to *increase* in their appearance due to expanding regional populations.	M/H
2a. Abundance	78	Overall numbers of birds are expected to have declined as a result of habitat loss, disturbance and reductions in breeding populations of migratory species. These trends would outweigh the increases in numbers of certain species.	M/H
2b. Community composition	87	Migratory waders would be more abundant under Reference condition, coots and omnivorous waterfowl more abundant due to more vegetated habitats and flooding of the floodplain, and wading birds less abundant.	M/H
Bird score	**78**		**M/H**

To establish the changes in present state (compared with the Reference condition) that are not as a result of changes in flow, but rather as a result of other anthropogenic activities, the Table below indicates the percentage of overall change predicted in particular components that are non-flow related.

Component	% change resulting from non-flow related activities	Motivation	Confidence
Water Quality	65%	A major component of the changes in water quality are attributable to anthropogenic impacts – increased nutrients (90%) changes in axial salinity gradient (40%)	M
Microalgae	37%	37% of the change attributable to habitat loss, 25% to elevated nutrient concentrations and change in axial salinity gradient.	M
Macrophytes	26%	26% of the changes are from loss of habitat due to urban, agricultural and other activities.	M

Invertebrates	50%	Significant changes that are non-flow related apply to the intertidal habitats particularly, brought about by saltpan construction, urban development, agriculture and other activities. Large areas now hypersaline with consolidated sediments. Shift in mouth position, dredging will affect directly on sandbanks and the associated infauna in the lower estuary.	M
Fish	80%	The significant drivers of change in the fish communities are non-flow related, and include historic legal gill net fishing in the estuary, present day illegal gill net fishing in the estuary, and present day and legal and illegal fishing outside of the estuary, introduction of alien freshwater fish, and reclamation of intertidal and shallow subtidal habitat in the lower estuary.	M
Birds	63%	Much of the change in the bird community is a result of reclamation of estuary habitat, construction of saltpans, changes in population numbers away from the estuary, and increases in human population.	M

3.4.3 Summary of Present Ecological Status

The Estuarine Health Index (EHI) scores allocated to the various abiotic and biotic health parameters for Berg River Estuary and the overall Present Ecological Status (PES) for the system under the present state are summarised in Table 3.32.

Table 3.32 PES of the Berg River Estuary

Variable	Weight	Score	Weighted score
Hydrology	25	72	18
Hydrodynamics and mouth condition	25	90	23
Water quality	25	40	10
Physical habitat alteration	25	59	15
HABITAT HEALTH SCORE			**65**
Microalgae	20	75	15
Macrophytes	20	54	11
Invertebrates	20	50	10
Fish	20	56	11
Birds	20	78	16
BIOTIC HEALTH SCORE			**63**
ESTUARINE HEALTH SCORE			**64**

The EHI score for the Berg River Estuary, based on its present state, was 64, translating into a PES of C as indicated in Table 3.33.

Table 3.33 EHI score for the Berg River Estuary

EHI Score	PRESENT ECOLOGICAL STATUS	GENERAL DESCRIPTION
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	C	Moderately modified
41 – 60	D	Largely modified
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

Although the present state of the Berg River Estuary currently falls within an Ecological Category C, it is likely that the estuary is on a negative trajectory of change, because of the extremely low lowflows under the present state (< 1 m^3s^{-1}), particularly during the summer months. Maintaining the *status quo* is therefore likely to result in continued modification of the Ecological Status of the estuary.

3.4.4 Importance of the Berg River Estuary

Importance scores were allocated to the Berg River Estuary in accordance with the methodology of DWA (DWAF 2008; Table 3.34).

Table 3.34 Importance scores for the Berg River Estuary

CRITERION	SCORE	WEIGHT	WEIGHTED SCORE
Estuary Size	100	15	15
Zonal Rarity Type	90	10	9
Habitat Diversity	100	25	25
Biodiversity Importance	98	25	24
Functional Importance	100	25	25
ESTUARINE IMPORTANCE SCORE			99

The Estuarine Importance Score for the Berg River Estuary, based on its present state, is 99, indicating that the estuary is highly important (Table 3.35).

Table 3.35 Estuarine importance scores and their significance

IMPORTANCE SCORE	DESCRIPTION
81 – 100	Highly important
61 – 80	Important
0 – 60	Of low to average importance

3.4.5 Ecological Reserve Category

The recommended Ecological Reserve Category (ERC) represents the level of protection assigned to an estuary.

For estuaries, the first step is to determine the 'minimum' ERC, based on its PES. The relationship between EHI Score, PES and minimum ERC is set out in Table 3.36.

Table 3.36 Relationship between the EHI, PES and minimum ERC[2]

EHI SCORE	PES	DESCRIPTION	MINIMUM ERC
91 – 100	A	Unmodified, natural	A
76 – 90	B	Largely natural with few modifications	B
61 – 75	C	Moderately modified	C
41 – 60	D	Largely modified	D
21 – 40	E	Highly degraded	-
0 – 20	F	Extremely degraded	-

[2] **NOTE:** Should the PES of an estuary be either an E or F category, recommendations must be made as to how the status can be elevated to achieve at least a Category D (as indicated above).

PES sets the minimum ERC. The degree to which the ERC needs to be elevated about the PES depends on the level of **importance** and level of **protection or desired** protection of a particular estuary (Table 3.37).

Table 3.37 Estuary protection status and importance, and basis for assigning a recommended ecological categories

Protection status and importance	Recommended Ecological Reserve Category	Policy basis
Protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area (based on complementarity)		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category
Important	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D category

* *BAS = Best Attainable State*

In addition to being categorised as a 'Highly important estuary' (see above), the Berg River Estuary has also been targeted as a Desired Protected Area (DWAF 2004a). Therefore, according to the guidelines for assigning a recommended ERC, the estuary needs to be in a Category A or the Best Attainable State (BAS).

4 QUANTIFICATION OF ECOLOGICAL RESERVE SCENARIOS

4.1 Description of the Scenarios

The scenarios analysed include the natural flow regime, the flow regime immediately before the Berg River Dam was constructed (Scenario 1), the present-day flow regime, i.e., with the Berg River Dam in place (the ‘Present Day” Scenario), plus the flow regimes resulting from a number of future development scenarios, including schemes that are being considered in the WCWSS Feasibility Study, such as diverting water from the Berg River into Voëlvlei Dam (Scenario 2 and 3), and raising Voëlvlei Dam (Scenario 4). They also include more ‘unlikely’ developments such as raising Misverstand Dam (Scenarios 5, 6 and 8), which increased range of estuarine inflows offered by the scenarios. Scenario 1 approximates the flow regime that was in place when much of the recent data for the estuary were collected. Because of the current surplus capacity in the WCWSS, the Berg River Dam has spilt in the years since construction of the dam and so even the current flow regime is probably midway between Scenario 1 and the ‘Present Day” Scenario.

The scenarios are summarized in Table 4.1.

Table 4.1 The scenarios evaluated in this study

Name	ID in the WRYM analysis	Scenario Description	Summer lowflow ($m3S^{-1}$)	Historic Firm Yield (Mm^3)	Historic Firm Yield: wrt. BRD (%)	Revised Estuary MAR (1920-2004)
Natural		Natural		-		926
Reference Condition	BergNat	Natural with evapotranspiration losses d/s Hermon				916
Present Day	BRD	Present day with Berg River Dam in Place	0.3	547	0	500
Scenario 1	NoBRD	‘Present day’ without Berg River Dam	0.3	462	-85	594
Scenario 2	VV1	Augmentation of Voelvlei dam - Phase1 - No raising. $3m^3s^{-1}$ diversion	0.3	574	27	471
Scenario 3	VV2a	Augmentation of Voelvlei dam - Phase2a - No raising. $20m3s^{-1}$ diversion	0.3	591	44	450
Scenario 4	Vv2b	Augmentation of Voelvlei dam - Phase2b - $20m^3s^{-1}$ diversion, raise Voelvlei dam by 9m	0.3	613	66	394
Scenario 5	MisvC	Raised Misverstand, Imposed resdss ifrC. Ifr = 23% of natural flow	0.3	571	24	405
Scenario 6	MisvD	Raised Misverstand, Imposed resdss ifrD. Ifr = 15% of natural flow	0.3	585	38	396
Scenario 7	$BRD_{0.9}$	Present day with Berg River Dam in Place	0.9	539	-8	506
Scenario 8	$MisvD_{0.15}$	Raised Misverstand, Imposed resdss ifrD. Ifr = 15% of natural flow	0.15	587	40	395

Scenario 9	ElevBaseflows	Present state with increased lowflows	Dec 2, Jan 1.5, Feb 1, Mar 1, Apr 3	529	-18	513
Scenario 10	ElevBaseflows	Present state with increased lowflows and improved anthropogenic	Dec 2, Jan 1.5, Feb 1, Mar 1, Apr 3	529	-18	513

Owing to the uncertainty surrounding the actual summer lowflows entering the estuary a value of 0.3 m^3s^{-1} ("summer lowflow" in Table 4.1) was assumed for most of the scenarios and additional scenarios (7 to 9) were added to determine the impact of increasing or decreasing this summer lowflow. The historic firm yield of the WCWSS is also presented along with the relative change in the yield with respect to the present state, and the average inflows for the period 1920 to 2004.

4.2 Abiotic Components

4.2.1 Variability in river inflow

The flow distributions (mean monthly flows in m^3s^{-1}) under the various Scenarios of the Berg River Estuary, derived from a 77-year simulated data set are provided in Table 4.2. The full 77-year series of simulated monthly runoff data for the Scenarios are provided in Table 4.3 to Table 4.8.

Table 4.2 A summary of the monthly flow (in m^3s^{-1}) distribution under Scenarios 1 to 4.

		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Scenario 1	99%ile	50.77	36.89	17.22	5.68	7.07	8.62	32.84	79.69	136.99	223.68	193.03	143.94
	90%ile	27.53	14.33	2.95	1.46	1.34	2.07	12.12	41.66	83.36	118.24	120.93	63.58
	80%ile	19.97	10.25	1.00	0.40	0.68	0.62	8.49	20.89	52.68	70.76	90.11	46.03
	70%ile	14.49	7.47	0.38	0.30	0.30	0.31	5.52	16.43	41.53	56.45	64.35	37.23
	60%ile	12.29	6.08	0.30	0.30	0.30	0.30	3.15	13.37	28.03	47.18	50.66	30.05
	50%ile	11.12	5.07	0.30	0.30	0.30	0.30	1.99	11.40	22.96	35.69	36.79	23.48
	40%ile	9.34	3.98	0.30	0.30	0.30	0.30	1.28	8.66	16.87	26.85	32.83	20.54
	30%ile	7.97	3.66	0.30	0.30	0.30	0.30	1.07	7.42	12.40	20.61	29.16	18.16
	20%ile	7.46	3.25	0.30	0.30	0.30	0.30	0.42	4.73	9.34	15.70	21.68	15.17
	10%ile	6.20	2.71	0.30	0.30	0.30	0.30	0.30	3.86	7.28	11.25	17.23	12.51
	1%ile	4.82	1.57	0.30	0.30	0.30	0.30	0.30	1.97	3.74	6.91	10.72	7.11

		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Scenario 2	99%ile	45.07	30.38	14.58	5.30	7.03	8.36	23.43	62.06	117.90	220.89	183.81	139.24
	90%ile	19.94	12.70	2.71	1.46	1.24	1.81	7.51	27.01	59.61	117.55	116.53	55.13
	80%ile	13.04	8.51	0.90	0.34	0.66	0.62	5.61	11.27	34.29	60.86	83.95	38.92
	70%ile	8.41	6.26	0.30	0.30	0.30	0.30	3.91	7.49	28.54	43.35	61.24	31.62
	60%ile	7.06	4.88	0.30	0.30	0.30	0.30	2.08	6.20	17.05	33.09	44.58	21.47
	50%ile	6.15	4.02	0.30	0.30	0.30	0.30	1.42	4.78	13.34	24.87	28.55	17.56
	40%ile	5.65	3.74	0.30	0.30	0.30	0.30	1.00	3.86	8.75	19.19	21.55	14.95
	30%ile	5.05	3.31	0.30	0.30	0.30	0.30	0.53	3.32	7.06	14.54	16.46	11.62
	20%ile	4.47	2.73	0.30	0.30	0.30	0.30	0.31	2.72	5.12	10.44	14.04	8.41
	10%ile	4.05	2.32	0.30	0.30	0.30	0.30	0.30	2.29	3.96	6.33	8.79	6.26
	1%ile	2.87	0.62	0.30	0.30	0.30	0.30	0.30	1.49	2.27	3.15	4.79	3.39

Scenario 3

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	44.64	30.38	14.58	5.30	7.03	8.36	23.43	53.77	118.12	220.64	185.30	138.90
90%ile	19.71	12.70	2.71	1.46	1.24	1.81	7.51	22.44	52.56	117.32	116.19	60.94
80%ile	12.55	8.51	0.90	0.34	0.66	0.62	5.61	9.55	28.60	66.60	84.67	38.07
70%ile	7.67	6.26	0.30	0.30	0.30	0.30	3.91	5.45	21.80	45.28	62.95	31.45
60%ile	6.24	4.88	0.30	0.30	0.30	0.30	2.08	4.71	12.54	29.71	45.44	21.13
50%ile	5.34	4.02	0.30	0.30	0.30	0.30	1.42	4.00	9.15	18.46	29.62	17.21
40%ile	4.96	3.74	0.30	0.30	0.30	0.30	1.00	3.13	6.03	15.57	18.05	15.09
30%ile	4.35	3.31	0.30	0.30	0.30	0.30	0.53	2.57	5.09	10.20	13.45	9.20
20%ile	3.77	2.73	0.30	0.30	0.30	0.30	0.31	1.97	3.92	7.24	10.61	6.72
10%ile	3.33	2.32	0.30	0.30	0.30	0.30	0.30	1.54	3.04	4.94	7.35	5.31
1%ile	2.14	0.62	0.30	0.30	0.30	0.30	0.30	0.90	1.56	2.47	3.85	2.70

Scenario 4

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	44.03	30.32	14.58	5.30	7.03	8.36	23.43	53.77	103.15	199.57	178.88	138.54
90%ile	18.14	12.70	2.71	1.46	1.24	1.81	7.51	22.60	54.31	85.62	111.30	45.98
80%ile	10.59	8.51	0.90	0.34	0.66	0.62	5.61	9.55	27.75	43.10	66.77	32.78
70%ile	7.31	6.26	0.30	0.30	0.30	0.30	3.91	5.45	20.49	35.58	42.28	27.10
60%ile	6.23	4.88	0.30	0.30	0.30	0.30	2.08	4.71	12.36	27.11	26.51	17.58
50%ile	5.34	4.02	0.30	0.30	0.30	0.30	1.42	4.00	9.15	17.57	18.83	13.93
40%ile	4.96	3.74	0.30	0.30	0.30	0.30	1.00	3.13	6.03	14.69	14.17	9.32
30%ile	4.35	3.31	0.30	0.30	0.30	0.30	0.53	2.57	5.09	9.97	12.65	8.14
20%ile	3.77	2.73	0.30	0.30	0.30	0.30	0.31	1.97	3.92	7.24	8.43	6.54
10%ile	3.33	2.32	0.30	0.30	0.30	0.30	0.30	1.54	3.04	4.94	6.53	4.56
1%ile	2.14	0.62	0.30	0.30	0.30	0.30	0.30	0.90	1.56	2.47	3.85	2.42

Scenario 5

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	44.48	22.82	6.95	2.04	1.78	1.75	6.71	32.06	102.56	217.90	159.68	137.79
90%ile	17.83	5.56	1.04	1.66	1.39	1.28	1.61	16.41	29.84	84.77	113.65	53.85
80%ile	11.73	5.46	0.84	0.61	0.91	0.82	1.36	11.08	22.69	50.10	71.57	32.14
70%ile	10.42	5.26	0.58	0.41	0.48	0.45	1.08	9.59	19.65	31.20	38.66	21.03
60%ile	9.69	4.88	0.30	0.35	0.35	0.30	0.96	8.63	17.79	27.00	23.03	19.22
50%ile	8.37	4.23	0.30	0.30	0.30	0.30	0.77	6.91	16.30	23.91	17.05	15.66
40%ile	7.68	3.94	0.30	0.30	0.30	0.30	0.64	5.44	12.08	20.47	14.85	14.32
30%ile	6.74	3.37	0.30	0.30	0.30	0.30	0.38	4.34	10.40	16.82	14.09	11.68
20%ile	6.10	2.69	0.30	0.30	0.30	0.30	0.30	3.48	8.39	12.76	12.54	10.40
10%ile	4.86	1.60	0.30	0.30	0.30	0.30	0.30	2.77	6.46	7.88	8.62	8.23
1%ile	3.21	0.82	0.30	0.30	0.30	0.30	0.30	1.56	3.78	4.68	5.26	4.55

Scenario 6

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	44.48	22.97	6.72	1.37	1.22	1.32	6.15	31.84	104.44	219.17	159.68	137.79
90%ile	18.52	4.05	0.30	1.16	0.96	0.87	1.05	16.45	36.48	88.87	113.65	53.85
80%ile	11.18	3.90	0.30	0.61	0.84	0.81	0.81	10.93	23.04	55.21	77.14	32.14
70%ile	9.23	3.74	0.30	0.41	0.48	0.45	0.54	9.15	19.15	27.59	45.64	21.03
60%ile	8.83	3.49	0.30	0.35	0.35	0.30	0.43	8.32	17.37	22.96	25.28	16.63
50%ile	7.99	3.36	0.30	0.30	0.30	0.30	0.30	6.91	16.00	21.10	14.34	14.51
40%ile	7.66	2.96	0.30	0.30	0.30	0.30	0.30	5.44	12.08	17.52	12.56	12.19
30%ile	6.60	2.55	0.30	0.30	0.30	0.30	0.30	4.34	10.40	15.15	11.99	11.11
20%ile	6.05	2.13	0.30	0.30	0.30	0.30	0.30	3.45	8.39	12.64	10.63	9.10
10%ile	4.47	1.35	0.30	0.30	0.30	0.30	0.30	2.77	6.46	7.88	7.90	7.32
1%ile	3.19	0.81	0.30	0.30	0.30	0.30	0.30	1.56	3.71	4.56	5.22	4.37

Scenario 7	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	46.97	30.38	14.58	5.30	7.03	8.36	23.43	64.98	120.14	220.34	185.50	139.78
90%ile	22.06	12.70	2.71	1.46	1.24	1.81	7.51	29.83	63.86	114.04	117.06	54.26
80%ile	15.53	8.51	0.93	0.90	0.90	0.90	5.61	13.83	37.23	60.90	85.14	38.81
70%ile	11.56	6.26	0.90	0.90	0.90	0.90	3.91	10.26	31.42	46.06	55.93	32.27
60%ile	9.69	4.88	0.90	0.90	0.90	0.90	2.08	8.59	19.69	36.07	44.29	23.95
50%ile	8.28	4.02	0.90	0.90	0.90	0.90	1.42	6.90	16.13	27.74	28.66	20.15
40%ile	7.56	3.74	0.90	0.90	0.90	0.90	1.00	5.43	11.46	21.97	22.95	15.90
30%ile	6.69	3.31	0.90	0.90	0.90	0.90	0.90	4.33	9.78	17.19	19.04	14.13
20%ile	6.22	2.73	0.90	0.90	0.90	0.90	0.90	3.43	7.75	13.22	15.91	11.00
10%ile	5.22	2.32	0.90	0.90	0.90	0.90	0.90	2.73	6.19	8.81	11.34	8.44
1%ile	3.79	0.90	0.90	0.90	0.90	0.90	0.90	1.49	3.61	4.67	7.28	4.83

Scenario 8	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	44.48	22.97	6.72	1.37	1.22	1.32	6.15	31.84	104.44	219.17	159.68	137.79
90%ile	18.52	4.05	0.15	1.16	0.96	0.87	1.05	16.45	36.48	88.87	113.65	53.85
80%ile	11.18	3.90	0.15	0.61	0.84	0.81	0.81	10.93	23.04	55.21	77.14	32.14
70%ile	9.23	3.74	0.15	0.41	0.48	0.45	0.54	9.15	19.15	27.59	45.64	21.03
60%ile	8.83	3.49	0.15	0.35	0.35	0.25	0.43	8.32	17.37	22.96	25.28	16.63
50%ile	7.99	3.36	0.15	0.30	0.21	0.15	0.30	6.91	16.00	21.10	14.34	14.51
40%ile	7.66	2.96	0.15	0.24	0.15	0.15	0.20	5.44	12.08	17.52	12.56	12.19
30%ile	6.60	2.55	0.15	0.20	0.15	0.15	0.15	4.34	10.40	15.15	11.99	11.11
20%ile	6.05	2.13	0.15	0.16	0.15	0.15	0.15	3.45	8.39	12.64	10.63	9.10
10%ile	4.47	1.35	0.15	0.15	0.15	0.15	0.15	2.77	6.46	7.88	7.90	7.32
1%ile	3.19	0.81	0.15	0.15	0.15	0.15	0.15	1.56	3.71	4.56	5.22	4.37

Scenario 9 - 10	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	46.97	30.38	14.58	5.30	7.03	8.36	23.43	64.98	120.14	220.34	185.50	139.78
90%ile	22.06	12.70	2.71	1.52	1.24	1.81	7.51	29.83	63.86	114.04	117.06	54.26
80%ile	15.53	8.51	2.00	1.50	1.00	1.00	5.61	13.83	37.23	60.90	85.14	38.81
70%ile	11.56	6.26	2.00	1.50	1.00	1.00	3.91	10.26	31.42	46.06	55.93	32.27
60%ile	9.69	4.88	2.00	1.50	1.00	1.00	3.00	8.59	19.69	36.07	44.29	23.95
50%ile	8.28	4.02	2.00	1.50	1.00	1.00	3.00	6.90	16.13	27.74	28.66	20.15
40%ile	7.56	3.74	2.00	1.50	1.00	1.00	3.00	5.43	11.46	21.97	22.95	15.90
30%ile	6.69	3.31	2.00	1.50	1.00	1.00	3.00	4.33	9.78	17.19	19.04	14.13
20%ile	6.22	2.73	2.00	1.50	1.00	1.00	3.00	3.43	7.75	13.22	15.91	11.00
10%ile	5.22	2.32	2.00	1.50	1.00	1.00	3.00	2.73	6.19	8.81	11.34	8.44
1%ile	3.79	0.62	2.00	1.50	1.00	1.00	3.00	1.49	3.61	4.67	7.28	4.83

4.2.2 Flood regime

Refer to description of inundations levels under the present state for detail on floods.

4.2.3 Droughts

Hydrological drought conditions in the Berg River Estuary are defined as years in which the annual inflow (million m^3) falls below the Reference condition 10%ile, i.e. 558 million m^3.

Scenario 1	Under Scenario 1, annual flows are less than 506 million m^3 for 56% of the time. An analysis of the 77-year period also highlights the occurrence of extended drought periods up to 8 years in a row (see Figure 4-1).
Scenario 2	Annual flows < 558million m^3 = 69% Extended drought periods up to 11 - 12 years in a row
Scenario 3	Annual flows < 558million m^3 = 73% Extended drought periods up to 11 - 12 years in a row
Scenario 4	Annual flows < 558million m^3 = 75% Extended drought periods up to 11 - 12 years in a row
Scenario 5	Annual flows < 558million m^3 = 77% Extended drought periods up to 11 - 12 years in a row
Scenario 6	Annual flows < 558million m^3 = 75% Extended drought periods up to 11 - 12 years in a row

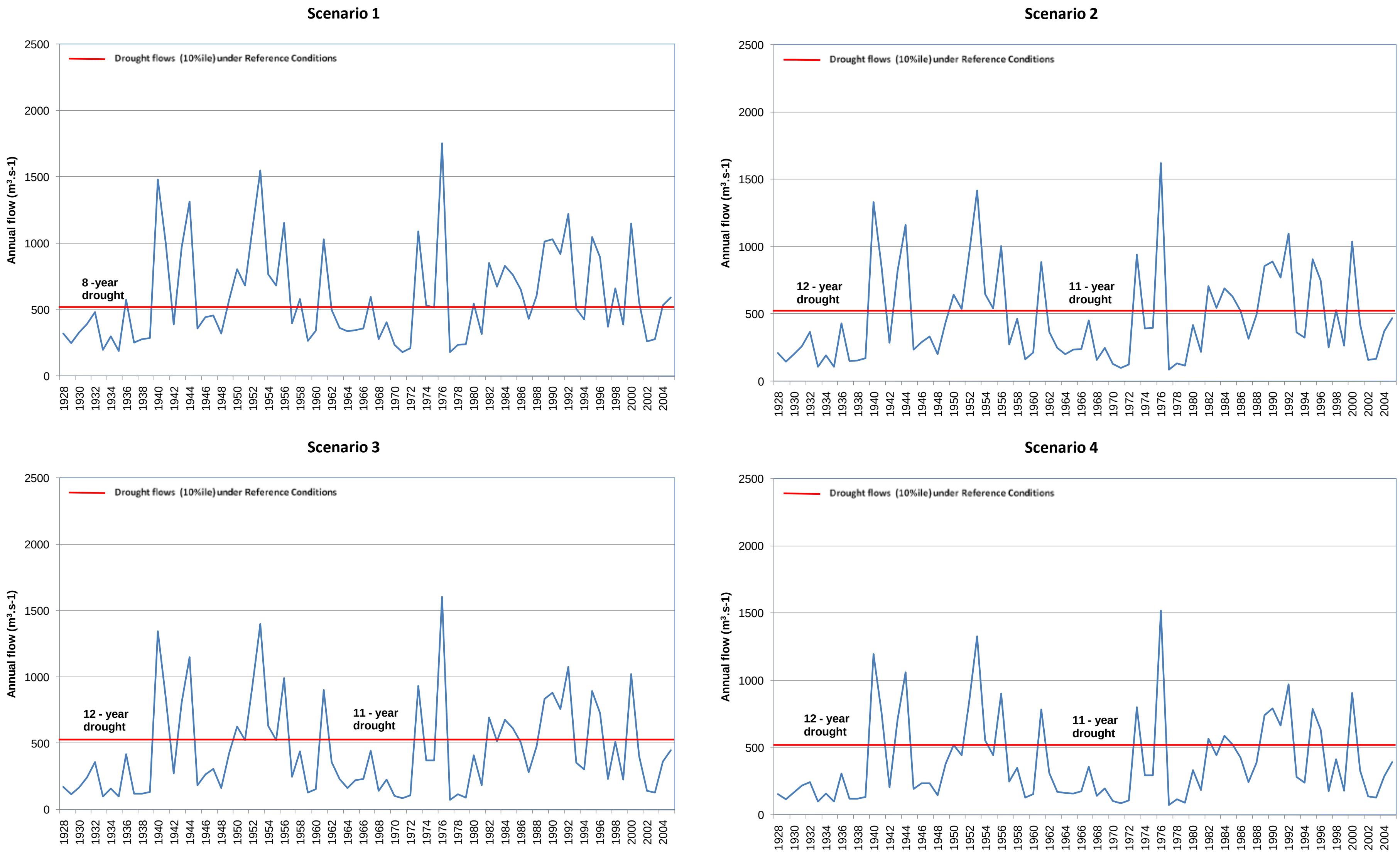


Figure 4-1 **Graphic illustrations of the number of times the annual inflow to the Berg River Estuary falls below the Reference drought conditions under the Scenarios 1 to 4.**

Figure 4-2 Graphic illustrations of the number of times the annual inflow to the Berg River Estuary falls below the Reference drought conditions under the Scenarios 5 to 8.

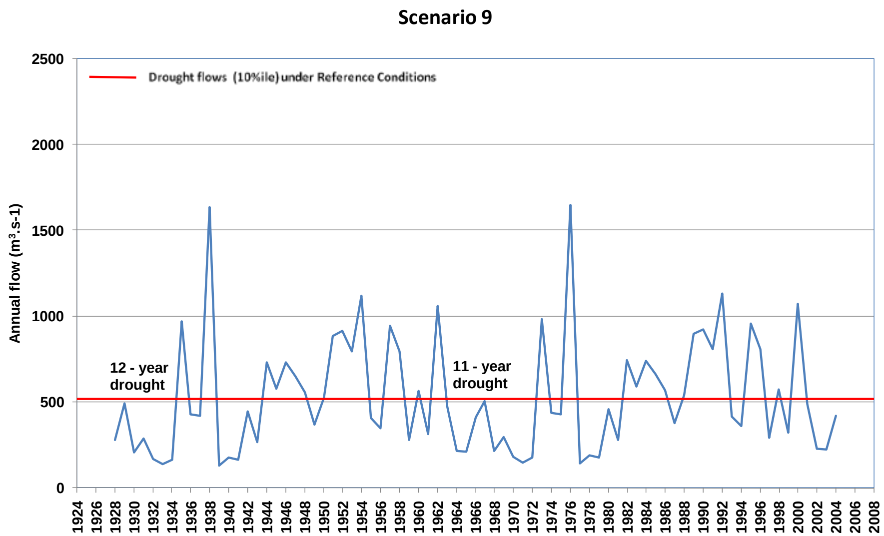


Figure 4-3 **Graphic illustrations of the number of times the annual inflow to the Berg River Estuary falls below the Reference drought conditions under the Scenarios 9.**

Table 4.3 Simulated monthly inflows to the Berg River Estuary for Scenario 1 (m^3s^{-1})

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1928	8.81	3.25	0.30	0.30	0.30	0.30	3.18	12.18	11.51	31.86	30.47	18.95	10.64
1929	7.55	2.78	0.30	0.30	0.38	0.30	0.32	1.65	3.13	10.45	16.72	50.40	8.50
1930	12.74	6.77	0.30	0.30	0.30	0.30	7.09	9.17	8.62	10.48	35.08	33.24	10.94
1931	17.02	5.56	0.30	0.30	11.59	4.97	0.45	16.93	27.16	23.24	22.11	19.42	13.08
1932	9.56	3.61	0.30	0.30	0.30	0.30	0.30	3.96	35.88	47.75	54.86	24.19	15.59
1933	12.04	4.02	0.30	0.30	0.30	0.30	0.40	10.19	8.15	10.20	13.53	15.16	6.86
1934	11.96	10.33	0.30	0.30	0.30	0.30	5.50	8.60	10.33	20.74	23.27	20.43	10.03
1935	9.42	4.36	0.30	0.30	0.30	0.30	0.30	5.30	4.71	8.44	17.45	19.46	6.45
1936	9.29	3.92	0.71	0.75	0.30	1.05	5.58	9.87	52.81	74.35	40.72	18.14	18.88
1937	7.97	2.77	0.30	0.30	0.30	0.30	9.05	10.64	9.39	14.97	17.34	21.80	8.46
1938	10.21	5.39	0.30	0.30	0.30	0.30	1.25	16.21	9.33	12.58	32.70	15.99	9.33
1939	6.89	2.87	0.30	0.30	0.58	0.30	4.96	8.27	28.60	20.93	19.60	15.23	9.69
1940	9.13	6.74	0.30	1.54	1.13	0.30	22.88	57.44	83.93	116.05	111.18	151.35	47.50
1941	35.83	9.22	0.30	0.30	0.30	0.30	0.30	24.30	135.07	57.07	90.36	26.32	32.20
1942	11.90	3.95	0.30	0.30	0.66	0.57	1.18	3.71	8.94	28.75	47.29	39.79	12.93
1943	15.01	8.76	0.30	0.30	0.30	0.30	2.66	16.37	77.61	71.37	124.46	47.52	31.07
1944	19.23	8.02	0.41	0.30	0.30	0.30	1.17	44.13	94.14	172.17	126.91	27.42	41.88
1945	7.97	3.81	0.30	0.30	0.30	0.30	1.30	6.75	7.38	16.93	29.55	60.73	11.83
1946	23.10	7.76	0.30	0.30	0.30	1.05	1.26	7.80	8.08	68.32	33.65	14.70	14.51
1947	9.94	4.63	0.30	0.30	0.30	5.08	5.38	13.98	16.97	46.33	31.21	37.45	14.91
1948	22.73	6.75	0.30	0.30	0.30	0.30	3.61	4.44	9.50	20.12	31.73	20.53	10.62
1949	12.64	13.88	2.89	0.30	0.30	0.30	22.66	5.16	7.07	96.71	22.90	31.97	18.74
1950	21.11	15.01	3.04	1.41	0.67	0.30	20.52	10.31	83.06	62.58	52.52	34.37	26.15
1951	14.37	10.26	0.30	0.30	0.30	0.30	1.61	11.40	12.88	25.74	100.58	80.43	22.21
1952	18.68	15.77	2.60	0.30	0.30	0.30	47.85	61.62	26.78	81.70	135.91	25.06	35.41
1953	7.39	5.77	0.59	0.30	0.30	0.30	11.50	71.63	43.22	230.92	172.21	37.18	49.14
1954	12.37	4.63	0.30	0.30	4.52	1.85	1.11	2.42	10.40	36.94	166.87	46.61	24.76
1955	22.53	12.63	0.32	0.30	0.30	0.30	0.78	11.32	43.62	57.33	81.10	26.40	22.10
1956	10.03	2.97	0.30	0.30	5.64	3.20	1.77	56.74	60.20	138.92	118.58	35.54	36.82
1957	47.55	15.59	0.30	0.30	0.48	0.30	0.44	18.66	13.78	12.74	24.63	14.09	13.09
1958	8.05	4.07	0.30	0.30	0.30	0.30	9.54	101.25	22.96	18.57	31.78	21.56	18.79
1959	13.40	5.56	0.30	0.30	0.30	0.30	1.08	13.27	32.45	15.61	10.36	7.68	8.96
1960	5.20	1.79	0.30	0.30	0.30	0.30	0.30	4.87	26.19	16.07	33.02	41.42	11.35
1961	12.64	3.68	0.30	0.30	0.30	0.55	8.60	4.15	139.67	50.97	132.33	36.98	33.12
1962	41.90	15.03	0.63	0.30	0.30	0.30	0.30	2.07	6.21	23.25	65.58	31.80	16.24
1963	8.60	7.06	1.05	0.33	0.75	0.30	0.54	4.70	23.91	24.40	41.79	23.48	12.18
1964	12.17	10.69	0.94	0.30	2.20	5.08	8.20	15.94	16.33	14.17	29.60	12.34	11.44
1965	6.06	2.52	0.30	0.30	0.30	2.40	4.06	4.19	12.61	42.09	33.15	22.28	11.45
1966	7.66	2.25	0.30	0.30	0.30	0.30	9.94	8.56	48.68	21.64	17.65	18.17	11.78
1967	11.12	6.19	0.30	0.30	0.30	0.30	10.05	24.11	29.60	48.97	71.20	21.76	19.33
1968	32.26	10.40	0.30	0.41	0.30	0.30	1.99	2.53	9.02	11.85	17.07	18.87	9.45
1969	12.37	5.07	0.30	0.30	0.30	0.30	0.30	12.28	30.45	28.52	35.79	26.53	13.18
1970	11.94	3.77	0.30	0.30	0.30	0.30	0.61	3.09	7.89	19.08	27.60	13.47	7.98
1971	5.69	1.80	0.30	0.30	0.30	0.30	3.43	6.88	11.62	11.26	13.99	12.27	6.20
1972	6.25	1.83	0.30	0.30	0.30	0.30	0.30	3.05	3.93	31.05	18.67	12.62	7.26
1973	7.86	2.62	0.30	0.30	0.30	0.30	0.30	16.68	41.11	19.24	258.98	62.31	34.78
1974	24.54	9.64	0.38	0.35	0.30	0.30	3.56	35.91	19.82	47.82	41.53	15.70	17.38
1975	8.28	3.44	0.30	0.30	0.30	0.30	8.56	4.11	57.00	56.42	36.79	19.38	16.85
1976	6.88	42.33	16.86	5.94	1.30	0.83	10.43	38.39	136.14	196.97	165.39	40.37	55.95
1977	12.48	3.91	1.38	0.30	0.30	0.98	3.11	5.57	4.74	3.49	16.28	15.47	6.43
1978	8.76	2.99	0.30	0.30	0.30	0.30	0.30	8.74	24.56	11.24	15.63	15.44	7.99
1979	16.40	5.17	0.30	1.28	0.30	0.30	2.88	18.20	18.57	10.04	10.83	6.11	8.18
1980	5.59	19.86	10.00	4.15	1.86	0.30	0.30	3.98	7.00	38.04	55.93	59.36	17.96
1981	6.60	3.18	3.63	3.81	0.85	5.65	13.06	13.38	18.48	17.63	25.48	8.06	10.78
1982	12.14	4.85	1.02	0.81	0.85	0.73	0.30	27.94	68.85	121.52	38.37	43.69	27.53
1983	7.91	1.67	0.30	0.30	0.30	0.53	0.42	72.89	9.58	60.32	33.48	65.50	21.66
1984	38.52	3.34	3.46	1.82	1.40	17.75	7.57	7.75	49.55	87.69	73.05	20.56	26.83
1985	6.54	3.28	0.30	0.30	0.30	0.31	5.83	15.98	29.80	63.19	112.51	48.63	24.59
1986	6.13	3.26	0.30	0.30	0.30	0.30	0.72	26.59	29.76	40.64	94.97	42.15	21.06
1987	11.99	3.41	0.38	0.30	0.30	0.30	6.55	13.35	23.40	31.36	24.81	47.11	14.28
1988	7.58	3.94	0.30	0.30	0.30	5.74	6.03	12.96	12.60	35.69	50.37	93.71	19.71
1989	15.60	9.12	0.30	0.30	0.68	0.30	28.09	52.29	43.61	127.02	89.88	13.67	32.38
1990	4.91	1.27	0.30	0.30	0.30	0.30	0.30	18.55	58.30	111.75	90.17	104.02	33.07
1991	27.00	11.36	1.20	0.30	0.95	0.32	13.06	14.92	96.75	113.77	32.51	36.74	29.85
1992	48.86	12.80	1.89	0.30	0.30	0.30	24.51	21.45	44.06	221.39	69.65	12.87	38.89
1993	5.96	2.89	0.30	0.30	0.30	0.30	3.11	6.89	83.82	54.51	19.40	14.40	16.71
1994	7.93	5.92	0.30	0.30	0.30	0.62	0.30	7.55	14.19	50.42	61.78	10.21	14.02
1995	28.33	6.47	18.36	1.82	0.99	0.42	1.20	8.46	58.52	56.57	74.51	141.60	33.90
1996	56.80	35.17	9.57	2.58	1.96	0.97	1.55	8.61	116.40	29.25	50.85	25.40	29.05
1997	4.55	6.78	0.30	0.96	0.30	0.30	1.53	40.02	16.78	38.82	21.57	8.16	12.42
1998	7.43	17.03	3.14	0.30	0.30	0.30	2.85	12.50	23.98	38.63	64.04	79.95	21.63
1999	20.27	4.62	0.30	0.41	0.30	0.45	1.04	15.41	22.20	24.55	18.67	38.21	12.96
2000	7.23	3.56	0.30	0.59	0.30	0.30	1.70	12.95	16.80	146.94	116.80	125.49	36.78
2001	20.16	10.20	1.15	5.59	1.95	0.62	2.14	18.38	22.16	52.93	51.63	23.07	18.29
2002	17.20	7.40	0.78	0.30	0.30	0.30	1.11	4.15	7.13	7.99	35.94	16.30	9.00
2003	9.45	5.44	0.30	0.30	0.30	0.30	2.87	2.91	18.25	14.08	42.38	7.42	9.36
2004	10.56	3.95	0.30	0.30	0.30	0.30	1.97	17.86	52.18	32.71	58.21	22.59	17.35

State 1	< 0.5	State 2	0.5-1	State 3	1 - 5	State 4	5 - 25	State 5	>25

Table 4.4 Simulated monthly inflows to the Berg River Estuary for Scenario 2 (m^3s^{-1})

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1928	4.77	3.09	0.30	0.30	0.30	0.30	1.65	5.52	7.06	22.59	19.12	14.57	7.15
1929	5.17	2.65	0.30	0.30	0.38	0.30	0.30	1.50	2.06	3.50	5.74	34.19	5.33
1930	6.57	5.53	0.30	0.30	0.30	0.30	5.39	4.60	5.44	4.83	22.54	20.72	6.98
1931	9.06	4.95	0.30	0.30	11.42	4.91	0.38	10.12	15.96	16.87	14.00	12.84	9.09
1932	6.36	3.48	0.30	0.30	0.30	0.30	0.30	2.46	24.80	34.78	47.90	18.36	12.12
1933	7.29	3.81	0.30	0.30	0.30	0.30	0.36	3.58	4.09	5.43	7.45	8.70	4.11
1934	6.85	9.32	0.30	0.30	0.30	0.30	3.89	4.06	7.15	14.56	14.17	12.12	6.78
1935	5.93	4.02	0.30	0.30	0.30	0.30	0.30	3.37	2.86	4.32	8.84	11.58	4.10
1936	6.11	3.76	0.71	0.75	0.30	1.05	3.30	3.60	34.97	58.70	35.60	14.62	14.38
1937	5.24	2.63	0.30	0.30	0.30	0.30	6.43	4.78	5.87	10.29	9.04	12.26	5.34
1938	5.86	4.10	0.30	0.30	0.30	0.30	0.47	5.20	5.10	8.65	19.55	8.33	5.46
1939	4.44	2.71	0.30	0.30	0.58	0.30	3.57	3.16	16.95	14.43	10.99	8.24	6.11
1940	5.11	4.51	0.30	1.54	1.13	0.30	11.38	39.23	70.39	118.77	106.34	146.76	42.81
1941	28.55	8.68	0.30	0.30	0.30	0.30	0.30	11.34	112.30	53.84	85.75	21.04	27.47
1942	7.88	3.82	0.30	0.30	0.66	0.57	1.02	2.28	4.62	21.49	32.11	33.87	9.73
1943	8.34	7.00	0.30	0.30	0.30	0.30	1.13	6.97	57.01	66.00	119.74	42.41	26.47
1944	14.10	6.82	0.40	0.30	0.30	0.30	0.86	29.73	74.52	167.78	122.08	20.12	37.11
1945	5.95	3.55	0.30	0.30	0.30	0.30	0.64	3.37	3.84	11.11	15.72	44.63	8.03
1946	12.55	6.29	0.30	0.30	0.30	1.01	1.19	3.18	4.15	51.81	19.54	9.35	9.79
1947	5.85	4.29	0.30	0.30	0.30	5.08	5.32	4.89	7.77	34.29	18.69	39.32	11.12
1948	15.70	6.06	0.30	0.30	0.30	0.30	1.96	2.54	5.20	13.05	18.84	11.64	6.92
1949	6.98	12.67	2.89	0.30	0.30	0.30	16.71	3.10	4.10	80.05	14.55	25.17	14.60
1950	12.78	12.75	3.04	1.41	0.67	0.30	9.05	3.19	63.51	61.40	47.51	29.31	21.15
1951	10.46	7.78	0.30	0.30	0.30	0.30	0.43	5.99	8.68	19.50	74.14	75.77	17.66
1952	13.34	12.96	2.60	0.30	0.30	0.30	37.35	44.93	17.42	75.85	131.10	19.15	30.31
1953	5.51	4.89	0.59	0.30	0.30	0.30	6.13	53.38	32.32	228.90	167.63	31.92	45.05
1954	8.25	4.44	0.30	0.30	4.27	1.78	1.01	2.02	6.31	24.87	149.20	41.38	21.08
1955	15.86	9.96	0.32	0.30	0.30	0.30	0.30	4.66	27.95	41.94	80.62	21.76	17.69
1956	6.15	2.82	0.30	0.30	5.64	3.20	1.68	36.79	42.94	134.40	114.39	30.31	32.22
1957	42.07	13.51	0.30	0.30	0.37	0.30	0.35	8.61	7.06	8.76	14.78	7.93	9.38
1958	5.05	3.85	0.30	0.30	0.30	0.30	6.84	80.92	18.65	16.73	25.89	16.37	15.17
1959	7.53	5.39	0.30	0.30	0.30	0.30	0.99	5.69	18.51	11.50	7.04	4.89	5.80
1960	3.71	1.79	0.30	0.30	0.30	0.30	0.30	2.33	13.47	11.02	20.89	27.43	7.35
1961	7.51	3.54	0.30	0.30	0.30	0.47	5.87	2.72	112.76	40.67	129.59	31.76	28.56
1962	36.34	12.78	0.63	0.30	0.30	0.30	0.30	1.47	4.04	9.26	49.24	25.01	12.26
1963	5.90	6.25	1.05	0.33	0.64	0.30	0.48	2.30	13.34	16.07	30.78	17.29	8.66
1964	8.70	8.97	0.94	0.30	2.20	4.74	5.50	4.66	8.02	9.58	17.34	6.44	7.23
1965	3.97	2.38	0.30	0.30	0.30	1.85	2.27	2.32	6.11	28.84	24.11	17.56	8.11
1966	5.04	2.24	0.30	0.30	0.30	0.30	5.64	2.90	32.88	15.67	13.71	12.37	8.11
1967	5.62	4.86	0.30	0.30	0.30	0.30	6.43	10.99	17.12	41.87	66.22	17.12	14.91
1968	25.04	9.21	0.30	0.30	0.30	0.30	1.87	2.04	3.10	3.60	6.35	8.04	5.71
1969	5.70	4.77	0.30	0.30	0.30	0.30	0.30	4.33	16.79	19.58	22.79	19.04	8.35
1970	7.15	3.53	0.30	0.30	0.30	0.30	0.54	1.67	2.78	11.13	13.79	7.10	4.66
1971	4.14	1.65	0.30	0.30	0.30	0.30	2.90	3.35	6.61	5.89	6.56	5.99	3.70
1972	4.22	1.67	0.30	0.30	0.30	0.30	0.30	1.88	2.34	18.98	9.38	7.92	4.68
1973	5.42	2.56	0.30	0.30	0.30	0.30	0.30	12.02	30.90	15.33	235.04	51.46	30.10
1974	18.64	7.85	0.35	0.35	0.30	0.30	2.86	20.31	8.93	32.13	45.10	11.97	13.15
1975	4.57	3.13	0.30	0.30	0.30	0.30	8.52	2.96	37.52	40.01	37.23	16.27	13.21
1976	4.06	34.09	13.44	5.42	1.09	0.65	5.11	22.94	134.17	194.60	161.12	35.23	51.79
1977	7.06	3.49	1.23	0.30	0.30	0.91	2.96	2.68	2.63	2.02	4.86	5.37	3.58
1978	3.72	2.54	0.30	0.30	0.30	0.30	0.30	3.63	14.53	7.51	8.73	9.24	4.87
1979	6.64	3.79	0.30	1.28	0.30	0.30	1.14	8.92	8.37	6.63	4.59	2.93	4.41
1980	2.45	16.08	7.89	3.69	1.86	0.30	0.30	2.61	3.83	26.94	43.80	49.00	13.99
1981	4.44	3.02	2.32	3.81	0.85	5.65	11.76	7.80	10.25	13.00	16.29	3.54	7.69
1982	5.26	4.28	0.97	0.81	0.85	0.71	0.30	13.53	51.72	116.73	33.31	38.72	23.04
1983	4.29	1.55	0.30	0.30	0.30	0.53	0.36	56.10	4.76	48.97	28.55	60.64	17.78
1984	32.00	2.87	2.88	1.82	1.40	16.96	6.33	4.18	33.99	74.08	68.16	15.45	22.47
1985	4.03	1.94	0.30	0.30	0.30	0.30	3.99	7.53	14.14	49.03	112.94	43.53	20.47
1986	4.08	2.41	0.30	0.30	0.30	0.30	0.54	13.53	18.96	30.17	90.62	37.19	17.17
1987	7.03	3.16	0.30	0.30	0.30	0.30	5.40	6.78	18.18	24.89	16.09	38.97	10.81
1988	4.16	3.33	0.30	0.30	0.30	5.42	5.25	6.34	7.48	27.17	40.36	88.76	16.34
1989	11.18	7.56	0.30	0.30	0.68	0.30	14.45	31.64	34.83	126.67	84.78	9.16	27.46
1990	3.21	0.37	0.30	0.30	0.30	0.30	0.30	7.41	34.08	106.24	85.06	99.00	28.60
1991	19.77	7.83	0.30	0.30	0.45	0.32	5.85	6.40	82.90	109.02	27.52	31.59	25.11
1992	43.27	10.11	1.41	0.30	0.30	0.30	19.03	12.60	32.89	218.36	64.73	8.70	35.03
1993	3.42	0.71	0.30	0.30	0.30	0.30	1.11	3.51	53.38	52.51	14.21	9.10	12.24
1994	4.60	3.20	0.30	0.30	0.30	0.62	0.30	4.48	7.16	33.73	61.94	5.81	10.87
1995	20.20	5.52	18.17	1.82	0.99	0.42	1.08	3.72	33.54	52.08	70.38	136.86	29.53
1996	50.76	29.21	8.68	2.58	1.96	0.97	1.42	5.27	94.94	24.36	46.28	19.09	24.59
1997	3.01	3.73	0.30	0.96	0.30	0.30	0.77	25.20	10.35	29.99	16.50	3.97	8.69
1998	4.66	13.87	2.93	0.30	0.30	0.30	1.61	6.50	11.54	23.18	61.07	74.72	17.50
1999	14.41	3.81	0.30	0.41	0.30	0.45	0.30	5.24	15.73	17.85	11.07	31.04	9.13
2000	4.95	2.63	0.30	0.59	0.30	0.30	0.69	6.51	8.86	134.59	112.43	120.59	33.40
2001	13.11	8.95	1.15	5.26	1.95	0.62	1.44	10.71	12.87	40.25	46.82	17.21	14.16
2002	9.89	5.81	0.45	0.30	0.30	0.30	0.99	2.73	4.22	4.89	23.33	7.69	5.82
2003	4.95	3.98	0.30	0.30	0.30	0.30	2.16	2.26	11.37	9.21	24.64	4.85	6.04
2004	7.05	3.72	0.30	0.30	0.30	0.30	1.46	7.49	34.34	22.54	47.38	16.53	12.39

State 1	< 0.5	State 2	0.5-1	State 3	1 - 5	State 4	5 - 25	State 5	>25

Table 4.5 Simulated monthly inflows to the Berg River Estuary for Scenario 3 (m^3s^{-1})

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVERAGE
1928	4.12	3.09	0.30	0.30	0.30	0.30	1.65	4.85	5.28	15.88	14.67	14.59	5.97
1929	4.49	2.65	0.30	0.30	0.38	0.30	0.30	0.92	1.29	2.85	4.44	26.94	4.40
1930	5.91	5.53	0.30	0.30	0.30	0.30	5.39	3.89	4.20	4.13	18.33	15.08	5.88
1931	11.15	4.95	0.30	0.30	11.42	4.91	0.38	9.38	12.12	12.25	10.47	15.60	8.43
1932	5.73	3.48	0.30	0.30	0.30	0.30	0.30	1.78	20.07	36.87	47.56	18.02	11.73
1933	6.42	3.81	0.30	0.30	0.30	0.30	0.36	2.95	3.38	4.75	6.63	7.73	3.72
1934	6.22	9.32	0.30	0.30	0.30	0.30	3.89	3.34	5.85	10.32	10.93	9.41	5.71
1935	5.30	4.02	0.30	0.30	0.30	0.30	0.30	2.61	2.19	3.65	7.83	10.34	3.68
1936	5.42	3.76	0.71	0.75	0.30	1.05	3.30	2.93	26.20	64.36	35.27	14.52	13.97
1937	4.59	2.63	0.30	0.30	0.30	0.30	6.43	4.12	4.39	6.88	7.06	9.11	4.40
1938	5.23	4.10	0.30	0.30	0.30	0.30	0.47	4.34	3.70	5.69	13.41	6.56	4.31
1939	3.76	2.71	0.30	0.30	0.58	0.30	3.57	2.45	12.53	9.74	7.54	6.40	4.79
1940	4.47	4.51	0.30	1.54	1.13	0.30	11.38	32.64	84.20	118.69	106.01	146.42	43.30
1941	28.12	8.68	0.30	0.30	0.30	0.30	0.30	8.29	113.05	53.52	85.41	20.71	27.17
1942	7.16	3.82	0.30	0.30	0.66	0.57	1.02	1.53	3.92	16.77	33.94	33.53	9.28
1943	7.52	7.00	0.30	0.30	0.30	0.30	1.13	6.14	49.31	70.16	119.40	42.07	25.98
1944	14.10	6.82	0.40	0.30	0.30	0.30	0.86	25.85	75.48	167.45	121.75	19.77	36.79
1945	5.28	3.55	0.30	0.30	0.30	0.30	0.64	2.59	3.14	7.32	10.52	36.41	6.41
1946	19.55	6.29	0.30	0.30	0.30	1.01	1.19	2.41	3.11	42.31	14.99	8.56	8.99
1947	5.22	4.29	0.30	0.30	0.30	5.08	5.32	4.23	5.34	25.82	16.97	44.35	10.38
1948	15.13	6.06	0.30	0.30	0.30	0.30	1.96	1.79	3.92	8.83	13.46	9.22	5.71
1949	6.24	12.67	2.89	0.30	0.30	0.30	16.71	2.33	3.12	69.05	11.56	36.07	14.14
1950	12.27	12.75	3.04	1.41	0.67	0.30	9.05	2.52	52.99	67.16	47.18	28.97	20.60
1951	10.46	7.78	0.30	0.30	0.30	0.30	0.43	5.33	7.16	15.00	76.11	75.40	17.24
1952	13.34	12.96	2.60	0.30	0.30	0.30	37.35	38.62	16.06	79.67	130.76	18.81	29.93
1953	4.82	4.89	0.59	0.30	0.30	0.30	6.13	45.57	34.98	228.90	167.30	31.57	44.50
1954	7.40	4.44	0.30	0.30	4.27	1.78	1.01	1.30	5.57	18.46	151.98	41.03	20.55
1955	15.44	9.96	0.32	0.30	0.30	0.30	0.30	4.00	20.73	38.19	86.26	21.41	17.12
1956	5.46	2.82	0.30	0.30	5.64	3.20	1.68	30.36	46.40	134.07	114.06	29.97	31.83
1957	41.65	13.51	0.30	0.30	0.37	0.30	0.35	7.82	5.26	6.01	11.05	6.53	8.47
1958	4.37	3.85	0.30	0.30	0.30	0.30	6.84	70.11	20.95	16.41	25.56	16.03	14.32
1959	6.86	5.39	0.30	0.30	0.30	0.30	0.99	5.00	12.40	7.83	5.59	4.19	4.70
1960	2.94	1.79	0.30	0.30	0.30	0.30	0.30	1.61	9.15	7.49	14.69	20.08	5.45
1961	6.70	3.54	0.30	0.30	0.30	0.47	5.87	1.96	98.41	63.65	129.32	31.41	29.10
1962	35.92	12.78	0.63	0.30	0.30	0.30	0.30	0.85	3.36	7.21	48.00	25.10	11.85
1963	5.24	6.25	1.05	0.33	0.64	0.30	0.48	1.55	9.92	11.02	33.74	16.94	8.06
1964	8.27	8.97	0.94	0.30	2.20	4.74	5.50	3.73	5.09	6.18	11.23	5.38	5.99
1965	3.24	2.38	0.30	0.30	0.30	1.85	2.27	1.56	4.58	21.06	28.52	17.22	7.55
1966	4.37	2.24	0.30	0.30	0.30	0.30	5.64	2.16	25.67	16.24	17.99	12.37	7.79
1967	4.93	4.86	0.30	0.30	0.30	0.30	6.43	9.79	12.55	45.11	65.88	17.12	14.61
1968	24.62	9.21	0.30	0.30	0.30	0.30	1.87	1.30	2.39	2.91	4.83	5.93	5.19
1969	5.02	4.77	0.30	0.30	0.30	0.30	0.30	3.68	13.15	14.48	18.80	24.88	7.66
1970	6.25	3.53	0.30	0.30	0.30	0.30	0.54	1.00	2.15	7.50	10.45	6.00	3.80
1971	3.39	1.65	0.30	0.30	0.30	0.30	2.90	2.59	5.06	5.22	5.64	5.20	3.25
1972	3.44	1.67	0.30	0.30	0.30	0.30	0.30	1.21	1.65	16.45	7.86	6.98	4.08
1973	4.71	2.56	0.30	0.30	0.30	0.30	0.30	11.39	26.10	11.31	242.31	51.67	29.87
1974	18.64	7.85	0.35	0.35	0.30	0.30	2.86	15.88	6.21	25.21	49.54	11.62	12.32
1975	3.80	3.13	0.30	0.30	0.30	0.30	8.52	2.27	29.95	36.75	38.54	16.27	12.29
1976	3.44	34.09	13.44	5.42	1.09	0.65	5.11	19.45	134.17	194.27	160.78	34.89	51.36
1977	5.75	3.49	1.23	0.30	0.30	0.91	2.96	1.93	2.00	1.24	3.76	4.08	3.09
1978	3.08	2.54	0.30	0.30	0.30	0.30	0.30	2.88	12.12	5.06	7.70	8.57	4.21
1979	5.24	3.79	0.30	1.28	0.30	0.30	1.14	6.44	5.92	4.25	3.87	2.17	3.56
1980	1.74	16.08	7.89	3.69	1.86	0.30	0.30	1.88	2.74	21.85	35.58	61.90	13.74
1981	3.76	3.02	2.32	3.81	0.85	5.65	11.76	5.93	7.52	9.58	12.81	2.87	6.62
1982	4.08	4.28	0.97	0.81	0.85	0.71	0.30	11.25	52.28	116.40	32.98	38.38	22.71
1983	3.64	1.55	0.30	0.30	0.30	0.53	0.36	48.61	3.61	45.98	29.62	60.30	16.82
1984	31.58	2.87	2.88	1.82	1.40	16.96	6.33	3.47	26.32	78.21	67.82	15.11	22.03
1985	3.25	1.94	0.30	0.30	0.30	0.30	3.99	4.78	9.59	50.81	112.78	43.19	19.90
1986	3.39	2.41	0.30	0.30	0.30	0.30	0.54	9.59	13.38	33.93	90.29	36.84	16.57
1987	5.34	3.16	0.30	0.30	0.30	0.30	5.40	4.59	13.88	17.57	11.82	44.62	9.63
1988	3.51	3.33	0.30	0.30	0.30	5.42	5.25	4.77	5.09	19.87	45.45	88.42	15.75
1989	11.18	7.56	0.30	0.30	0.68	0.30	14.45	25.97	29.15	132.62	84.45	6.54	26.77
1990	2.46	0.37	0.30	0.30	0.30	0.30	0.30	4.66	26.38	114.88	84.72	98.66	28.33
1991	19.34	7.83	0.30	0.30	0.45	0.32	5.85	4.79	81.48	108.69	27.19	31.25	24.74
1992	42.84	10.11	1.41	0.30	0.30	0.30	19.03	10.44	30.08	218.03	64.40	7.00	34.38
1993	2.78	0.71	0.30	0.30	0.30	0.30	1.11	2.83	42.53	59.83	14.02	8.91	11.80
1994	3.98	3.20	0.30	0.30	0.30	0.62	0.30	3.74	4.62	28.75	62.48	4.83	10.10
1995	19.96	5.52	18.17	1.82	0.99	0.42	1.08	2.98	25.17	56.94	70.05	136.52	29.10
1996	50.34	29.21	8.68	2.58	1.96	0.97	1.42	4.53	86.74	26.47	45.44	18.16	23.84
1997	2.26	3.73	0.30	0.96	0.30	0.30	0.77	20.17	7.99	30.34	16.17	3.10	7.94
1998	4.03	13.87	2.93	0.30	0.30	0.30	1.61	4.74	7.61	15.89	68.39	74.38	16.95
1999	10.75	3.81	0.30	0.41	0.30	0.45	0.30	3.49	10.57	12.69	7.92	36.16	7.98
2000	4.23	2.63	0.30	0.59	0.30	0.30	0.69	5.07	5.83	134.56	112.09	120.24	32.91
2001	12.62	8.95	1.15	5.26	1.95	0.62	1.44	7.98	8.62	40.15	46.49	17.21	13.50
2002	9.30	5.81	0.45	0.30	0.30	0.30	0.99	2.00	2.93	3.20	20.60	6.66	5.15
2003	4.29	3.98	0.30	0.30	0.30	0.30	2.16	1.51	7.60	6.39	18.15	4.21	4.78
2004	6.39	3.72	0.30	0.30	0.30	0.30	1.46	4.61	25.44	15.36	62.59	16.31	12.00

State 1	< 0.5	State 2	0.5-1	State 3	1 - 5	State 4	5 - 25	State 5	>25

Table 4.6 Simulated monthly inflows to the Berg River Estuary for Scenario 4 (m^3s^{-1})

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1928	4.12	3.09	0.30	0.30	0.30	0.30	1.65	4.85	5.28	15.88	13.85	8.56	5.40
1929	4.49	2.65	0.30	0.30	0.38	0.30	0.30	0.92	1.29	2.85	4.44	26.94	4.40
1930	5.91	5.53	0.30	0.30	0.30	0.30	5.39	3.89	4.20	4.13	18.33	15.08	5.88
1931	7.30	4.95	0.30	0.30	11.42	4.91	0.38	9.38	12.12	12.25	10.47	9.56	7.61
1932	5.73	3.48	0.30	0.30	0.30	0.30	0.30	1.78	20.07	27.40	21.16	11.84	8.23
1933	6.44	3.81	0.30	0.30	0.30	0.30	0.36	2.95	3.38	4.75	6.63	7.73	3.72
1934	6.22	9.32	0.30	0.30	0.30	0.30	3.89	3.34	5.85	10.32	10.93	9.41	5.71
1935	5.30	4.02	0.30	0.30	0.30	0.30	0.30	2.61	2.19	3.65	7.83	10.34	3.68
1936	5.42	3.76	0.71	0.75	0.30	1.05	3.30	2.93	26.20	46.69	15.77	9.27	10.44
1937	4.59	2.63	0.30	0.30	0.30	0.30	6.43	4.12	4.39	6.88	7.06	9.12	4.40
1938	5.23	4.10	0.30	0.30	0.30	0.30	0.47	4.34	3.70	5.69	13.41	6.56	4.31
1939	3.76	2.71	0.30	0.30	0.58	0.30	3.57	2.45	12.53	9.74	7.54	6.40	4.79
1940	4.47	4.51	0.30	1.54	1.13	0.30	11.38	32.64	61.57	84.39	105.66	146.08	38.49
1941	27.48	8.68	0.30	0.30	0.30	0.30	0.30	8.29	108.04	30.28	85.04	20.66	24.72
1942	7.16	3.82	0.30	0.30	0.66	0.57	1.02	1.53	3.92	16.77	25.38	15.62	7.07
1943	7.36	7.00	0.30	0.30	0.30	0.30	1.13	6.14	51.76	41.58	109.70	41.60	22.94
1944	13.80	6.82	0.40	0.30	0.30	0.30	0.86	25.85	66.25	143.22	121.43	19.23	33.90
1945	5.28	3.55	0.30	0.30	0.30	0.30	0.64	2.59	3.14	7.32	10.52	39.30	6.66
1946	9.74	6.29	0.30	0.30	0.30	1.01	1.19	2.41	3.11	42.31	14.62	7.47	8.05
1947	5.22	4.29	0.30	0.30	0.30	5.08	5.32	4.23	5.34	25.82	13.54	19.45	8.02
1948	8.09	6.06	0.30	0.30	0.30	0.30	1.96	1.79	3.92	8.83	13.46	9.22	5.12
1949	6.24	12.67	2.89	0.30	0.30	0.30	16.71	2.33	3.12	69.05	11.49	17.48	12.58
1950	8.28	12.75	3.04	1.41	0.67	0.30	9.05	2.52	57.83	35.53	38.36	28.49	17.26
1951	10.01	7.78	0.30	0.30	0.30	0.30	0.43	5.33	7.16	15.00	57.37	64.30	14.71
1952	13.02	12.96	2.60	0.30	0.30	0.30	37.35	40.05	12.30	48.90	130.14	18.26	27.05
1953	4.82	4.89	0.59	0.30	0.30	0.30	6.13	45.57	20.43	217.03	167.01	31.08	42.24
1954	7.40	4.44	0.30	0.30	4.27	1.78	1.01	1.30	5.57	18.46	124.09	40.53	18.19
1955	14.81	9.96	0.32	0.30	0.30	0.30	0.30	4.00	20.73	39.07	59.31	17.55	14.58
1956	5.46	2.82	0.30	0.30	5.64	3.20	1.68	30.36	41.08	106.57	113.71	29.48	29.02
1957	41.09	13.51	0.30	0.30	0.37	0.30	0.35	7.82	5.26	6.01	11.05	6.53	8.42
1958	4.37	3.85	0.30	0.30	0.30	0.30	6.84	70.11	11.98	10.03	13.10	10.37	11.53
1959	6.73	5.39	0.30	0.30	0.30	0.30	0.99	5.00	12.40	7.83	5.59	4.19	4.68
1960	2.94	1.79	0.30	0.30	0.30	0.30	0.30	1.61	9.15	7.49	14.69	20.08	5.45
1961	6.70	3.54	0.30	0.30	0.30	0.47	5.87	1.96	99.61	33.37	114.88	30.91	25.43
1962	35.35	12.78	0.63	0.30	0.30	0.30	0.30	0.85	3.36	7.21	45.07	11.43	10.42
1963	5.24	6.25	1.05	0.33	0.64	0.30	0.48	1.55	9.92	11.02	19.92	8.84	6.23
1964	6.02	8.97	0.94	0.30	2.20	4.74	5.50	3.73	5.09	6.18	12.96	4.78	5.90
1965	3.24	2.38	0.30	0.30	0.30	1.85	2.27	1.56	4.58	21.06	13.87	8.18	5.58
1966	4.37	2.24	0.30	0.30	0.30	0.30	5.64	2.16	25.67	11.63	7.92	6.85	6.11
1967	4.93	4.86	0.30	0.30	0.30	0.30	6.43	9.79	12.72	31.28	46.98	16.96	11.89
1968	24.04	9.21	0.30	0.30	0.30	0.30	1.87	1.30	2.39	2.91	4.83	5.93	5.14
1969	5.02	4.77	0.30	0.30	0.30	0.30	0.30	3.68	13.15	14.48	17.68	13.93	6.66
1970	6.25	3.53	0.30	0.30	0.30	0.30	0.54	1.00	2.15	7.50	10.45	6.00	3.80
1971	3.39	1.65	0.30	0.30	0.30	0.30	2.90	2.59	5.06	5.22	5.64	5.20	3.25
1972	3.44	1.67	0.30	0.30	0.30	0.30	0.30	1.21	1.65	16.45	7.86	6.98	4.08
1973	4.71	2.56	0.30	0.30	0.30	0.30	0.30	11.39	26.10	11.31	216.48	27.75	25.73
1974	15.30	7.85	0.35	0.35	0.30	0.30	2.86	15.88	6.21	29.14	24.30	7.97	9.96
1975	3.80	3.13	0.30	0.30	0.30	0.30	8.52	2.27	29.95	35.79	18.83	8.51	9.92
1976	3.44	33.84	13.44	5.42	1.09	0.65	5.11	20.43	101.61	194.06	160.46	34.42	48.63
1977	5.75	3.49	1.23	0.30	0.30	0.91	2.96	1.93	2.00	1.24	3.76	4.08	3.09
1978	3.08	2.54	0.30	0.30	0.30	0.30	0.30	2.88	12.12	5.06	7.70	8.57	4.21
1979	5.24	3.79	0.30	1.28	0.30	0.30	1.14	6.44	5.92	4.25	3.87	2.17	3.56
1980	1.74	16.08	7.89	3.69	1.86	0.30	0.30	1.88	2.74	21.85	35.02	33.21	11.30
1981	3.76	3.02	2.32	3.81	0.85	5.65	11.76	5.93	7.52	9.58	12.81	2.87	6.62
1982	4.08	4.28	0.97	0.81	0.85	0.71	0.30	11.25	37.54	83.12	32.54	37.91	18.64
1983	3.64	1.55	0.30	0.30	0.30	0.53	0.36	48.61	3.61	40.87	16.15	50.88	14.49
1984	31.29	2.87	2.88	1.82	1.40	16.96	6.33	3.47	26.90	60.52	51.69	14.86	19.21
1985	3.25	1.94	0.30	0.30	0.30	0.30	3.99	4.78	9.59	43.29	86.66	42.72	17.06
1986	3.39	2.41	0.30	0.30	0.30	0.30	0.54	9.59	13.38	26.68	67.46	36.40	14.03
1987	5.34	3.16	0.30	0.30	0.30	0.30	5.40	4.59	13.88	17.57	12.04	29.82	8.42
1988	3.51	3.33	0.30	0.30	0.30	5.42	5.25	4.77	5.09	19.94	26.10	73.43	12.89
1989	10.74	7.56	0.30	0.30	0.68	0.30	14.45	25.97	30.74	97.56	84.03	6.33	23.89
1990	2.46	0.37	0.30	0.30	0.30	0.30	0.30	4.66	29.91	83.24	80.11	98.26	25.57
1991	18.73	7.83	0.30	0.30	0.45	0.32	5.85	4.79	68.25	87.47	26.79	30.77	21.74
1992	42.24	10.11	1.41	0.30	0.30	0.30	19.03	10.58	27.96	183.10	64.00	6.49	31.18
1993	2.78	0.71	0.30	0.30	0.30	0.30	1.11	2.83	51.96	35.92	6.37	4.10	9.56
1994	3.98	3.20	0.30	0.30	0.30	0.62	0.30	3.74	4.62	29.94	39.02	4.23	8.19
1995	17.74	5.52	18.17	1.82	0.99	0.42	1.08	2.98	25.77	41.18	49.08	136.16	25.87
1996	49.69	29.21	8.68	2.58	1.96	0.97	1.42	4.53	86.74	17.05	21.66	18.20	21.02
1997	2.26	3.73	0.30	0.96	0.30	0.30	0.77	20.17	8.02	21.39	5.78	2.49	6.29
1998	4.03	13.87	2.93	0.30	0.30	0.30	1.61	4.74	7.61	16.44	41.58	63.66	13.87
1999	10.75	3.81	0.30	0.41	0.30	0.45	0.30	3.49	10.57	12.69	7.92	17.59	6.44
2000	4.23	2.63	0.30	0.59	0.30	0.30	0.69	5.07	5.83	114.19	89.70	119.82	29.31
2001	11.95	8.95	1.15	5.26	1.95	0.62	1.44	7.98	8.62	31.69	27.28	17.21	11.14
2002	8.63	5.81	0.45	0.30	0.30	0.30	0.99	2.00	2.93	3.20	20.60	6.66	5.10
2003	4.29	3.98	0.30	0.30	0.30	0.30	2.16	1.51	7.60	6.39	18.15	4.21	4.78
2004	6.39	3.72	0.30	0.30	0.30	0.30	1.46	4.61	25.44	15.36	40.77	9.51	9.62

State 1	< 0.5	State 2	0.5-1	State 3	1 - 5	State 4	5 - 25	State 5	>25

Table 4.7 Simulated monthly inflows to the Berg River Estuary for Scenario 5 (m^3s^{-1})

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1928	6.61	2.67	0.30	0.30	0.30	0.30	1.07	7.59	10.41	23.91	14.91	13.88	7.46
1929	6.83	1.78	0.30	0.37	0.63	0.30	0.30	1.57	3.34	5.77	7.34	25.49	5.19
1930	8.72	5.37	0.30	0.30	0.30	0.30	2.30	5.94	8.69	7.56	19.10	19.26	7.17
1931	11.31	5.14	0.30	0.30	1.79	1.28	0.30	12.43	19.35	20.22	12.85	15.28	9.04
1932	8.43	2.96	0.30	0.30	0.30	0.30	0.30	2.58	22.06	31.05	16.84	14.25	8.85
1933	9.91	4.04	0.30	0.30	0.30	0.32	0.30	5.38	6.93	8.08	6.50	11.87	5.15
1934	8.81	5.42	0.56	0.30	0.30	0.30	1.31	5.34	10.39	17.90	14.46	15.52	7.45
1935	7.99	4.23	0.30	0.38	0.30	0.30	0.30	3.92	5.11	6.40	11.94	14.79	5.25
1936	7.73	3.42	0.84	1.03	0.30	1.11	1.16	5.20	19.85	31.78	14.59	10.27	8.87
1937	7.07	1.91	0.30	0.34	0.30	0.30	1.39	6.44	9.16	13.63	10.81	15.66	6.22
1938	7.90	4.33	0.30	0.30	0.31	0.30	0.58	7.71	8.38	10.18	14.36	11.71	6.20
1939	6.11	2.78	0.30	0.30	0.67	0.30	1.15	4.55	19.23	16.93	8.07	9.97	6.53
1940	7.21	4.71	0.30	1.65	1.23	0.30	1.61	19.55	27.36	79.47	104.10	143.98	33.31
1941	28.63	5.73	0.30	0.32	0.30	0.30	0.30	11.02	94.40	55.79	83.68	20.99	25.78
1942	10.23	4.05	0.30	0.39	0.92	0.74	0.77	2.87	7.39	23.90	18.56	19.23	8.13
1943	10.90	5.35	0.40	0.30	0.30	0.30	0.93	9.45	22.58	61.90	117.15	39.26	23.13
1944	12.24	5.43	0.66	0.43	0.30	0.30	0.70	17.19	66.31	165.39	119.43	20.05	34.76
1945	7.17	3.28	0.30	0.30	0.30	0.30	0.74	4.22	6.64	14.45	13.42	27.71	7.18
1946	11.81	5.43	0.30	0.30	0.30	1.17	0.54	4.15	7.35	37.82	15.09	10.71	8.61
1947	7.77	4.52	0.30	0.30	0.30	1.49	1.07	6.91	11.16	26.43	14.09	19.77	8.49
1948	11.33	5.28	0.30	0.30	0.30	0.30	1.03	3.16	8.42	16.38	14.81	15.03	7.05
1949	9.37	5.37	1.01	0.42	0.30	0.30	1.97	3.89	7.26	48.08	12.52	19.21	9.87
1950	11.35	5.46	1.07	1.67	0.94	0.30	1.38	4.80	26.74	49.85	47.46	28.52	15.72
1951	10.46	5.53	0.58	0.30	0.30	0.30	0.54	7.59	11.95	22.19	46.05	77.21	15.98
1952	11.97	6.44	1.13	0.42	0.30	0.30	9.18	44.20	22.71	77.03	130.88	19.17	27.70
1953	5.64	4.93	0.80	0.46	0.30	0.30	1.07	17.76	45.00	225.79	164.63	32.23	42.32
1954	10.83	4.68	0.30	0.38	1.63	1.28	0.32	2.39	9.19	25.67	118.96	40.20	18.75
1955	15.24	5.48	0.59	0.35	0.30	0.30	0.30	6.28	21.12	27.07	71.98	21.20	14.92
1956	8.37	2.31	0.30	0.30	1.78	1.30	0.61	19.98	40.01	131.31	109.58	30.50	29.54
1957	42.03	6.69	0.30	0.30	0.61	0.30	0.30	11.09	10.43	7.20	14.07	10.61	9.38
1958	6.65	3.95	0.30	0.30	0.30	0.30	1.45	28.22	16.93	10.26	11.24	11.93	8.27
1959	10.07	5.01	0.30	0.30	0.30	0.30	0.47	7.82	17.32	14.86	5.42	5.36	6.26
1960	4.14	0.89	0.30	0.30	0.30	0.30	0.30	2.67	16.88	14.36	14.62	20.38	6.84
1961	10.13	3.38	0.30	0.30	0.30	0.65	1.37	3.38	32.86	46.50	125.85	31.76	22.04
1962	36.11	6.08	0.87	0.35	0.30	0.30	0.30	1.54	6.17	12.54	26.71	17.94	9.75
1963	7.65	5.26	1.00	0.61	0.90	0.30	0.30	2.84	16.71	19.63	15.63	14.70	7.88
1964	9.01	5.51	0.95	0.38	1.53	1.53	1.26	7.21	11.42	12.54	12.75	8.28	6.83
1965	4.86	1.53	0.30	0.30	0.30	1.40	1.04	2.95	9.39	26.05	14.39	14.43	7.07
1966	6.75	1.30	0.30	0.30	0.30	0.30	1.43	4.04	21.99	19.61	8.98	11.48	6.95
1967	7.89	5.03	0.30	0.30	0.30	0.30	1.38	12.56	18.08	26.90	17.35	13.28	9.35
1968	12.58	5.54	0.30	0.51	0.30	0.30	0.78	2.49	5.95	6.30	9.05	11.56	5.37
1969	7.87	4.80	0.30	0.30	0.30	0.30	0.30	6.07	19.60	22.94	16.48	17.32	8.61
1970	9.80	3.45	0.30	0.30	0.30	0.30	0.30	1.80	5.23	14.45	14.98	10.35	5.76
1971	4.24	1.08	0.30	0.30	0.30	0.30	1.06	4.38	9.90	8.49	7.67	8.37	4.46
1972	4.74	0.96	0.45	0.30	0.30	0.34	0.30	1.99	3.92	22.21	12.62	10.90	5.60
1973	6.90	1.65	0.30	0.41	0.30	0.30	0.30	13.39	25.67	18.12	153.17	50.26	23.17
1974	17.81	5.59	0.63	0.61	0.38	0.30	1.05	13.29	12.34	25.82	23.27	11.31	10.13
1975	7.03	3.36	0.30	0.30	0.30	0.30	5.51	3.17	22.41	29.50	26.62	14.22	10.09
1976	5.40	22.99	5.60	2.03	1.33	0.84	1.50	15.80	128.42	190.16	158.12	35.96	48.14
1977	9.74	3.71	1.24	0.34	0.43	1.08	0.85	3.23	5.09	3.48	7.96	8.63	4.61
1978	5.60	2.77	0.30	0.31	0.46	0.30	0.30	4.74	17.89	10.83	9.61	9.71	5.85
1979	10.26	4.02	0.30	1.54	0.40	0.30	0.73	10.46	11.75	6.75	4.75	4.26	5.33
1980	2.84	5.64	1.23	1.85	1.48	0.30	0.30	3.88	7.03	28.20	22.67	17.25	8.49
1981	6.09	3.25	0.84	2.09	1.12	1.52	1.81	9.96	13.61	16.32	14.58	4.93	7.14
1982	7.95	4.27	0.83	1.09	1.09	0.89	0.30	10.92	19.96	64.69	33.15	36.25	15.88
1983	6.39	1.07	0.30	0.30	0.30	0.69	0.30	24.88	7.99	44.89	29.64	59.24	15.28
1984	31.44	3.11	0.93	1.90	1.53	2.44	1.60	5.54	23.62	75.21	66.44	15.52	19.90
1985	4.88	2.18	0.30	0.30	0.30	0.43	0.78	9.54	17.10	27.10	95.93	42.85	17.48
1986	4.85	2.63	0.30	0.30	0.56	0.30	0.30	10.43	17.64	25.69	66.08	37.44	14.53
1987	9.62	3.39	0.45	0.30	0.30	0.30	1.19	9.58	18.52	20.84	12.90	19.39	8.80
1988	5.96	3.56	0.30	0.30	0.32	1.36	1.33	9.04	10.85	24.64	17.05	65.87	12.36
1989	10.41	5.48	0.30	0.30	0.93	0.30	5.94	17.18	27.82	127.42	83.09	7.16	24.57
1990	3.33	0.59	0.30	0.30	0.30	0.30	0.30	9.62	18.98	92.72	84.04	99.25	26.43
1991	17.87	4.97	0.36	0.32	0.70	0.50	0.80	9.12	58.01	106.57	26.22	31.19	22.18
1992	42.63	4.97	0.84	0.30	0.34	0.30	4.70	12.29	24.43	215.41	64.13	8.15	32.29
1993	4.18	0.93	0.30	0.30	0.30	0.42	0.74	5.62	24.73	50.17	14.02	8.83	9.93
1994	6.57	3.43	0.30	0.30	0.52	0.81	0.30	6.81	10.51	30.68	24.25	5.53	8.20
1995	18.35	4.78	11.23	1.84	1.24	0.61	0.62	4.92	18.03	41.02	69.93	135.83	26.50
1996	50.35	22.76	1.08	1.93	1.48	1.17	0.60	7.58	66.82	28.27	45.62	19.37	21.38
1997	3.34	3.93	0.45	1.22	0.41	0.30	0.67	15.90	13.93	21.92	6.70	4.64	6.90
1998	6.02	5.46	2.26	0.39	0.47	0.30	0.97	9.21	14.95	22.89	21.34	71.90	13.81
1999	13.30	4.04	0.30	0.68	0.36	0.65	0.39	8.01	15.43	20.06	9.69	19.15	8.44
2000	6.33	2.52	0.30	0.86	0.39	0.30	0.76	9.15	12.27	66.44	111.31	120.37	28.31
2001	14.04	5.48	1.01	1.85	1.52	0.82	0.89	10.75	16.30	28.27	36.92	16.86	12.02
2002	11.37	5.22	0.71	0.44	0.30	0.33	0.71	3.89	5.09	5.05	21.85	10.89	6.28
2003	6.67	4.21	0.30	0.30	0.30	0.30	1.08	2.85	14.75	12.50	15.38	5.73	6.10
2004	9.15	3.95	0.30	0.30	0.30	0.30	0.94	9.47	17.56	19.77	18.45	13.10	8.46

State 1	< 0.5	State 2	0.5-1	State 3	1 - 5	State 4	5 - 25	State 5	>25

Table 4.8 Simulated monthly inflows to the Berg River Estuary for Scenario 6 (m^3s^{-1})

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1928	6.61	2.03	0.30	0.30	0.30	0.30	0.53	7.59	10.41	20.31	12.45	11.42	6.64
1929	6.49	1.49	0.30	0.37	0.63	0.30	0.30	1.57	3.34	5.77	6.67	21.93	4.76
1930	8.72	3.85	0.30	0.30	0.30	0.30	1.74	5.94	8.69	7.56	16.44	15.80	6.49
1931	9.37	3.63	0.30	0.30	1.22	0.86	0.30	11.94	19.07	17.41	11.01	12.55	7.96
1932	8.43	2.26	0.30	0.30	0.30	0.30	0.30	2.58	21.55	26.85	14.22	11.87	7.97
1933	8.91	3.39	0.30	0.30	0.30	0.32	0.30	5.38	6.93	8.08	6.45	11.87	4.98
1934	8.81	3.86	0.30	0.30	0.30	0.30	0.76	5.34	10.39	16.24	12.13	13.45	6.71
1935	7.99	3.29	0.30	0.38	0.34	0.30	0.30	3.92	5.11	6.40	10.38	14.51	5.04
1936	7.73	2.53	0.30	1.03	0.30	0.81	0.60	5.20	19.35	27.41	12.32	8.93	7.96
1937	6.36	1.55	0.30	0.34	0.30	0.30	0.83	6.44	9.16	13.07	9.31	13.67	5.75
1938	7.90	3.55	0.30	0.30	0.31	0.30	0.30	7.71	8.38	8.99	11.92	10.90	5.74
1939	6.11	2.05	0.30	0.30	0.81	0.32	0.60	4.55	18.74	14.43	7.28	8.53	6.01
1940	7.21	3.57	0.30	1.14	0.89	0.30	1.05	18.82	26.85	85.35	104.41	143.98	33.53
1941	28.63	4.18	0.30	0.32	0.30	0.30	0.30	10.28	96.87	55.79	83.68	20.99	25.77
1942	9.05	3.20	0.30	0.39	0.84	0.74	0.31	2.87	7.39	20.60	15.78	17.78	7.28
1943	9.70	3.79	0.30	0.30	0.30	0.30	0.39	9.15	29.99	66.34	117.15	39.26	23.78
1944	12.24	3.89	0.30	0.43	0.30	0.30	0.30	16.45	69.50	165.39	119.43	20.05	34.75
1945	6.39	2.45	0.30	0.30	0.30	0.30	0.34	4.22	6.64	13.23	11.11	24.10	6.41
1946	9.87	3.88	0.30	0.30	0.30	0.87	0.30	4.15	7.35	33.51	12.60	9.24	7.57
1947	7.77	3.44	0.30	0.30	0.30	1.06	0.52	6.91	11.16	22.60	11.71	16.30	7.51
1948	9.39	3.74	0.30	0.30	0.30	0.30	0.48	3.16	8.42	14.92	12.39	13.37	6.23
1949	9.15	3.81	0.30	0.42	0.30	0.30	1.41	3.89	7.06	43.54	10.62	15.83	8.76
1950	9.44	6.01	0.30	1.15	0.83	0.30	0.82	4.80	49.00	63.80	47.46	28.52	18.44
1951	9.21	3.97	0.30	0.30	0.30	0.30	0.34	7.59	11.95	18.94	50.50	77.21	15.78
1952	11.97	6.44	0.30	0.42	0.30	0.30	8.62	45.64	22.71	77.03	130.88	19.17	27.70
1953	5.26	3.47	0.30	0.46	0.30	0.30	0.51	17.56	48.28	225.79	164.63	32.23	42.31
1954	9.11	3.42	0.30	0.38	1.08	0.86	0.30	2.39	9.19	21.91	124.91	40.20	18.56
1955	15.24	3.92	0.30	0.35	0.30	0.30	0.30	6.28	20.62	23.00	78.43	21.20	14.89
1956	8.06	1.83	0.30	0.30	1.22	0.87	0.30	19.24	42.67	131.31	109.58	30.50	29.51
1957	42.03	6.69	0.30	0.30	0.61	0.30	0.30	11.09	10.43	6.74	12.01	9.06	8.99
1958	6.60	2.87	0.30	0.30	0.30	0.30	0.90	27.48	16.45	9.24	12.16	15.14	8.27
1959	9.01	3.56	0.30	0.30	0.30	0.30	0.30	7.82	16.82	13.09	5.38	5.21	5.80
1960	4.03	0.88	0.30	0.30	0.30	0.30	0.30	2.67	16.88	13.65	12.21	16.85	6.27
1961	9.32	2.51	0.30	0.30	0.30	0.65	0.81	3.38	32.36	52.86	125.85	31.76	22.34
1962	36.11	6.08	0.30	0.35	0.30	0.30	0.30	1.54	6.17	12.54	23.88	20.02	9.62
1963	7.61	3.74	0.30	0.61	0.90	0.30	0.30	2.84	16.71	16.59	12.96	11.95	6.95
1964	8.85	3.95	0.30	0.38	0.97	1.10	0.69	7.21	11.42	10.84	10.46	7.21	6.05
1965	4.53	1.27	0.30	0.30	0.30	0.98	0.49	2.95	9.39	22.10	11.86	11.70	6.17
1966	6.75	1.14	0.30	0.30	0.30	0.30	0.87	4.04	21.48	16.58	8.04	9.57	6.36
1967	7.82	3.53	0.30	0.30	0.30	0.30	0.82	11.83	17.58	23.00	14.62	11.16	8.32
1968	22.17	3.98	0.30	0.51	0.30	0.30	0.30	2.49	5.95	6.30	7.81	11.46	5.86
1969	7.87	3.38	0.30	0.30	0.30	0.30	0.30	6.07	19.10	19.81	13.78	14.13	7.68
1970	8.86	2.56	0.30	0.30	0.30	0.30	0.30	1.80	5.23	14.45	12.53	9.39	5.31
1971	4.14	1.00	0.30	0.30	0.30	0.30	0.52	4.38	9.90	8.49	7.01	7.39	4.26
1972	4.51	0.93	0.30	0.30	0.30	0.34	0.30	1.99	3.83	21.12	10.64	9.34	5.12
1973	6.90	1.40	0.30	0.41	0.30	0.30	0.30	12.71	25.16	16.15	154.16	50.26	22.96
1974	17.81	4.03	0.30	0.61	0.38	0.30	0.50	12.55	12.34	21.90	30.56	11.31	10.12
1975	6.73	2.68	0.30	0.30	0.30	0.30	4.98	3.17	21.90	25.33	32.37	14.22	10.06
1976	4.78	23.62	5.60	1.35	0.96	0.84	0.94	17.32	128.42	190.16	158.12	35.96	48.13
1977	8.09	2.72	0.30	0.34	0.43	0.79	0.32	3.23	4.97	3.48	7.96	8.63	4.23
1978	5.60	2.37	0.30	0.31	0.46	0.30	0.30	4.74	17.89	10.39	8.75	9.05	5.65
1979	8.31	3.06	0.30	1.15	0.40	0.30	0.30	9.73	11.75	6.17	4.71	4.19	4.86
1980	2.84	4.07	0.30	1.17	0.93	0.30	0.30	3.74	7.03	24.59	19.90	13.67	7.31
1981	6.04	2.52	0.30	1.41	0.93	1.10	1.25	9.23	13.61	15.20	12.65	4.63	6.50
1982	7.78	2.89	0.30	1.09	0.98	0.87	0.30	10.18	19.45	78.10	33.15	36.25	16.65
1983	6.39	0.89	0.30	0.30	0.30	0.69	0.30	24.14	7.99	46.10	29.64	59.24	15.28
1984	31.44	2.77	0.30	1.23	0.98	2.02	1.05	5.54	23.12	79.01	66.44	15.52	19.88
1985	4.41	2.10	0.30	0.30	0.30	0.43	0.30	8.81	16.60	22.89	102.12	42.85	17.45
1986	4.39	2.29	0.30	0.30	0.56	0.30	0.30	9.69	17.14	22.07	71.96	37.44	14.52
1987	7.79	2.76	0.30	0.30	0.30	0.30	0.63	8.93	18.02	17.69	11.28	15.92	7.72
1988	5.96	2.85	0.30	0.30	0.32	0.94	0.77	8.91	10.85	21.10	14.34	84.31	13.22
1989	10.41	3.93	0.30	0.30	0.93	0.30	5.38	16.44	27.32	130.69	83.09	7.16	24.55
1990	3.30	0.59	0.30	0.30	0.30	0.30	0.30	8.88	18.48	94.16	84.04	99.25	26.42
1991	17.87	3.41	0.30	0.32	0.70	0.50	0.30	8.80	60.46	106.57	26.22	31.19	22.14
1992	42.63	3.41	0.30	0.30	0.34	0.30	4.14	11.55	26.39	217.08	64.13	8.15	32.27
1993	3.91	0.93	0.30	0.30	0.30	0.42	0.30	5.62	24.22	51.35	14.02	8.83	9.92
1994	6.57	3.12	0.30	0.30	0.52	0.81	0.30	6.81	10.51	26.65	27.71	5.46	8.10
1995	19.50	3.24	10.26	1.17	1.08	0.61	0.30	4.92	17.53	45.00	69.93	135.83	26.56
1996	50.35	22.76	0.76	1.25	0.93	0.83	0.30	7.58	69.46	28.27	45.62	19.37	21.40
1997	3.31	3.17	0.30	1.22	0.41	0.30	0.30	15.16	13.93	18.33	6.12	4.43	6.32
1998	5.42	3.90	1.28	0.39	0.47	0.30	0.44	8.52	14.95	19.23	29.91	76.89	14.27
1999	13.30	3.36	0.30	0.68	0.36	0.65	0.30	8.01	14.95	16.99	8.56	15.72	7.68
2000	6.14	1.98	0.30	0.86	0.39	0.30	0.30	9.15	12.27	72.85	111.31	120.37	28.74
2001	14.04	3.92	0.30	1.18	0.96	0.82	0.38	10.01	16.00	24.09	45.76	16.86	11.97
2002	11.37	3.68	0.30	0.44	0.30	0.33	0.30	3.70	4.96	4.90	19.32	10.89	5.81
2003	6.67	3.51	0.30	0.30	0.30	0.30	0.56	2.85	14.75	12.33	12.66	5.66	5.75
2004	8.62	3.20	0.30	0.30	0.30	0.30	0.43	8.74	17.06	16.62	15.65	10.93	7.53

State 1	< 0.5	State 2	0.5-1	State 3	1 - 5	State 4	5 - 25	State 5	>25

Table 4.9 Simulated monthly inflows to the Berg River Estuary for Scenario 7 (m^3s^{-1})

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1928	6.49	3.09	0.90	0.90	0.90	0.90	1.65	7.58	9.79	25.47	21.96	15.24	8.23
1929	6.71	2.65	0.90	0.90	0.90	0.90	0.90	1.50	3.06	5.22	8.35	37.09	6.15
1930	8.61	5.53	0.90	0.90	0.90	0.90	5.39	5.92	8.04	7.01	25.35	23.57	8.13
1931	11.79	4.95	0.90	0.90	11.42	4.91	0.90	12.44	18.75	19.68	16.79	15.00	10.39
1932	8.32	3.48	0.90	0.90	0.90	0.90	0.90	2.57	27.62	39.94	48.10	22.20	13.29
1933	9.85	3.81	0.90	0.90	0.90	0.90	0.90	5.37	6.31	7.53	9.96	11.24	5.26
1934	8.72	9.32	0.90	0.90	0.90	0.90	3.89	5.32	9.76	17.37	16.95	14.88	7.95
1935	7.87	4.02	0.90	0.90	0.90	0.90	0.90	3.90	4.46	5.87	11.38	14.18	4.99
1936	7.61	3.76	0.90	0.90	0.90	1.05	3.30	5.18	37.92	59.78	32.16	15.65	14.77
1937	6.96	2.63	0.90	0.90	0.90	0.90	6.43	6.42	8.52	13.07	11.79	15.03	6.53
1938	7.79	4.10	0.90	0.90	0.90	0.90	0.90	7.71	7.74	11.43	22.41	11.06	6.75
1939	5.98	2.71	0.90	0.90	0.90	0.90	3.57	4.52	19.76	17.25	13.77	10.99	7.28
1940	7.10	4.51	0.90	1.54	1.13	0.90	11.38	42.10	72.78	111.90	106.87	147.30	42.93
1941	30.96	8.68	0.90	0.90	0.90	0.90	0.90	14.11	114.90	55.42	86.28	23.11	28.47
1942	10.13	3.82	0.90	0.90	0.90	0.90	1.02	2.83	6.77	24.32	34.89	35.73	10.76
1943	12.97	7.00	0.90	0.90	0.90	0.90	1.13	9.48	59.96	67.12	120.27	42.95	27.49
1944	15.56	6.82	0.90	0.90	0.90	0.90	0.90	32.53	77.94	168.30	122.61	24.21	38.18
1945	7.51	3.55	0.90	0.90	0.90	0.90	0.90	4.20	6.01	13.91	18.56	47.58	9.12
1946	15.43	6.29	0.90	0.90	0.90	1.01	1.19	4.12	6.71	54.76	22.39	11.67	11.00
1947	7.66	4.29	0.90	0.90	0.90	5.08	5.32	6.90	10.53	37.24	21.54	32.25	11.57
1948	18.74	6.06	0.90	0.90	0.90	0.90	1.96	3.12	7.81	15.85	21.68	14.40	8.14
1949	9.28	12.67	2.89	0.90	0.90	0.90	16.71	3.83	6.64	83.00	17.33	25.93	15.61
1950	18.84	12.75	3.04	1.41	0.90	0.90	9.05	4.77	68.08	61.18	48.19	29.86	22.25
1951	11.78	7.78	0.90	0.90	0.90	0.90	0.90	7.61	11.34	22.32	84.43	76.53	19.29
1952	14.81	12.96	2.60	0.90	0.90	0.90	37.35	47.80	20.26	75.26	131.63	22.06	31.14
1953	6.98	4.89	0.90	0.90	0.90	0.90	6.13	56.31	34.08	228.90	168.16	33.87	45.77
1954	11.01	4.44	0.90	0.90	4.27	1.78	1.01	2.33	8.60	27.74	151.32	41.92	21.98
1955	19.59	9.96	0.90	0.90	0.90	0.90	0.90	6.28	30.85	44.89	78.33	22.30	18.47
1956	8.28	2.82	0.90	0.90	5.64	3.20	1.68	39.66	48.42	133.32	114.92	32.02	33.19
1957	42.83	13.51	0.90	0.90	0.90	0.90	0.90	11.09	9.80	11.53	17.58	10.56	10.56
1958	6.55	3.85	0.90	0.90	0.90	0.90	6.84	83.87	18.33	16.98	26.75	19.47	15.86
1959	11.50	5.39	0.90	0.90	0.90	0.90	0.99	7.82	21.37	14.29	9.69	7.07	7.18
1960	4.50	1.79	0.90	0.90	0.90	0.90	0.90	2.64	16.28	13.81	23.75	30.33	8.39
1961	10.01	3.54	0.90	0.90	0.90	0.90	5.87	3.33	115.71	42.12	129.37	33.13	29.28
1962	38.25	12.78	0.90	0.90	0.90	0.90	0.90	1.48	5.57	12.02	52.10	26.47	13.14
1963	7.52	6.25	1.05	0.90	0.90	0.90	0.90	2.81	16.13	18.91	28.90	20.95	9.46
1964	10.24	8.97	0.94	0.90	2.20	4.74	5.50	7.19	10.79	12.36	20.20	8.39	8.43
1965	5.20	2.38	0.90	0.90	0.90	1.85	2.27	2.90	8.79	31.78	22.17	18.56	8.66
1966	6.62	2.24	0.90	0.90	0.90	0.90	5.64	4.00	35.78	18.48	15.74	14.33	9.14
1967	7.93	4.86	0.90	0.90	0.90	0.90	6.43	13.59	19.94	43.97	66.75	18.81	15.92
1968	28.68	9.21	0.90	0.90	0.90	0.90	1.87	2.42	5.32	5.74	9.02	10.79	6.86
1969	7.79	4.77	0.90	0.90	0.90	0.90	0.90	6.06	19.58	22.42	25.65	19.86	9.44
1970	9.69	3.53	0.90	0.90	0.90	0.90	0.90	1.75	4.62	13.92	16.57	9.67	5.71
1971	5.23	1.65	0.90	0.90	0.90	0.90	2.90	4.36	9.28	7.94	9.09	8.47	4.69
1972	5.16	1.67	0.90	0.90	0.90	0.90	0.90	1.95	3.79	21.74	12.05	10.45	5.54
1973	6.79	2.56	0.90	0.90	0.90	0.90	0.90	13.89	33.71	18.13	240.39	49.65	31.13
1974	19.44	7.85	0.90	0.90	0.90	0.90	2.86	23.12	11.70	35.23	42.56	13.93	13.90
1975	6.95	3.13	0.90	0.90	0.90	0.90	8.52	3.12	40.44	43.72	32.91	16.27	13.61
1976	5.97	34.09	13.44	5.42	1.09	0.90	5.11	25.37	134.17	194.65	161.65	35.79	52.24
1977	9.68	3.49	1.23	0.90	0.90	0.91	2.96	3.18	4.43	2.91	7.42	7.99	4.50
1978	5.48	2.54	0.90	0.90	0.90	0.90	0.90	4.73	17.29	10.28	11.28	11.31	5.95
1979	9.28	3.79	0.90	1.28	0.90	0.90	1.14	11.68	11.13	9.39	6.82	3.97	5.59
1980	2.73	16.08	7.89	3.69	1.86	0.90	0.90	3.85	6.40	29.77	46.75	45.19	14.49
1981	5.98	3.02	2.32	3.81	0.90	5.65	11.76	10.56	13.01	15.78	19.07	5.10	8.87
1982	7.86	4.28	0.97	0.90	0.90	0.90	0.90	16.29	50.62	117.25	33.99	39.27	23.54
1983	6.26	1.55	0.90	0.90	0.90	0.90	0.90	59.02	7.34	51.92	28.66	61.18	18.71
1984	34.28	2.87	2.88	1.82	1.40	16.96	6.33	5.51	36.92	77.73	68.69	17.20	23.51
1985	4.93	1.94	0.90	0.90	0.90	0.90	3.99	10.29	16.95	53.77	107.20	44.08	20.97
1986	5.53	2.41	0.90	0.90	0.90	0.90	0.90	16.33	21.81	33.06	89.97	37.73	17.99
1987	9.74	3.16	0.90	0.90	0.90	0.90	5.40	9.54	20.99	27.80	18.90	39.08	11.98
1988	5.84	3.33	0.90	0.90	0.90	5.42	5.25	9.01	10.24	30.08	38.00	89.31	17.03
1989	12.61	7.56	0.90	0.90	0.90	0.90	14.45	34.50	37.68	127.34	85.31	11.93	28.39
1990	4.32	0.90	0.90	0.90	0.90	0.90	0.90	10.18	37.01	106.47	85.59	99.76	29.29
1991	20.44	7.83	0.90	0.90	0.90	0.90	5.85	9.09	83.51	109.54	28.05	32.35	25.59
1992	45.17	10.11	1.41	0.90	0.90	0.90	19.03	15.36	36.52	217.64	65.26	11.04	35.90
1993	5.21	0.90	0.90	0.90	0.90	0.90	1.11	5.58	61.06	50.74	14.89	10.54	13.23
1994	6.46	3.20	0.90	0.90	0.90	0.90	0.90	6.79	9.92	36.64	55.26	8.35	11.35
1995	24.48	5.52	18.17	1.82	0.99	0.90	1.08	4.89	36.49	52.92	70.91	137.41	30.39
1996	52.67	29.21	8.68	2.58	1.96	0.97	1.42	7.55	97.89	26.54	45.46	22.06	25.54
1997	4.12	3.73	0.90	0.96	0.90	0.90	0.90	28.03	13.11	29.78	14.81	5.89	9.25
1998	6.59	13.87	2.93	0.90	0.90	0.90	1.61	9.22	14.33	26.08	58.63	75.49	18.22
1999	17.20	3.81	0.90	0.90	0.90	0.90	0.90	7.96	18.56	20.69	13.85	30.52	10.25

2000	6.21	2.63	0.90	0.90	0.90	0.90	0.90	9.16	11.64	134.09	112.96	121.13	34.00
2001	16.04	8.95	1.15	5.26	1.95	0.90	1.44	13.47	15.68	43.45	47.50	20.15	15.43
2002	14.33	5.81	0.90	0.90	0.90	0.90	0.99	3.95	6.83	7.59	26.10	10.24	7.18
2003	6.57	3.98	0.90	0.90	0.90	0.90	2.16	2.78	14.16	11.98	27.59	6.81	7.09
2004	9.10	3.72	0.90	0.90	0.90	0.90	1.46	10.26	37.29	25.43	45.43	19.41	13.35
State 1	< 0.5		State 2	0.5-1		State 3	1 - 5		State 4	5 - 25		State 5	>25

Table 4.10 Simulated monthly inflows to the Berg River Estuary for Scenario 8 (m^3s^{-1})

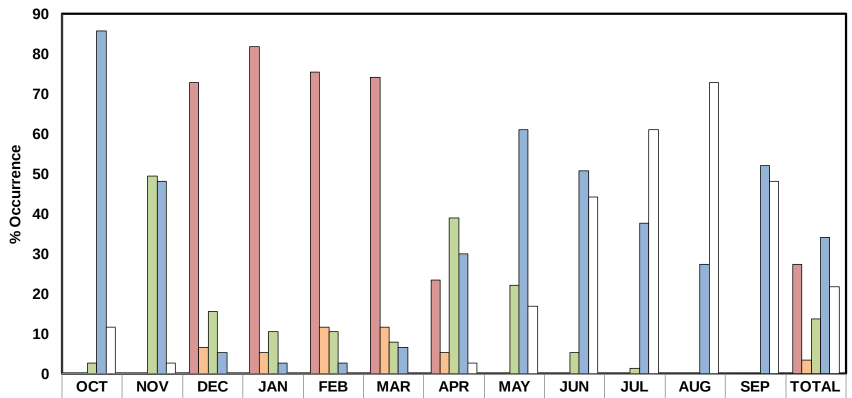
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1928	6.61	2.03	0.15	0.16	0.15	0.15	0.53	7.59	10.41	20.31	12.45	11.42	8.86
1929	6.49	1.49	0.15	0.37	0.63	0.15	0.15	1.57	3.34	5.77	6.67	21.93	15.56
1930	8.72	3.85	0.15	0.20	0.15	0.15	1.74	5.94	8.69	7.56	16.44	15.80	6.49
1931	9.37	3.63	0.15	0.27	1.22	0.86	0.15	11.94	19.07	17.41	11.01	12.55	9.11
1932	8.43	2.26	0.15	0.18	0.15	0.15	0.15	2.58	21.55	26.85	14.22	11.87	5.34
1933	8.91	3.39	0.15	0.22	0.15	0.32	0.15	5.38	6.93	8.08	6.45	11.87	4.37
1934	8.81	3.86	0.15	0.25	0.15	0.15	0.76	5.34	10.39	16.24	12.13	13.45	5.18
1935	7.99	3.29	0.15	0.38	0.34	0.15	0.15	3.92	5.11	6.40	10.38	14.51	30.77
1936	7.73	2.53	0.15	1.03	0.15	0.81	0.60	5.20	19.35	27.41	12.32	8.93	13.52
1937	6.36	1.55	0.15	0.34	0.15	0.15	0.83	6.44	9.16	13.07	9.31	13.67	13.24
1938	7.90	3.55	0.15	0.18	0.31	0.15	0.29	7.71	8.38	8.99	11.92	10.90	51.86
1939	6.11	2.05	0.15	0.16	0.81	0.32	0.60	4.55	18.74	14.43	7.28	8.53	4.11
1940	7.21	3.57	0.15	1.14	0.89	0.15	1.05	18.82	26.85	85.35	104.41	143.98	5.56
1941	28.63	4.18	0.15	0.32	0.15	0.15	0.15	10.28	96.87	55.79	83.68	20.99	5.22
1942	9.05	3.20	0.15	0.39	0.84	0.74	0.31	2.87	7.39	20.60	15.78	17.78	14.10
1943	9.70	3.79	0.15	0.30	0.15	0.15	0.39	9.15	29.99	66.34	117.15	39.26	8.48
1944	12.24	3.89	0.15	0.43	0.15	0.15	0.25	16.45	69.50	165.39	119.43	20.05	23.15
1945	6.39	2.45	0.15	0.15	0.15	0.15	0.34	4.22	6.64	13.23	11.11	24.10	18.37
1946	9.87	3.88	0.15	0.21	0.15	0.87	0.15	4.15	7.35	33.51	12.60	9.24	23.12
1947	7.77	3.44	0.15	0.15	0.15	1.06	0.52	6.91	11.16	22.60	11.71	16.30	20.62
1948	9.39	3.74	0.15	0.26	0.15	0.15	0.48	3.16	8.42	14.92	12.39	13.37	17.61
1949	9.15	3.81	0.15	0.42	0.15	0.15	1.41	3.89	7.06	43.54	10.62	15.83	11.62
1950	9.44	6.01	0.15	1.15	0.83	0.15	0.82	4.80	49.00	63.80	47.46	28.52	16.69
1951	9.21	3.97	0.15	0.26	0.15	0.15	0.34	7.59	11.95	18.94	50.50	77.21	28.04
1952	11.97	6.44	0.15	0.42	0.15	0.15	8.62	45.64	22.71	77.03	130.88	19.17	28.95
1953	5.26	3.47	0.15	0.46	0.17	0.15	0.51	17.56	48.28	225.79	164.63	32.23	25.20
1954	9.11	3.42	0.15	0.38	1.08	0.86	0.15	2.39	9.19	21.91	124.91	40.20	35.53
1955	15.24	3.92	0.15	0.35	0.19	0.15	0.16	6.28	20.62	23.00	78.43	21.20	12.86
1956	8.06	1.83	0.15	0.20	1.22	0.87	0.20	19.24	42.67	131.31	109.58	30.50	10.97
1957	42.03	6.69	0.15	0.25	0.61	0.15	0.15	11.09	10.43	6.74	12.01	9.06	30.00
1958	6.60	2.87	0.15	0.15	0.15	0.15	0.90	27.48	16.45	9.24	12.16	15.14	25.16
1959	9.01	3.56	0.15	0.22	0.15	0.15	0.15	7.82	16.82	13.09	5.38	5.21	8.87
1960	4.03	0.88	0.15	0.21	0.16	0.15	0.15	2.67	16.88	13.65	12.21	16.85	17.84
1961	9.32	2.51	0.15	0.15	0.15	0.65	0.81	3.38	32.36	52.86	125.85	31.76	9.86
1962	36.11	6.08	0.15	0.35	0.15	0.15	0.15	1.54	6.17	12.54	23.88	20.02	33.62
1963	7.61	3.74	0.15	0.61	0.90	0.20	0.15	2.84	16.71	16.59	12.96	11.95	15.05
1964	8.85	3.95	0.15	0.38	0.97	1.10	0.69	7.21	11.42	10.84	10.46	7.21	6.79
1965	4.53	1.27	0.15	0.18	0.15	0.98	0.49	2.95	9.39	22.10	11.86	11.70	6.71
1966	6.75	1.14	0.15	0.15	0.15	0.15	0.87	4.04	21.48	16.58	8.04	9.57	13.01
1967	7.82	3.53	0.15	0.24	0.15	0.15	0.82	11.83	17.58	23.00	14.62	11.16	16.02
1968	22.17	3.98	0.15	0.51	0.15	0.15	0.30	2.49	5.95	6.30	7.81	11.46	6.86
1969	7.87	3.38	0.15	0.16	0.15	0.15	0.15	6.07	19.10	19.81	13.78	14.13	9.44
1970	8.86	2.56	0.15	0.20	0.15	0.29	0.15	1.80	5.23	14.45	12.53	9.39	5.71
1971	4.14	1.00	0.15	0.15	0.20	0.15	0.52	4.38	9.90	8.49	7.01	7.39	4.69
1972	4.51	0.93	0.15	0.15	0.15	0.34	0.15	1.99	3.83	21.12	10.64	9.34	5.54
1973	6.90	1.40	0.15	0.41	0.15	0.15	0.15	12.71	25.16	16.15	154.16	50.26	31.13
1974	17.81	4.03	0.15	0.61	0.38	0.15	0.50	12.55	12.34	21.90	30.56	11.31	13.90
1975	6.73	2.68	0.15	0.29	0.21	0.15	4.98	3.17	21.90	25.33	32.37	14.22	13.61
1976	4.78	23.62	5.60	1.35	0.96	0.84	0.94	17.32	128.42	190.16	158.12	35.96	52.24
1977	8.09	2.72	0.29	0.34	0.43	0.79	0.32	3.23	4.97	3.48	7.96	8.63	4.50
1978	5.60	2.37	0.15	0.31	0.46	0.20	0.15	4.74	17.89	10.39	8.75	9.05	5.95
1979	8.31	3.06	0.15	1.15	0.40	0.15	0.19	9.73	11.75	6.17	4.71	4.19	5.59
1980	2.84	4.07	0.25	1.17	0.93	0.17	0.15	3.74	7.03	24.59	19.90	13.67	14.49
1981	6.04	2.52	0.15	1.41	0.93	1.10	1.25	9.23	13.61	15.20	12.65	4.63	8.87
1982	7.78	2.89	0.15	1.09	0.98	0.87	0.15	10.18	19.45	78.10	33.15	36.25	23.54
1983	6.39	0.89	0.15	0.15	0.15	0.69	0.15	24.14	7.99	46.10	29.64	59.24	18.71
1984	31.44	2.77	0.15	1.23	0.98	2.02	1.05	5.54	23.12	79.01	66.44	15.52	23.51
1985	4.41	2.10	0.15	0.15	0.15	0.43	0.22	8.81	16.60	22.89	102.12	42.85	20.97
1986	4.39	2.29	0.15	0.30	0.56	0.15	0.15	9.69	17.14	22.07	71.96	37.44	17.99
1987	7.79	2.76	0.15	0.15	0.15	0.15	0.63	8.93	18.02	17.69	11.28	15.92	11.98
1988	5.96	2.85	0.15	0.15	0.32	0.94	0.77	8.91	10.85	21.10	14.34	84.31	17.03
1989	10.41	3.93	0.15	0.15	0.93	0.15	5.38	16.44	27.32	130.69	83.09	7.16	28.39
1990	3.30	0.59	0.15	0.15	0.23	0.15	0.15	8.88	18.48	94.16	84.04	99.25	29.29
1991	17.87	3.41	0.15	0.32	0.70	0.50	0.24	8.80	60.46	106.57	26.22	31.19	25.59
1992	42.63	3.41	0.15	0.15	0.34	0.15	4.14	11.55	26.39	217.08	64.13	8.15	35.90
1993	3.91	0.93	0.15	0.24	0.15	0.42	0.20	5.62	24.22	51.35	14.02	8.83	13.23
1994	6.57	3.12	0.15	0.19	0.52	0.81	0.15	6.81	10.51	26.65	27.71	5.46	11.35
1995	19.50	3.24	10.26	1.17	1.08	0.61	0.15	4.92	17.53	45.00	69.93	135.83	30.39
1996	50.35	22.76	0.76	1.25	0.93	0.83	0.15	7.58	69.46	28.27	45.62	19.37	25.54
1997	3.31	3.17	0.15	1.22	0.41	0.17	0.15	15.16	13.93	18.33	6.12	4.43	9.25
1998	5.42	3.90	1.28	0.39	0.47	0.28	0.44	8.52	14.95	19.23	29.91	76.89	18.22
1999	13.30	3.36	0.15	0.68	0.36	0.65	0.17	8.01	14.95	16.99	8.56	15.72	10.25
2000	6.14	1.98	0.15	0.86	0.39	0.16	0.28	9.15	12.27	72.85	111.31	120.37	34.00
2001	14.04	3.92	0.15	1.18	0.96	0.82	0.38	10.01	16.00	24.09	45.76	16.86	15.43
2002	11.37	3.68	0.15	0.44	0.28	0.33	0.27	3.70	4.96	4.90	19.32	10.89	7.18
2003	6.67	3.51	0.15	0.27	0.26	0.15	0.56	2.85	14.75	12.33	12.66	5.66	7.09
2004	8.62	3.20	0.15	0.15	0.15	0.15	0.43	8.74	17.06	16.62	15.65	10.93	13.35
State 1	< 0.5		State 2	0.5-1		State 3	1 - 5		State 4	5 - 25		State 5	>25

Table 4.11 Simulated monthly inflows to the Berg River Estuary for Scenario 9 (m^3s^{-1})

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1928	6.49	3.09	2.00	1.50	1.00	1.00	3.00	7.58	9.79	25.47	21.96	15.24	8.86
1929	6.71	2.65	2.00	1.50	1.00	1.00	3.00	1.50	3.06	5.22	8.35	37.09	15.56
1930	8.61	5.53	2.00	1.50	1.00	1.00	5.39	5.92	8.04	7.01	25.35	23.57	6.49
1931	11.79	4.95	2.00	1.50	11.42	4.91	3.00	12.44	18.75	19.68	16.79	15.00	9.11
1932	8.32	3.48	2.00	1.50	1.00	1.00	3.00	2.57	27.62	39.94	48.10	22.20	5.34
1933	9.85	3.81	2.00	1.50	1.00	1.00	3.00	5.37	6.31	7.53	9.96	11.24	4.37
1934	8.72	9.32	2.00	1.50	1.00	1.00	3.89	5.32	9.76	17.37	16.95	14.88	5.18
1935	7.87	4.02	2.00	1.50	1.00	1.00	3.00	3.90	4.46	5.87	11.38	14.18	30.77
1936	7.61	3.76	2.00	1.50	1.00	1.05	3.30	5.18	37.92	59.78	32.16	15.65	13.52
1937	6.96	2.63	2.00	1.50	1.00	1.00	6.43	6.42	8.52	13.07	11.79	15.03	13.24
1938	7.79	4.10	2.00	1.50	1.00	1.00	3.00	7.71	7.74	11.43	22.41	11.06	51.86
1939	5.98	2.71	2.00	1.50	1.00	1.00	3.57	4.52	19.76	17.25	13.77	10.99	4.11
1940	7.10	4.51	2.00	1.54	1.13	1.00	11.38	42.10	72.78	111.90	106.87	147.30	5.56
1941	30.96	8.68	2.00	1.50	1.00	1.00	3.00	14.11	114.90	55.42	86.28	23.11	5.22
1942	10.13	3.82	2.00	1.50	1.00	1.00	3.00	2.83	6.77	24.32	34.89	35.73	14.10
1943	12.97	7.00	2.00	1.50	1.00	1.00	3.00	9.48	59.96	67.12	120.27	42.95	8.48
1944	15.56	6.82	2.00	1.50	1.00	1.00	3.00	32.53	77.94	168.30	122.61	24.21	23.15
1945	7.51	3.55	2.00	1.50	1.00	1.00	3.00	4.20	6.01	13.91	18.56	47.58	18.37
1946	15.43	6.29	2.00	1.50	1.00	1.01	3.00	4.12	6.71	54.76	22.39	11.67	23.12
1947	7.66	4.29	2.00	1.50	1.00	5.08	5.32	6.90	10.53	37.24	21.54	32.25	20.62
1948	18.74	6.06	2.00	1.50	1.00	1.00	3.00	3.12	7.81	15.85	21.68	14.40	17.61
1949	9.28	12.67	2.89	1.50	1.00	1.00	16.71	3.83	6.64	83.00	17.33	25.93	11.62
1950	18.84	12.75	3.04	1.50	1.00	1.00	9.05	4.77	68.08	61.18	48.19	29.86	16.69
1951	11.78	7.78	2.00	1.50	1.00	1.00	3.00	7.61	11.34	22.32	84.43	76.53	28.04
1952	14.81	12.96	2.60	1.50	1.00	1.00	37.35	47.80	20.26	75.26	131.63	22.06	28.95
1953	6.98	4.89	2.00	1.50	1.00	1.00	6.13	56.31	34.08	228.90	168.16	33.87	25.20
1954	11.01	4.44	2.00	1.50	4.27	1.78	3.00	2.33	8.60	27.74	151.32	41.92	35.53
1955	19.59	9.96	2.00	1.50	1.00	1.00	3.00	6.28	30.85	44.89	78.33	22.30	12.86
1956	8.28	2.82	2.00	1.50	5.64	3.20	3.00	39.66	48.42	133.32	114.92	32.02	10.97
1957	42.83	13.51	2.00	1.50	1.00	1.00	3.00	11.09	9.80	11.53	17.58	10.56	30.00
1958	6.55	3.85	2.00	1.50	1.00	1.00	6.84	83.87	18.33	16.98	26.75	19.47	25.16
1959	11.50	5.39	2.00	1.50	1.00	1.00	3.00	7.82	21.37	14.29	9.69	7.07	8.87
1960	4.50	1.79	2.00	1.50	1.00	1.00	3.00	2.64	16.28	13.81	23.75	30.33	17.84
1961	10.01	3.54	2.00	1.50	1.00	1.00	5.87	3.33	115.71	42.12	129.37	33.13	9.86
1962	38.25	12.78	2.00	1.50	1.00	1.00	3.00	1.48	5.57	12.02	52.10	26.47	33.62
1963	7.52	6.25	2.00	1.50	1.00	1.00	3.00	2.81	16.13	18.91	28.90	20.95	15.05
1964	10.24	8.97	2.00	1.50	2.20	4.74	5.50	7.19	10.79	12.36	20.20	8.39	6.79
1965	5.20	2.38	2.00	1.50	1.00	1.85	3.00	2.90	8.79	31.78	22.17	18.56	6.71
1966	6.62	2.24	2.00	1.50	1.00	1.00	5.64	4.00	35.78	18.48	15.74	14.33	13.01
1967	7.93	4.86	2.00	1.50	1.00	1.00	6.43	13.59	19.94	43.97	66.75	18.81	16.02
1968	28.68	9.21	2.00	1.50	1.00	1.00	3.00	2.42	5.32	5.74	9.02	10.79	6.86
1969	7.79	4.77	2.00	1.50	1.00	1.00	3.00	6.06	19.58	22.42	25.65	19.86	9.44
1970	9.69	3.53	2.00	1.50	1.00	1.00	3.00	1.75	4.62	13.92	16.57	9.67	5.71
1971	5.23	1.65	2.00	1.50	1.00	1.00	3.00	4.36	9.28	7.94	9.09	8.47	4.69
1972	5.16	1.67	2.00	1.50	1.00	1.00	3.00	1.95	3.79	21.74	12.05	10.45	5.54
1973	6.79	2.56	2.00	1.50	1.00	1.00	3.00	13.89	33.71	18.13	240.39	49.65	31.13
1974	19.44	7.85	2.00	1.50	1.00	1.00	3.00	23.12	11.70	35.23	42.56	13.93	13.90
1975	6.95	3.13	2.00	1.50	1.00	1.00	8.52	3.12	40.44	43.72	32.91	16.27	13.61
1976	5.97	34.09	13.44	5.42	1.09	1.00	5.11	25.37	134.17	194.65	161.65	35.79	52.24
1977	9.68	3.49	2.00	1.50	1.00	1.00	3.00	3.18	4.43	2.91	7.42	7.99	4.50
1978	5.48	2.54	2.00	1.50	1.00	1.00	3.00	4.73	17.29	10.28	11.28	11.31	5.95
1979	9.28	3.79	2.00	1.50	1.00	1.00	3.00	11.68	11.13	9.39	6.82	3.97	5.59
1980	2.73	16.08	7.89	3.69	1.86	1.00	3.00	3.85	6.40	29.77	46.75	45.19	14.49
1981	5.98	3.02	2.32	3.81	1.00	5.65	11.76	10.56	13.01	15.78	19.07	5.10	8.87
1982	7.86	4.28	2.00	1.50	1.00	1.00	3.00	16.29	50.62	117.25	33.99	39.27	23.54
1983	6.26	1.55	2.00	1.50	1.00	1.00	3.00	59.02	7.34	51.92	28.66	61.18	18.71
1984	34.28	2.87	2.88	1.82	1.40	16.96	6.33	5.51	36.92	77.73	68.69	17.20	23.51
1985	4.93	1.94	2.00	1.50	1.00	1.00	3.99	10.29	16.95	53.77	107.20	44.08	20.97
1986	5.53	2.41	2.00	1.50	1.00	1.00	3.00	16.33	21.81	33.06	89.97	37.73	17.99
1987	9.74	3.16	2.00	1.50	1.00	1.00	5.40	9.54	20.99	27.80	18.90	39.08	11.98
1988	5.84	3.33	2.00	1.50	1.00	5.42	5.25	9.01	10.24	30.08	38.00	89.31	17.03
1989	12.61	7.56	2.00	1.50	1.00	1.00	14.45	34.50	37.68	127.34	85.31	11.93	28.39
1990	4.32	0.37	2.00	1.50	1.00	1.00	3.00	10.18	37.01	106.47	85.59	99.76	29.29
1991	20.44	7.83	2.00	1.50	1.00	1.00	5.85	9.09	83.51	109.54	28.05	32.35	25.59
1992	45.17	10.11	2.00	1.50	1.00	1.00	19.03	15.36	36.52	217.64	65.26	11.04	35.90
1993	5.21	0.71	2.00	1.50	1.00	1.00	3.00	5.58	61.06	50.74	14.89	10.54	13.23
1994	6.46	3.20	2.00	1.50	1.00	1.00	3.00	6.79	9.92	36.64	55.26	8.35	11.35
1995	24.48	5.52	18.17	1.82	1.00	1.00	3.00	4.89	36.49	52.92	70.91	137.41	30.39
1996	52.67	29.21	8.68	2.58	1.96	1.00	3.00	7.55	97.89	26.54	45.46	22.06	25.54
1997	4.12	3.73	2.00	1.50	1.00	1.00	3.00	28.03	13.11	29.78	14.81	5.89	9.25
1998	6.59	13.87	2.93	1.50	1.00	1.00	3.00	9.22	14.33	26.08	58.63	75.49	18.22
1999	17.20	3.81	2.00	1.50	1.00	1.00	3.00	7.96	18.56	20.69	13.85	30.52	10.25
2000	6.21	2.63	2.00	1.50	1.00	1.00	3.00	9.16	11.64	134.09	112.96	121.13	34.00
2001	16.04	8.95	2.00	5.26	1.95	1.00	3.00	13.47	15.68	43.45	47.50	20.15	15.43
2002	14.33	5.81	2.00	1.50	1.00	1.00	3.00	3.95	6.83	7.59	26.10	10.24	7.18
2003	6.57	3.98	2.00	1.50	1.00	1.00	3.00	2.78	14.16	11.98	27.59	6.81	7.09
2004	9.10	3.72	2.00	1.50	1.00	1.00	3.00	10.26	37.29	25.43	45.43	19.41	13.35

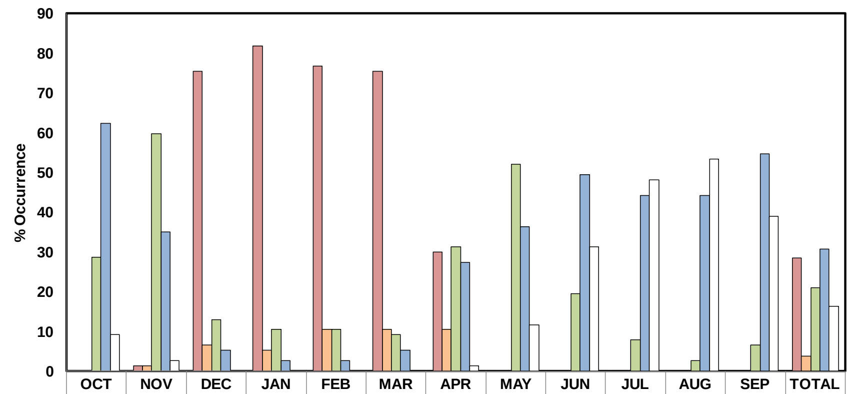
State 1	< 0.5	State 2	0.5-1	State 3	1 - 5	State 4	5 - 25	State 5	>25

Scenario 1



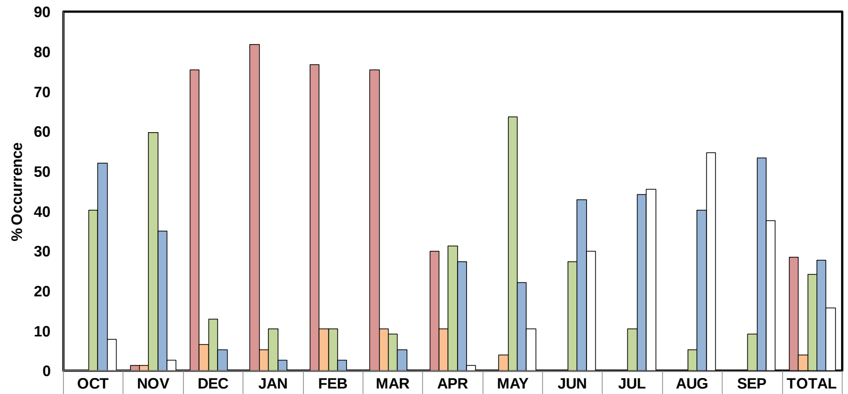
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0	0	73	82	75	74	23	0	0	0	0	0	27.3
State 2	0	0	6	5	12	12	5	0	0	0	0	0	3.4
State 3	3	49	16	10	10	8	39	22	5	1	0	0	13.6
State 4	86	48	5	3	3	6	30	61	51	38	27	52	34.1
State 5	12	3	0	0	0	0	3	17	44	61	73	48	21.6

Scenario 2



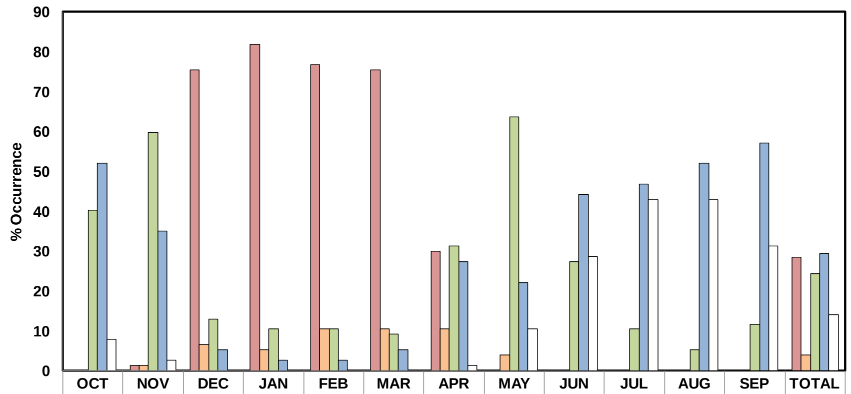
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0	1	75	82	77	75	30	0	0	0	0	0	28.4
State 2	0	1	6	5	10	10	10	0	0	0	0	0	3.7
State 3	29	60	13	10	10	9	31	52	19	8	3	6	20.9
State 4	62	35	5	3	3	5	27	36	49	44	44	55	30.7
State 5	9	3	0	0	0	0	1	12	31	48	53	39	16.3

Scenario 3



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0	1	75	82	77	75	30	0	0	0	0	0	28.4
State 2	0	1	6	5	10	10	10	4	0	0	0	0	4.0
State 3	40	60	13	10	10	9	31	64	27	10	5	9	24.1
State 4	52	35	5	3	3	5	27	22	43	44	40	53	27.7
State 5	8	3	0	0	0	0	1	10	30	45	55	38	15.8

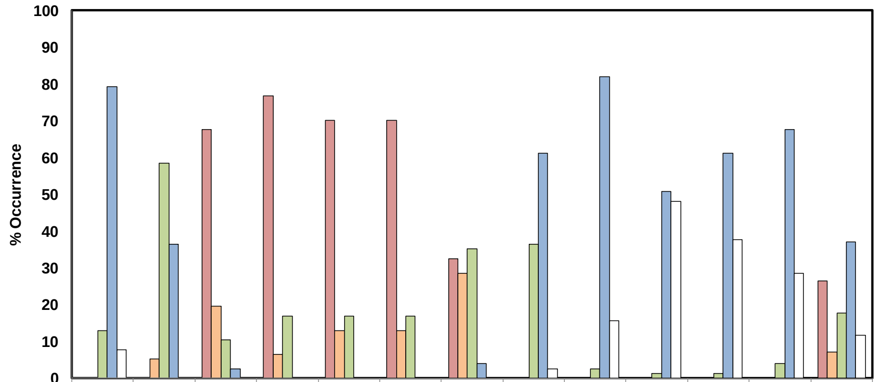
Scenario 4



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0	1	75	82	77	75	30	0	0	0	0	0	28.4
State 2	0	1	6	5	10	10	10	4	0	0	0	0	4.0
State 3	40	60	13	10	10	9	31	64	27	10	5	12	24.4
State 4	52	35	5	3	3	5	27	22	44	47	52	57	29.3
State 5	8	3	0	0	0	0	1	10	29	43	43	31	14.0

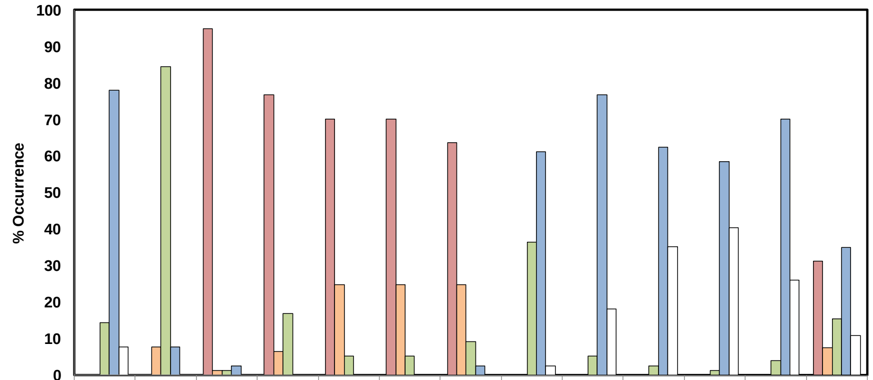
Figure 4-4 Graphic illustrations of the percentage occurrence of the various abiotic states under Scenario 1 to 4.

Scenario 5



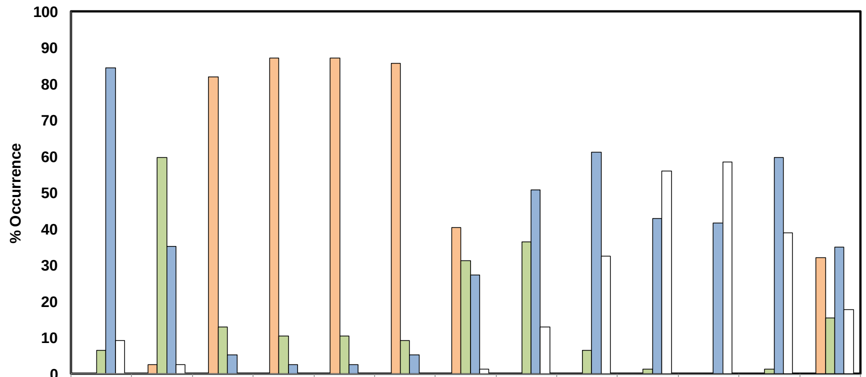
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0	0	68	77	70	70	32	0	0	0	0	0	26.4
State 2	0	5	19	6	13	13	29	0	0	0	0	0	7.1
State 3	13	58	10	17	17	17	35	36	3	1	1	4	17.7
State 4	79	36	3	0	0	0	4	61	82	51	61	68	37.0
State 5	8	0	0	0	0	0	0	3	16	48	38	29	11.7

Scenario 6



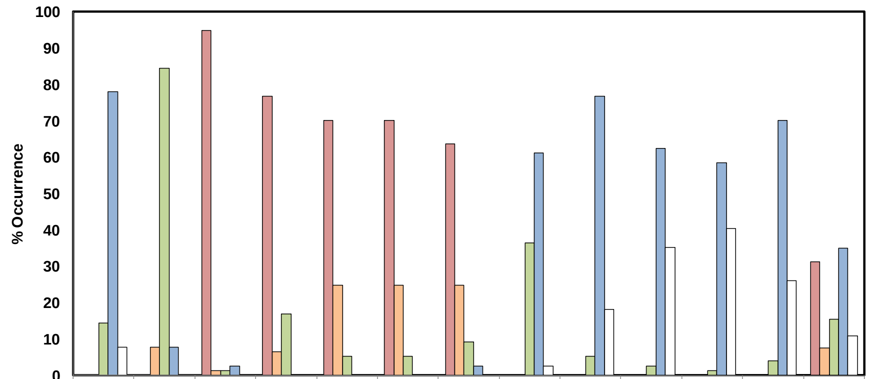
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0	0	95	77	70	70	64	0	0	0	0	0	31.3
State 2	0	8	1	6	25	25	25	0	0	0	0	0	7.5
State 3	14	84	1	17	5	5	9	36	5	3	1	4	15.5
State 4	78	8	3	0	0	0	3	61	77	62	58	70	35.0
State 5	8	0	0	0	0	0	0	3	18	35	40	26	10.8

Scenario 7



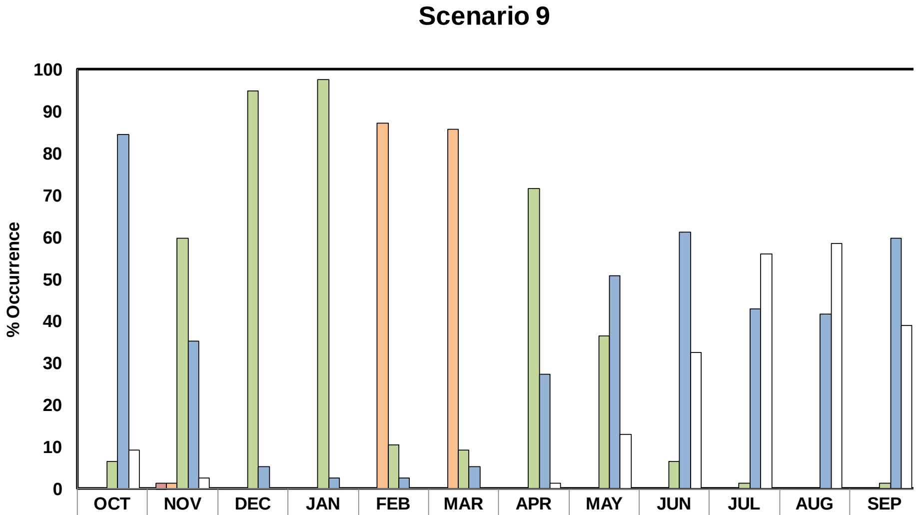
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0.0
State 2	0	3	82	87	87	86	40	0	0	0	0	0	32.0
State 3	6	60	13	10	10	9	31	36	6	1	0	1	15.5
State 4	84	35	5	3	3	5	27	51	61	43	42	60	34.8
State 5	9	3	0	0	0	0	1	13	32	56	58	39	17.6

Scenario 8



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
State 1	0	0	95	77	70	70	64	0	0	0	0	0	31.3
State 2	0	8	1	6	25	25	25	0	0	0	0	0	7.5
State 3	14	84	1	17	5	5	9	36	5	3	1	4	15.5
State 4	78	8	3	0	0	0	3	61	77	62	58	70	35.0
State 5	8	0	0	0	0	0	0	3	18	35	40	26	10.8

Figure 4-5 Graphic illustrations of the percentage occurrence of the various abiotic states under Scenario 5 to 8.



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
State 1	0	1	0	0	0	0	0	0	0	0	0	0
State 2	0	1	0	0	87	86	0	0	0	0	0	0
State 3	6	60	95	97	10	9	71	36	6	1	0	1
State 4	84	35	5	3	3	5	27	51	61	43	42	60
State 5	9	3	0	0	0	0	1	13	32	56	58	39

Figure 4-6 Graphic illustrations of the percentage occurrence of the various abiotic states under Scenario 9.

4.2.4 Sediment processes

In terms of differences between the scenarios, the lack of data and the resolution of the analyses/scoring in terms of impacts on morphology and sediment, some of the scenarios are very similar and cannot practically be differentiated. Furthermore, the differences between some of the flow scenarios are virtually only related to changes in the lowflows and not to the flood regimes. Also, floods affect sediment dynamics and morphology, while changes in lowflows do significant affect these. Thus, the scenarios are grouped as indicated in the Table 4.12.

Table 4.12 Grouping of future flow scenarios for the evaluation of impacts on sediment dynamics

Scenario name	Description	% MAR Reduction
Reference condition	Natural flows	0
present state, Scenario 7 (BRD) and Scenario 9	Present day with Berg River Dam	46
Scenario 1	Present day without Berg River Dam	36
Scenarios 2 (VV1) and 3 (VV2a)	Voelvlei augmentation, no raising	~50
Scenarios 4 (Vv2b), 5 (MisvC), 6 (MisvD) and 8 (MisvD)	Voelvlei/Misverstand rasing, reduced baseflows	*c*. 56

4.2.5 Health Index Scoring

4.2.5.1 Hydrology

This section describes changes in the occurrence of the different abiotic states for the different run-off scenarios as a proxy for the change in hydrology.

Table 4.13 Percentage occurrence (%) of the various abiotic states under the Reference condition, Present Day and various future scenarios.

State	Reference (% Occ.)	Present (% Occ.)	Scenario (% Occurrence)								
			1	2	3	4	5	6	7	8	9
1	0.5	28.4	27.3	28.4	28.4	28.4	26.4	31.3	0.0	31.3	0.1
2	3.1	3.7	3.4	3.7	4.0	4.0	7.1	7.5	32.0	7.5	14.5
3	28.0	15.5	13.6	20.9	24.1	24.4	17.7	15.5	15.5	15.5	32.9
4	31.3	34.8	34.1	30.7	27.7	29.3	37.0	35.0	34.8	35.0	34.8
5	37.0	17.6	21.6	16.3	15.8	14.0	11.7	10.8	17.6	10.8	17.6

This section provides a description of the changes in the floods for each of the scenarios.

Scenario 1

About 77% of the floods occurred between June and September, with 23% of these simulated for August. In total the floodplain experience some inundation for 37% of the months. For about 4 % of the months in the 77-year simulation period floods will inundate between 90 to 100% of the floodplain. Similarly for about 3% of the months floods will inundate between 80 and 90% of the floodplain. While between 70 and 80% of the floodplain will be inundated in ~ 7% of the months in the simulation period. Between 50 and 70% of the flood plain will be inundated for about 16 % of the months. These lower levels of inundation are caused by floods with flows between 100 and 300 m^3s^{-1}. These size classes of floods are relatively sensitive to setup in the preceding flood volumes, i.e. whether they are coming through as a single event or as a combination of pulses. The later can increase the level of inundation significantly, e.g. from 50% to 60%. Water resources development in the catchment will have the effect of reducing complex flood patterns to shorter and sharper pulses. For the Reserve analysis the assumption was made that flood peaks are coming through as a discreet events for comparative reasons. Baseflows occurring between June and July will on average inundate about 34.7% of the system.

Table 4.14 Occurrence of floods and extend of inundation under Scenario 1 based on simulated monthly flow data for a 77-year period

Flood size (Daily average flow in m^3s^{-1})	Area (ha)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	% Occurrence/ flood class	% Inundated	% Occurrence
100-200	3521.1	15	7	2	0	0	1	3	18	15	14	16	28	10	50-70	15
200-300	4329.5	3	0	0	0	0	0	2	4	11	10	10	9	4		
300-400	4901.3	4	2	0	0	0	0	0	3	6	9	16	13	5	70-80	8
400-500	5393.1	2	0	0	0	0	0	1	2	4	7	5	5	4		
500-600	5759.3	1	0	0	0	0	0	0	3	4	7	4	3	1	80-90	3
600-800	6105.2	0	0	0	0	0	0	0	2	5	5	7	3	2		
800-1000	6684.2	0	0	0	0	0	0	0	1	2	2	5	2	1	>90%	5
>1000	6827.4	0	0	0	0	0	0	0	0	4	11	12	3	3		
Annual % occurrence		8	3	1	0	0	0	2	10	15	20	23	20			24

Formula for calculating the Flood scores is as follows: $Similarity_{Floods} = \sum \min(Fraction_{Ci,Zi\ in\ Ref},\ Fraction_{Ci,Zi\ in\ Present/Future\ scenario})$

Where Ci represent the % occurrence of the *ith* flood class over the duration of the flow record (Z = 77-years).

Scenario 2

Flood size (Daily average flow in m^3s^{-1})	Area (ha)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	% Occurrence/ flood class	% Inundated	% Occurrence
100-200	3521.1	9	3	2	0	0	1	3	4	12	14	20	18	9.3	50-70	11
200-300	4329.5	2	1	0	0	0	0	0	3	4	9	7	9	3.8		
300-400	4901.3	4	1	0	0	0	0	1	2	10	9	5	11	4.7	70-80	6
400-500	5393.1	1	0	0	0	0	0	0	2	2	6	8	2	2.3		
500-600	5759.3	0	0	0	0	0	0	0	1	2	2	2	1	0.9	80-90	3
600-800	6105.2	0	0	0	0	0	0	0	1	3	4	6	2	1.7		
800-1000	6684.2	0	0	0	0	0	0	0	0	1	0	4	2	0.8	>90%	4
>1000	6827.4	0	0	0	0	0	0	0	0	3	11	12	3	3.1		
Annual % occurrence		7	2	1	0	0	0	2	5	15	22	26	20			24

Scenario 3

Flood size (Daily average flow in m^3s^{-1})	Area (ha)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	% Occurrence/ flood class	% Inundated	% Occurrence
100-200	3521.1	8	3	2	0	0	1	3	3	5	14	13	19	7.68	50-70	11
200-300	4329.5	3	1	0	0	0	0	0	3	10	5	4	8	3.68		
300-400	4901.3	3	1	0	0	0	0	1	2	2	6	6	12	3.57	70-80	6
400-500	5393.1	1	0	0	0	0	0	0	2	4	4	7	1	2.06		
500-600	5759.3	0	0	0	0	0	0	0	0	0	2	2	2	0.65	80-90	3
600-800	6105.2	0	0	0	0	0	0	0	1	3	7	6	2	2.06		
800-1000	6684.2	0	0	0	0	0	0	0	0	2	0	5	2	0.97	>90%	4
>1000	6827.4	0	0	0	0	0	0	0	0	2	11	12	3	3.03		
Annual % occurrence		7	2	1	0	0	0	2	5	13	22	25	22			24

Scenario 4

Flood size (Daily average flow in m^3s^{-1})	Area (ha)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	% Occurrence / flood class	% Inundated	% Occurrence
100-200	3521.1	5	3	2	0	0	1	3	3	4	14	18	15	7.36	50-70	11
200-300	4329.5	3	1	0	0	0	0	0	3	10	8	5	8	4.11		
300-400	4901.3	3	1	0	0	0	0	1	2	2	10	6	8	3.57	70-80	5
400-500	5393.1	1	0	0	0	0	0	0	2	2	2	4	1	1.30		
500-600	5759.3	0	0	0	0	0	0	0	0	2	1	2	2	0.76	80-90	2
600-800	6105.2	0	0	0	0	0	0	0	1	2	3	3	1	1.08		
800-1000	6684.2	0	0	0	0	0	0	0	0	3	3	4	1	1.19	>90%	3
>1000	6827.4	0	0	0	0	0	0	0	0	1	6	10	3	2.16		
Annual % occurrence		6	3	1	0	0	1	2	6	13	24	26	20			21

Scenario 5

Flood size (Daily average flow in m^3s^{-1})	Area (ha)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	% Occurrence/ flood class	% Inundated	% Occurrence
100-200	3521.1	5	3	2	0	0	1	3	3	4	14	18	15	7.36	50-70	11
200-300	4329.5	3	1	0	0	0	0	0	3	10	8	5	8	4.11		
300-400	4901.3	3	1	0	0	0	0	1	2	2	10	6	8	3.57	70-80	5
400-500	5393.1	1	0	0	0	0	0	0	2	2	2	4	1	1.30		
500-600	5759.3	0	0	0	0	0	0	0	0	2	1	2	2	0.76	80-90	2
600-800	6105.2	0	0	0	0	0	0	0	1	2	3	3	1	1.08		
800-1000	6684.2	0	0	0	0	0	0	0	0	3	3	4	1	1.19	>90%	3
>1000	6827.4	0	0	0	0	0	0	0	0	1	6	10	3	2.16		
Annual % occurrence		6	3	1	0	0	1	2	6	13	24	26	20			21

Scenario 6

Floods:

Flood size (Daily average flow in m^3s^{-1})	Area (ha)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	% Occurrence/ flood class	% Inundated	% Occurrence
100-200	3521.1	7	2	0	0	0	0	0	7	29	32	10	22	11.8	50-70	15
200-300	4329.5	2	0	0	0	0	0	0	2	7	7	6	6	3.2		
300-400	4901.3	3	0	0	0	0	0	0	0	1	1	2	6	1.4	70-80	3
400-500	5393.1	1	0	0	0	0	0	0	1	2	5	4	1	1.5		
500-600	5759.3	0	0	0	0	0	0	0	0	1	1	0	1	0.3	80-90	2
600-800	6105.2	0	0	0	0	0	0	0	0	2	6	6	3	1.8		
800-1000	6684.2	0	0	0	0	0	0	0	0	1	2	3	1	0.8	>90%	3
>1000	6827.4	0	0	0	0	0	0	0	0	1	7	11	3	2.4		
Annual % occurrence		6	1	0	0	0	0	0	5	20	28	20	20			23

Scenario 7

Floods:

Flood size (Daily average flow in m^3s^{-1})	Area (ha)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	% Occurrence/ flood class	% Inundated	% Occurrence
100-200	3521.1	11	3	2	0	0	1	3	8	17	18	20	24	11.6	50-70	15
200-300	4329.5	3	1	0	0	0	0	0	2	2	10	9	9	3.9		
300-400	4901.3	3	1	0	0	0	0	1	4	11	7	6	11	4.8	70-80	7
400-500	5393.1	2	0	0	0	0	0	0	1	2	8	7	3	2.5		
500-600	5759.3	0	0	0	0	0	0	0	2	2	4	2	1	1.2	80-90	3
600-800	6105.2	0	0	0	0	0	0	0	0	4	4	5	2	1.6		
800-1000	6684.2	0	0	0	0	0	0	0	1	1	0	5	2	1.0	>90%	4
>1000	6827.4	0	0	0	0	0	0	0	0	3	11	12	3	3.1		
Annual % occurrence		7	2	1	0	0	0	1	7	15	23	24	20			29

Scenario 8

Floods:

Flood size (Daily average flow in m^3s^{-1})	Area (ha)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	% Occurrence/ flood class	% Inundated	% Occurrence
100-200	3521.1	7	2	0	0	0	0	0	7	29	32	10	22	11.8	50-70	15
200-300	4329.5	2	0	0	0	0	0	0	2	7	7	6	6	3.2		
300-400	4901.3	3	0	0	0	0	0	0	0	1	1	2	6	1.4	70-80	3
400-500	5393.1	1	0	0	0	0	0	0	1	2	5	4	1	1.5		
500-600	5759.3	0	0	0	0	0	0	0	0	1	1	0	1	0.3	80-90	2
600-800	6105.2	0	0	0	0	0	0	0	0	2	6	6	3	1.8		
800-1000	6684.2	0	0	0	0	0	0	0	0	1	2	3	1	0.8	>90%	3
>1000	6827.4	0	0	0	0	0	0	0	0	1	7	11	3	2.4		
Annual % occurrence		6	1	0	0	0	0	0	5	20	28	20	20			23

Scenarios 9 and 10

Floods: Note: Scenario 9 assumes that lowflows can be supplied from Voëlvlei, if the summer low flow were supplemented from an in-channel dam, it could influence the occurrence of small floods/freshettes.

Flood size (Daily average flow in m^3s^{-1})	Area (ha)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	% Occurrence/ flood size class	% Floodplain inundated	% Occurrence/
100-200	3789.4	14	1	1	0	0	0	3	9	9	6	12	24	6.2	50-70	13
200-300	4347.1	5	1	0	0	0	0	2	1	8	7	9	11	8.5		
300-400	5000.8	5	1	0	0	0	0	0	4	6	7	10	12	4.8	70-80	9
400-500	5471.1	0	0	0	0	0	0	1	2	7	9	11	3	4.9		
500-600	5810.1	0	0	0	0	0	0	0	2	4	5	8	3	3.6	80-90	6
600-800	6149.6	0	0	0	0	0	0	0	4	5	14	7	6	2.4		
800-1000	6692.4	0	0	0	0	0	0	0	0	2	6	6	1	3.9	>90%	6
>1000	6927.9	0	0	0	0	0	0	0	3	10	10	11	2	1.6		
Annual % occurrence		8	1	0	0	0	0	2	8	16	21	24	20			34

Table 4.15 Water quality scores for the various future scenarios

Scenario	a.% similarity in period of lowflows OR MAR as a% of MAR in the Reference condition			b.% similarity in mean annual frequency and magnitude of floods			Overall score
	Score	L/M/H	Summary of change	Score	L/M/H	Summary of change	
Present	68	M	⇧ 16% in low flow conditions	79	L	Magnitude and frequency: ⇩	72
1	70	M	⇧ 13% in low flow conditions	85	L	Magnitude and frequency: ⇩	76
2	71	M	⇧ 21% in low flow conditions	71	L	Magnitude and frequency: ⇩	71
3	71	M	⇧ 25% in low flow conditions	71	L	Magnitude and frequency: ⇩	71
4	71	M	⇧ 25% in low flow conditions	62	L	Magnitude and frequency: ⇩	67
5	64	M	⇧ 20% in low flow conditions	62	L	Magnitude and frequency: ⇩	63
6	61	M	⇧ 23% in low flow conditions	62	L	Magnitude and frequency: ⇩	61
7	68	M	⇧ 16% in low flow conditions	79	L	Magnitude and frequency: ⇩	72
8	61	M	⇧ 23% in low flow conditions	62	L	Magnitude and frequency: ⇩	61
9	80	M	⇧ 15% in low flow conditions	79	L	Magnitude and frequency: ⇩	80
10	80	M	⇧ 15% in low flow conditions	79	L	Magnitude and frequency: ⇩	80

4.2.5.2 Hydrodynamics and mouth condition

This section describes the changes in the mouth conditions for the different run-off scenarios.
Note: method scores mouth closure conservatively following the guidelines provided in DWAF (2008)

Table 4.16 Change in mouth condition and score under the future scenarios

Scenario	Change in mean duration of closure over 77 year period in relation to the Reference Condition			Overall score
	Score	L/M/H	Summary of change	
Present	90	M	The system would have been significantly more constricted during the summer months before mouth stabilisation – allow a 5 %. There is also anecdotal information that indicates that the Berg might have closed for short periods during drought conditions under the Reference condition – allow an additional 5 %.	90
1 - 10	90	M	Similar to Reference	90

4.2.5.3 Water quality

Salinity:

The change in salinity was evaluated on two conditions, change in the average salinity and change in the structure of the Berg River Estuary. Change in the average salinity was calculated as the average salinity per state for a zone multiplied by the percentage occurrence of the state. Change in structure was evaluated on the loss of State 3 and 4, which represents the highly stratified states.

Scenario 1

The change in salinity was evaluated on change in the average salinity. Change in the average salinity was calculated as the average salinity per state for a zone (A to D) multiplied by the% occurrence of the state. There was an average change in salinity of about 66%.

Average Salinity over 12 months

Zone	A	B	C	D
Salinity	23	12	4	1

Average Salinity for 6 summer months (October to March)

Zone	A	B	C	D
Salinity	30	19	8	2

Scenario 2

Average Salinity over 12 months

Zone	A	B	C	D
Salinity	24	13	5	1

Average Salinity for 6 summer months (October to March)

Zone	A	B	C	D
Salinity	30	19	8	2

There was an average change in salinity of about 63%.

Scenario 3

Average Salinity over 12 months

Zone	A	B	C	D
Salinity	25	13	5	1

Average Salinity for 6 summer months (October to March)

Zone	A	B	C	D
Salinity	31	19	8	2

There was an average change in salinity of about 61%.

Scenario 4

Average Salinity over 12 months

Zone	A	B	C	D
Salinity	25	13	5	1

Average Salinity for 6 summer months (October to March)

Zone	A	B	C	D
Salinity	31	19	8	2

There was an average change in salinity of about 61%.

Scenario 5

Average Salinity over 12 months

Zone	A	B	C	D
Salinity	25	13	5	1

Average Salinity for 6 summer months (October to March)

Zone	A	B	C	D
Salinity	30	19	7	2

There was an average change in salinity of about 60%.

Scenario 6

Average Salinity over 12 months

Zone	A	B	C	D
24	26	14	5	1

Average Salinity for 6 summer months (October to March)

Zone	A	B	C	D
Salinity	31	20	8	2

There was an average change in salinity of about 57%.

Scenario 7

Average Salinity over 12 months

Zone	A	B	C	D
24	23	10	3	0

Average Salinity for 6 summer months (October to March)

Zone	A	B	C	D
Salinity	29	15	4	2

There was an average change in salinity of about 64%.

Scenario 8

Average Salinity over 12 months

Zone	A	B	C	D
24	26	15	8	2

Average Salinity for 6 summer months (October to March)

Zone	A	B	C	D
Salinity	31	22	12	3

There was an average change in salinity of about 52% (57%) minus an additional 5% for the decrease in lowflows under State 1.

Scenarios 9 and 10

Average Salinity over 12 months

Zone	A	B	C	D
24	23	10	2	0

Average Salinity for 6 summer months (October to March)

Zone	A	B	C	D
Salinity	28	14	3	0

There was an average change in salinity of about 72%.

DIN/DIP, SS/Turbidity/ Transparency, DO and Toxic substances

Scoring of Future scenarios followed a similar approach as described in Section 3.4.1.3. Details on the change in the axial salinity gradient, DIN/DIP, turbidity, dissolved oxygen, and toxic substances are provided in Table 4.17.

Table 4.17 Expected changes in water quality in the Berg estuary under the various future flow scenarios.

Scenario	1. Changes in longitudinal salinity gradient and vertical stratification		2a. DIN/DIP in estuary		2b. SS/Turbidity/ Transparency in estuary		2c. DO in estuary		2d. Toxic substances in estuary		Overall score
	Score L/M/H	Summary of change	Score L/M/H	Summary of change	Score L/M/H	Summary of change	Score L/M/H	Summary of change	Score L/M/H	Summary of change	
Present	63% M/H	⇧Salinity	25% M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	85% M/H	⇧ Summer (lower zones)	85% M/H	⇩ Summer (middle zones)	80% L	⇧Overall accumulation	40%
1	66% M/H	⇧Salinity	24% M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	89% M/H	⇧ Summer (lower zones)	88% M/H	⇩ Summer (middle zones)	80% L	⇧Overall accumulation	41%
2	63% M/H	⇧Salinity	26% M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	83% M/H	⇧ Summer (lower zones)	80% M/H	⇩ Summer (middle zones)	80% L	⇧Overall accumulation	41%
3	61% M/H	⇧Salinity	27% M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	81% M/H	⇧ Summer (lower zones)	77% M/H	⇩ Summer (middle zones	80% L	⇧Overall accumulation	41%
4	61% M/H	⇧Salinity	27% M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	80% M/H	⇧ Summer (lower zones)	77% M/H	⇩ Summer (middle zones)	80% L	⇧Overall accumulation	41%
5	60% M/H	⇧Salinity	27% M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	81% M/H	⇧ Summer (lower zones)	82% M/H	⇩ Summer (middle zones)	80% L	⇧Overall accumulation	40%
6	57% M/H	⇧Salinity	26% M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	79% M/H	⇧ Summer (lower zones)	79% M/H	⇩ Summer (middle zones)	80% L	⇧Overall accumulation	38%
7	64% M/H	⇧Salinity	32% M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	85% M/H	⇧ Summer (lower zones)	85% M/H	⇩ Summer (middle zones)	80% L	⇧Overall accumulation	45%
8	52% M/H	⇧Salinity	26% M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	79% M/H	⇧ Summer (lower zones)	79% M/H	⇩ Summer (middle zones)	80% L	⇧Overall accumulation	36%
9	72% M/H	⇧Salinity	33% M/H	⇧ Summer (lower zones) ⇧⇧ Winter (overall)	86% M/H	⇧ Summer (lower zones)	87% M/H	⇩ Summer (middle zones)	80% L	⇧Overall accumulation	49%
10	72% M/H	⇧Salinity	51% M/H	⇧ Summer (lower zones) ⇧ Winter (overall)	86% M/H	⇧ Summer (lower zones)	87% M/H	⇩ Summer (middle zones)	80% L	⇧Overall accumulation	59%

Anthropogenic sources contribute significantly to inorganic nutrient (DIN/DIP) loading in the Berg River Estuary, comparing the present state to the Reference condition. Inappropriate uses of fertilizers in the catchment, as well as high nutrient loads in wastewater discharged from the fish processing industries near the mouth are probably the most important of these. For Scenario 10, it was assumed that nutrient loading from these sources were mitigated as far as reasonably possible through, for example, reducing quantities of fertilizer applied (i.e. preventing significant quantities of excess fertilizer entering the river system from agricultural return flows) and the implementation of cleaner technologies in the fish processing industry (e.g. reducing the nutrient load in wastewater from the industry) thereby improving the overall water quality score without changing freshwater flow.

4.2.5.4 Physical habitat alteration

Scoring motivation: All assessments and scoring was done relative to the present day situation. Anthropogenic influences are considered to be virtually the same for all the scenarios. Thus, it is only the flow related issues that change relative to the present. (Therefore, flow related scoring is motivated as relative percentage difference from present day.)

Scenario 1. Present day without Berg River Dam				
VARIABLE		**SCORE**	**MOTIVATION**	**CONFIDENCE**
1. Resemblance of intertidal sediment structure and distribution to Reference condition				
1a	% Similarity in intertidal area exposed	65%	Lower reaches : Anthropogenic impacts virtually unchanged from present: 75% of 25% Flow related: (25% of 25%) + 10% increase relative to present (~10% bigger and more floods; less sediment trapped in dams) Total = 26% Middle reaches : Anthropogenic impacts virtually unchanged from present: 50% of 50% Flow related: (50% of 50%) + 10% increase relative to present (~10% bigger and more floods; less sediment trapped in dams) Total = 53%	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)

			Upper reaches : Anthropogenic impacts virtually unchanged from present: 25% of 75% Flow related: (75% of 75%) + 10% increase relative to present (~10% bigger and more floods; less sediment trapped in dams) Total = 81% The 3 zones represent 21%, 13% and 66% of the total intertidal area of the total estuary. **Weighted (based on intertidal areas) mathematical average for all 3 zones = 65%**	
1b	% Similarity in sand fraction relative to total sand and mud	77%	Lower reaches: More marine sediment intrusion through permanently open mouth and greater tidal Δ – 10% Upper reaches: dams trapping some coarse fluvial sediments – (5-10%) % (~10% bigger and more floods relative to present; less sediment trapped in dams) Whole estuary : reduced sediment transport and scouring capacity through reduced floods, thus more marine sediment intrusion; also less dynamic sediment bottom and greater potential for consolidation – (10-10%)% (~10% bigger and more floods relative to present; less sediment trapped in dams) **Cumulative impact = 23%, thus score = 77%**	L (virtually no sediment data for Reference condition; paucity of such data for present; big uncertainty about net 50yr+ effects)
2	Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology	64%	Most of impacts listed in 1a are considered to have affect both intertidal and subtidal areas. Thus practically same total score. The 3 zones represent 15%, 29% and 56% of the total subtidal area of the total estuary. **Weighted (based on subtidal areas) mathematical average for all 3 zones = 64%**	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)
	Physical habitat score	68%		
Anthropogenic influence:				
	Percentage of overall change in intertidal and supratidal habitat caused by **anthropogenic** activity as opposed to	25%	*Morphology/habitat: the same anthropogenic influences as before, but the relative importance increases by 10% due to the flow related impacts decreasing by 10%* Lower reaches anthropogenic influence: 83% Middle reaches : 55%	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)

	modifications to water flow into estuary		Upper reaches : 28% Weighted mathematical average for all 3 zones = 43% *Sediment composition:* More marine sediment intrusion through permanently open mouth and greater tidal Δ : 10% of total 23% impact **Thus total cumulative anthropogenic influence** = 43% of 35% impact + 10%/23% of 23% impact = 15% + 10% **= 25%**	
	Percentage of overall change in subtidal habitat caused by **anthropogenic** modifications (e.g. bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary	26%	Most of impacts listed in 1a are considered to affect intertidal and subtidal areas. Thus similar total scores. *Morphology/habitat: the same anthropogenic influences as before, but the relative importance increases by 10% due to the flow related impacts reducing by 10%* *Sediment composition:* More marine sediment intrusion through permanently open mouth and greater tidal Δ: 10% of total 23% impact Thus total cumulative anthropogenic influence = 44% of 36% impact + 10%/23% of 23% impact = 16% + 10% = 26%	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)

Scenarios 2 (VV1) and 3 (VV2a)				
VARIABLE		**SCORE**	**MOTIVATION**	**CONFIDENCE**
1. Resemblance of intertidal sediment structure and distribution to Reference condition				
1a	% Similarity in intertidal area exposed	59%	Lower reaches : Anthropogenic impacts virtually unchanged from present: 75% of 25% Flow related: (25% of 25%) - 5% decrease relative to present (~5% smaller and fewer floods; more sediment trapped in dams) Total = 25% Middle reaches : Anthropogenic impacts virtually unchanged from present: 50% of 50% Flow related: (50% of 50%) - 5% decrease relative to present (~5% smaller and fewer floods; more sediment trapped in dams) Total = 49% Upper reaches: Anthropogenic impacts virtually unchanged from present: 25% of 75% Flow related: (75% of 75%) - 5% decrease relative to present (~5% smaller and fewer floods; more sediment trapped in dams) Total = 72% The 3 zones represent 21%, 13% and 66% of the total intertidal area of the total estuary. **Weighted (based on intertidal areas) mathematical average for all 3 zones = 59%**	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)
1b	% Similarity in sand fraction relative to total sand and mud	74%	Lower reaches : More marine sediment intrusion through permanently open mouth and greater tidal Δ – 10% Upper reaches : dams trapping some coarse fluvial sediments – (5+5%) % (~5% smaller and fewer floods relative to present; more sediment trapped in dams) Whole estuary: reduced sediment scouring because of reduced floods, thus more marine sediment intrusion and less dynamic sediment bed and greater potential for consolidation – (10+5%) % (~5% smaller and fewer floods relative to PD; some sediment trapped in dams) **Cumulative impact = 26%, thus score = 74%**	L (virtually no sediment data for Reference condition; paucity of such data for present; big uncertainty about net 50yr+ effects)
2	Resemblance of subtidal estuary to Reference condition: depth, bed or channel morphology	58%	Most of impacts listed in 1a are considered to have effects through intertidal into subtidal area. Thus a similar total score. The 3 zones represent 15%, 29% and 56% of the total subtidal area of the total estuary. **Weighted (based on subtidal areas) mathematical average for all 3 zones = 58%**	L (few sediment or morphology data for Reference condition; paucity of such data for present)
Physical habitat score		**62**		

Anthropogenic influence:				
	Percentage of overall change in intertidal and supratidal habitat caused by **anthropogenic** activity as opposed to modifications to water flow into estuary	25%	*Morphology/habitat: the same anthropogenic influences as before, but the relative importance decreases by 5% due to the flow related impacts increasing by 5%* Lower reaches anthropogenic influence: 71% Middle reaches : 48% Upper reaches : 24% Weighted mathematical average for all 3 zones = 37% *Sediment composition:* More marine sediment intrusion through permanently open mouth and greater tidal ∆ : 10% of total 26% impact **Thus total cumulative anthropogenic influence** = 37% of 41% impact + 10%/26% of 26% impact = 16% + 10% **= 25%**	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)
	Percentage of overall change in subtidal habitat caused by **anthropogenic** modifications (e.g. bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary	26%	**Most of impacts listed in 1a are considered to have effects through intertidal into subtidal area. Thus practically same total score.** *Morphology/habitat: the same anthropogenic influences as before, but the relative importance decreases by 5% due to the flow related impacts increasing by 5%* *Sediment composition:* More marine sediment intrusion through permanently open mouth and greater tidal ∆ : 10% of total 26% impact **Thus total cumulative anthropogenic influence** = 38% of 42% impact + 10%/26% of 26% impact = 16% + 10% **= 26%**	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)

Scenarios 4 (Vv2b), 5 (MisvC), 6 (MisvD) and 8 (MisvD)				
VARIABLE		**SCORE**	**MOTIVATION**	**CONFIDENCE**
1. Resemblance of intertidal sediment structure and distribution to Reference condition				
1a	% Similarity in intertidal area exposed	57%	Lower reaches : Anthropogenic impacts virtually unchanged from present: 75% of 25% Flow related: (25% of 25%) - 10% decrease relative to present (~10% smaller and fewer floods; more sediment trapped in dams) Total = 24% Middle reaches : Anthropogenic impacts virtually unchanged from present: 50% of 50% Flow related: (50% of 50%) - 10% decrease relative to present (~10% smaller and fewer floods; more sediment trapped in dams) Total = 48% Upper reaches : Anthropogenic impacts virtually unchanged from present: 25% of 75% Flow related: (75% of 75%) - 10% decrease relative to present (~10% smaller and fewer floods; more sediment trapped in dams) Total = 69% The 3 zones represent 21%, 13% and 66% of the total intertidal area of the total estuary. **Weighted (based on intertidal areas) mathematical average for all 3 zones = 57%**	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)
1b	% Similarity in sand fraction relative to total sand and mud	74%	Lower reaches : More marine sediment intrusion through permanently open mouth and greater tidal Δ – 10% Upper reaches : dams trapping some coarse fluvial sediments – (5+10%) % (~10% smaller and fewer floods relative to present; more sediment trapped in dams) Whole estuary : reduced scouring through reduced floods and more marine sediment intrusion; also less dynamic sediment bed and greater potential for consolidation – (10+10%) % (~10% smaller and fewer floods relative to present; more sediment trapped in dams) **Cumulative impact = 26%, thus score = 74%**	L (virtually no sediment data for Reference condition; paucity of such data for present; big uncertainty about net 50yr+ effects)
2	Resemblance of subtidal estuary to Reference condition: depth, bed or channel morphology	56%	Most of impacts listed in 1a are considered to have effects through intertidal into subtidal area. Thus practically same total score. The 3 zones represent 15%, 29% and 56% of the total subtidal area of the total estuary. **Weighted (based on subtidal areas) mathematical average for all 3 zones = 56%**	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)
Physical habitat score		**61%**		

Anthropogenic influence:				
	Percentage of overall change in intertidal and supratidal habitat caused by **anthropogenic** activity as opposed to modifications to water flow into estuary	25%	*Morphology/habitat: the same anthropogenic influences as before, but the relative importance decreases by 10% due to the flow related impacts increasing by 10%* Lower reaches anthropogenic influence: 68% Middle reaches : 45% Upper reaches : 23% Weighted mathematical average for all 3 zones = 36% *Sediment composition:* More marine sediment intrusion through permanently open mouth and greater tidal Δ : 10% of total 26% impact **Thus total cumulative anthropogenic influence** = 35% of 43% impact + 10%/26% of 26% impact = 15% + 10% **= 25%**	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)
	Percentage of overall change in subtidal habitat caused by **anthropogenic** modifications (e.g. bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary	26%	**Most of impacts listed in 1a are considered to have effects through intertidal into subtidal area. Thus practically same total score.** *Morphology/habitat: the same anthropogenic influences as before, but the relative importance decreases by 5% due to the flow related impacts increasing by 5%* *Sediment composition:* More marine sediment intrusion through permanently open mouth and greater tidal Δ : 10% of total 26% impact **Thus total cumulative anthropogenic influence** = 36% of 44% impact + 10%/26% of 26% impact = 16% + 10% **= 26%**	L (virtually no sediment or morphology data for Reference condition; paucity of such data for present)

Scenario 9 and 10

In terms of sediment dynamics and morphology related to flow, scenarios 9 and 10 are virtually equivalent to Present day with Berg River Dam, as floods are not affected (only low-flows). However, in Scenario 10, anthropogenic impacts were significant in lowering all the total scores for sediment dynamics and morphology (i.e. channel morphology and nature of sediments related to anthropogenic impacts). If all practical improvements were implemented, the total scores (for sediment dynamics and morphology) would increase by *c*.5%.

Possible mitigation measures are to:

- Remove derelict, redundant and old quays, jetties, wharfs and revetments; and rehabilitate banks to natural sediments. Optimise use of remaining such structures to minimize requirement for more such structures.
- Prohibit dumping of dredge (from lower main channel and the marina) in inappropriate areas.
- Install additional culverts into road and rail bridge embankments.
- Manage agricultural practises to avoid trampling by livestock.
- Manage agricultural practises to avoid reduce sediment loads.
- Eradicate invasive alien vegetation (especially dense tree stands) from floodplains.

4.3 Biotic components

In this section, predicted biotic characteristics for the future Scenarios are compared with and scored relative to the Reference condition. Principle factors responsible for the predicted changes and confidence levels for all predictions (H/M/L) are listed.

4.3.1 Microalgae

4.3.1.1 Description and explanation of changes

An explanation of the projected changes in phytoplankton and benthic microalage composition and abundance under the various future flow scenarios is provided in Table 4.18.

Table 4.18 Projected changes in phytoplankton and benthic microalage composition and abundance under the various future flow scenarios

Scenario 1	Microalgal data were based on a 2005 study, prior to the completion of the Berg River Dam. Full description given in present state. *Microalgal species richness:* Full salinity gradient exists; richness 0∆ (same for all scenarios). *Phytoplankton abundance*: Occurrence of states (50%ile) are 1 (27%), 2 (3%), 3 (14%), 4 (34%) and 5 (22%). Likely average Chl-a during various states are 1 (3.3 µg/L), 2 (2.8 µg/L), 3 (5.8 µg/L), 4 (8.0 µg/L) and 5 (8.0 µg/L). The 2.2 ➔ 6.2 µg/L change from Reference represents a 20% ⇧ assuming a worst-case scenario of 20 µg/L (severe bloom). *Benthic microalgal abundance*: High Chl-a (>10 µg/g) was measured in the blind arm, Die Plaat and in subtidal sediment from 28 km representing ~50% of the estuary. Changes in subtidal and intertidal areas 35% related to morphology and flow. Overall DIN/DIP score 24; 11% loss of biomass. *Phytoplankton community composition*: Based on 2005 results, the largest change expected is a general decrease in the flagellate:diatom ratio as river flow decreases (same for all scenarios). *Benthic microalgal composition*: 23% similarity in sand fraction relative to total sand and mud ➔ 23% shift from epipelic to episammic diatom taxa.
Scenario 2	*Phytoplankton abundance*: Occurrence of states (50%ile) are 1 (28%), 2 (4%), 3 (21%), 4 (31%) and 5 (16%). Likely average Chl-a during various states are 1 (3.3 µg/L), 2 (2.8 µg/L), 3 (5.8 µg/L), 4 (8.0 µg/L) and 5 (8.0 µg/L). The 2.2 ➔ 6.0 µg/L change from Reference represents a 19% ⇧ assuming a worst-case scenario of 20 µg/L (severe bloom). *Benthic microalgal abundance*: Changes in subtidal and intertidal areas 41% related to

	morphology and flow. Overall DIN/DIP score 26; 15% loss of biomass. *Benthic microalgal composition*: 26% similarity in sand fraction relative to total sand and mud ➔ 26% shift from epipelic to episammic diatom taxa.
Scenario 3	*Phytoplankton abundance*: Occurrence of states (50%ile) are 1 (28%), 2 (4%), 3 (24%), 4 (28%) and 5 (16%). Likely average Chl-a during various states are 1 (3.3 µg/L), 2 (2.8 µg/L), 3 (5.8 µg/L), 4 (8.0 µg/L) and 5 (8.0 µg/L). The 2.2 ➔ 5.9 µg/L change from Reference represents an 18% ⇧ assuming a worst-case scenario of 20 µg/L (severe bloom). *Benthic microalgal abundance*: Changes in subtidal and intertidal areas 41% related to morphology and flow. Overall DIN/DIP score 27; 14% loss of biomass. *Benthic microalgal composition*: 26% similarity in sand fraction relative to total sand and mud ➔ 26% shift from epipelic to episammic diatom taxa.
Scenario 4	*Phytoplankton abundance*: Occurrence of states (50%ile) are 1 (28%), 2 (4%), 3 (24%), 4 (29%) and 5 (14%). Likely average Chl-a during various states are 1 (3.3 µg/L), 2 (2.8 µg/L), 3 (5.8 µg/L), 4 (8.0 µg/L) and 5 (8.0 µg/L). The 2.2 ➔ 5.9 µg/L change from Reference represents an 18% ⇧ assuming a worst-case scenario of 20 µg/L (severe bloom). *Benthic microalgal abundance*: Changes in subtidal and intertidal areas 43% related to morphology and flow. Overall DIN/DIP score 27; 16% loss of biomass. *Benthic microalgal composition*: 26% similarity in sand fraction relative to total sand and mud ➔ 26% shift from epipelic to episammic diatom taxa.
Scenario 5	*Phytoplankton abundance*: Occurrence of states (50%ile) are 1 (26%), 2 (7%), 3 (18%), 4 (37%) and 5 (12%). Likely average Chl-a during various states are 1 (3.3 µg/L), 2 (2.8 µg/L), 3 (5.8 µg/L), 4 (8.0 µg/L) and 5 (8.0 µg/L). The 2.2 ➔ 6.0 µg/L change from Reference represents a 19% ⇧ assuming a worst-case scenario of 20 µg/L (severe bloom). *Benthic microalgal abundance*: Changes in subtidal and intertidal areas 43% related to morphology and flow. Overall DIN/DIP score 27; 16% loss of biomass. *Benthic microalgal composition*: 26% similarity in sand fraction relative to total sand and mud ➔ 26% shift from epipelic to episammic diatom taxa.
Scenario 6	*Phytoplankton abundance*: Occurrence of states (50%ile) are 1 (31%), 2 (8%), 3 (16%), 4 (35%) and 5 (11%). Likely average Chl-a during various states are 1 (3.3 µg/L), 2 (2.8 µg/L), 3 (5.8 µg/L), 4 (8.0 µg/L) and 5 (8.0 µg/L). The 2.2 ➔ 5.8 µg/L change from Reference represents an 18% ⇧ assuming a worst-case scenario of 20 µg/L (severe bloom). *Benthic microalgal abundance*: Changes in subtidal and intertidal areas 43% related to morphology and flow. Overall DIN/DIP score 26; 17% loss of biomass. *Benthic microalgal composition*: 26% similarity in sand fraction relative to total sand and mud ➔ 26% shift from epipelic to episammic diatom taxa.
Scenario 7	*Phytoplankton abundance*: Occurrence of states (50%ile) are 1 (0%), 2 (32%), 3 (16%), 4 (35%) and 5 (18%). Likely average Chl-a during various states are 1 (3.3 µg/L), 2 (2.8 µg/L), 3 (5.8 µg/L), 4 (8.0 µg/L) and 5 (8.0 µg/L). The 2.2 ➔ 6.0 µg/L change from Reference represents a 19% ⇧ assuming a worst-case scenario of 20 µg/L (severe bloom). *Benthic microalgal abundance*: Changes in subtidal and intertidal areas 37% related to morphology and flow. Overall DIN/DIP score 32; 5% loss of biomass. *Benthic microalgal composition*: 25% similarity in sand fraction relative to total sand and mud ➔ 25% shift from epipelic to episammic diatom taxa.
Scenario 8	*Phytoplankton abundance*: Occurrence of states (50%ile) are 1 (31%), 2 (8%), 3 (16%), 4 (35%) and 5 (11%). Likely average Chl-a during various states are 1 (3.3 µg/L), 2 (2.8 µg/L), 3 (5.8 µg/L), 4 (8.0 µg/L) and 5 (8.0 µg/L). The 2.2 ➔ 5.8 µg/L change from Reference represents an 18% ⇧ assuming a worst-case scenario of 20 µg/L (severe bloom). *Benthic microalgal abundance*: Changes in subtidal and intertidal areas 43% related to morphology and flow. Overall DIN/DIP score 26; 17% loss of biomass. *Benthic microalgal composition*: 26% similarity in sand fraction relative to total sand and mud ➔ 26% shift from epipelic to episammic diatom taxa.
Scenario 9	*Phytoplankton abundance*: Occurrence of states (50%ile) are 1 (0%), 2 (15%), 3 (33%), 4 (35%) and 5 (18%). Likely average Chl-a during various states are 1 (3.3 µg/L), 2 (2.8 µg/L), 3 (5.8 µg/L), 4 (8.0 µg/L) and 5 (8.0 µg/L). The 2.2 ➔ 6.5 µg/L change from Reference represents a 21% ⇧ assuming a worst-case scenario of 20 µg/L (severe bloom). *Benthic microalgal abundance*: Changes in subtidal and intertidal areas 37% related to

	morphology and flow. Overall DIN/DIP score 33; 4% loss of biomass. *Benthic microalgal composition*: 25% similarity in sand fraction relative to total sand and mud ➔ 25% shift from epipelic to episammic diatom taxa.
Scenario 10	*Full salinity gradient exists: species richness 0∆* *Phytoplankton abundance: Occurrence of states are similar to present (50%ile) are 1 (28%), 2 (4%), 3 (15%), 4 (35%) and 5 (18%). Likely average chl-a during various states are 1 (3.3 µg/L), 2 (2.8 µg/L), 3 (3.3 µg/L), 4 (4.0 µg/L) and 5 (4.0 µg/L). The 2.2 ➔ 3.6 µg/L change from Reference represents a 7% ⇧ assuming a worse case scenario of 20 µg/L (severe bloom).* *Phytoplankton community composition has been based on the percentage occurrence of flow states and these are similar to present; 20% change.* *Benthic microalgal abundance*: Changes in subtidal and intertidal areas 32% related to morphology and flow. Overall DIN/DIP score 49; 17% increase in biomass. *Benthic microalgal composition*: 20% similarity in sand fraction relative to total sand and mud ➔ 20% shift from epipelic to episammic diatom taxa.

4.3.1.2 Summary of changes

Projected changes in species richness, biomass and community composition of phytoplankton and benthic microalgae under the various future flow scenarios are summarised in Table 4.19.

Table 4.19 Summary of projected changes in species richness, biomass and community composition of phytoplankton and benthic microalage under the various future flow scenarios.

	Pres	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc7	Sc8	Sc9	Sc10
Phyto-plankton											
Species richness	0∆	0∆	0∆	0∆	0∆	0∆	0∆	0∆	0∆	0∆	0∆
Biomass	19%⇧	20%⇧	19%⇧	18%⇧	18%⇧	19%⇧	18%⇧	19%⇧	18%⇧	21%⇧	7%⇧
Community composition	20%	20%	21%	22%	22%	20%	18%	19%	18%	25%⇧	20%
Benthic microalgae											
Species richness	0∆	0∆	0∆	0∆	0∆	0∆	0∆	0∆	0∆	0∆	0∆
Biomass	12%⇩	11%⇩	15%⇩	14%⇩	16%⇩	16%⇩	17%⇩	5%⇩	17%⇩	4%⇩	17%⇧
Community composition	25%	23%	26%	26%	26%	26%	26%	25%	26%	25%	20%

4.3.1.3 Score

Projected changes in scores for species richness, biomass and community composition of phytoplankton and benthic microalgae under the various future flow scenarios are summarised in Table 4.20.

Table 4.20 Projected changes in scores for species richness, biomass and community composition of phytoplankton and benthic microalgae under the various future flow scenarios.

Score	Pres	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	Sc10	Confi-dence*
1. Species richness# (% similarity in brackets)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	M
2a. Abundance	81 (M)	80	81	82	82	81	82	81	82	79	83	L
2b.Community composition	75	77	74	74	74	74	74	75	74	75	80	L
Overall score	75	77	74	74	74	81	74	75	74	75	80	

*Confidence levels for scenarios that differ from the general level specified in the last column are included in brackets

Average instantaneous species richness (the number of species one would expect to record in a reasonably comprehensive once-off survey, not the cumulative total from exhaustive sampling)

4.3.2 Macrophytes

4.3.2.1 Description and explanation of changes

An explanation of the projected changes in macrophyte composition and abundance under the various future flow scenarios is provided in Table 4.21.

Table 4.21 Projected changes in macrophyte composition and abundance under the various future flow scenarios

Scenario 1	Low flow conditions and flooding are improved compared to the present state. This would influence species richness, biomass and community composition. Loss of brackish sedge pans (*Juncus maritimus,* and waterblommetjies *Aponogeton distachyos)* because of increase in salinity and reduced flooding compared with Reference conditions. Macrophyte species richness decreases in response to an increase in salinity for the different scenarios. Species would be lost from the salinity sensitive habitats i.e. sedge marsh and sedge pans. The abundance score changes in response to salinity and flooding. Drought periods occur for up to 8 years at a time that would result in extensive dieback of floodplain habitats. The open pans, halophytic and xeric floodplain become drier with less biomass and vegetation cover. Saline intrusion during summer causes dieback of the fringing reeds and sedges that grow best in a salinity of less than 15 ppt. Salinity conditions for the 6 drier summer months in Zone B would be 11.5 compared to 18.4 ppt, present state. In Zone C, salinity would be 4.4 compared to 7.6 ppt in Zone C for the present state. Community composition changes in response to the increase in nutrients and salinity. Increased low flows would encourage growth of *Eicchorrnia crassipes* (water hyacinth) which would displace pond weed, *Potamogeton pectinus* in the upper reaches of the estuary. Mats of decaying water hyacinth washed downstream also cause dieback of salt marsh and subsequent erosion. Macroalgae, particularly the filamentous species, form extensive mats in the lower reaches that displace the eelgrass, (*Zostera capensis*) beds. Overall, there would be a change in community composition from the freshwater brackish wetlands to halophytic floodplain and saltmarsh and from sedge pans to open saline pans.

Scenario 2	Decrease in low flows, which increases salinity and a reduction in floods compared to Scenario 1. Drought periods occur for up to 11-12 years at a time, which would result in extensive dieback of floodplain habitats (Scenarios 2-8) and the vegetation, may not recover from this if the areas remain saline.
Scenario 3	Floods and salinity conditions similar to that of Scenario 2.
Scenario 4	Low flows are similar to Scenario 3 but there is a further decrease in flooding due to a 9 m dam wall. The open pans, halophytic and xeric floodplain become drier with less biomass and vegetation cover.
Scenario 5	Compared to Scenario 4 there is an improvement in low flow conditions but floods remain similar to that of Scenario 4.
Scenario 6	Low flow conditions increase slightly which increases salinity. Floods are similar to that of Scenarios 4 and 5.
Scenario 7	MAR is the same as the present state, there are lowflow releases from the dam and thus an overall improvement in lowflow conditions with improved salinity conditions. Flooding conditions are improved compared to previous scenarios and is more similar to the present state.
Scenario 8	Same MAR as Scenario 4 but decrease in lowflow, which results in high salinity in Zones B, C, and D in the 6 drier summer month period. Salinity in Zone B is 21.7 ppt compared to 8.5 ppt for Reference conditions, salinity in Zone C is 11.8 compared with 0.2 for Reference conditions and salinity in Zone D is 2.7 compared with 0 ppt for Reference conditions. Flooding is reduced compared to Scenario 7. The open pans, halophytic and xeric floodplain become drier with less biomass and vegetation cover.
Scenario 9	This scenario represents the present state but with an increase in lowflow in summer. This improves salinity conditions positively influencing the species richness, abundance and community composition of macrophytes.
Scenario 10	This scenario represents Scenario 9 with some removal of anthropogenic impacts. Banks will be rehabilitated and alien trees removed. Agricultural practices will be controlled to avoid trampling and grazing of the estuarine vegetation. Anthropogenic activities have removed 2100 ha of estuary habitat. This scenario assumes that 1000 ha of habitat will be rehabilitated back to its natural state.

4.3.2.2 Summary of changes

Projected changes in key drivers for macrophytes and change in macrophyte abundance under the various future flow scenarios are summarized in Table 4.22.

Table 4.22 Summary of projected changes in key drivers for macrophytes and projected changes in macrophyte abundance under the various future flow scenarios

Parameters	**Present**	**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**	**Sc8**	**Sc9**	**Sc10**
MAR	54	64	51	49	43	44	43	54	43	58	58
% similarity in mean annual frequency of flooding	79⇩	85⇧	71⇩	71⇩	62⇩	62⇩	62⇩	79⇩	62⇩	79⇩	79⇩
Annual % occurrence	30	24	24	24	21	21	23	29	23	34	34

Parameters	**Present**	**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**	**Sc8**	**Sc9**	**Sc10**
% change in macrophyte abundance based on flooding for each scenario	11	8	15	15	19	19	19	10.5	19	10.5	10.5
Difference in total summer salinity (ppt) for Zones B, C, D compared to Reference conditions	18.9⇧	8.1⇧	19.3⇧	19.6⇧	19.6⇧	18.7⇧	20.5⇧	11.4⇧	27.5⇧	8.3⇧	8.3⇧
% change in macrophyte abundance based on summer salinity for each scenario	10	4	10	10	10	9	10	6	14	4	4
% change in macrophyte abundance (flooding + salinity + 26% loss of habitat due to removal)	46	38	50	50	55	54	55	42	59	41	29

Projected changes in various macrophyte groups in response to changes in water quantity and quality under the various future flow scenarios are summarized in Table 4.23.

Table 4.24 presents data on the area of macrophytes lost due to removal by anthropogenic activities, e.g. marina, saltpan development and those habitats that have been converted to open saline pan areas as a result of changes in water quality and quantity).

Table 4.23 Details for macrophyte changes in response to water quantity and quality changes

Macroalgae (lower reaches) Water hyacinth (upper reaches)	⇧ due to increase nutrients and low flows	⇧ Similar increases across different scenarios as nutrient levels remain the same. These changes influenced the community composition but not the abundance score as the cover of macroalgae for the Reference condition is unknown.
Zostera capensis	⇧ due to reduced flooding	⇧ However variable distribution, therefore not included in abundance scores. Changes in *Zostera* were included in the community composition but not the abundance score. Abundance would increase in response to reduced flooding but would decrease in response to increases in turbidity and disturbance such as recreational activities.
Potamogeton pectinatus	⇧ due to increase nutrients and low flows	⇧ Similar increases across different scenarios as nutrient levels remain the same. Changes in *Potamogeton* were included in the community composition but not the abundance score. Abundance would increase as a result of the nutrient input but would decrease because of increased salinity and turbidity.
Intertidal salt marsh	⇧	Salinity maintained by tidal influences therefore no major changes between scenarios, increase in area due to increased sediment stability and tidal exchange in the lower reaches. However, net effect is a loss of habitat as a result of human disturbance.
Open pan (saline)	⇧	⇧ Due to high salinity and reduced flooding, replaces other macrophyte habitat types that are lost.
Halophytic and xeric floodplain	⇩	⇩ Due to high salinity and reduced flooding, dieback and formation of dry bare saline areas.
Reeds and sedges	⇩	⇩ due to increase in saline intrusion (refine, longitudinal salinity). Potential replacement by intertidal salt marsh along estuary channel.
Sedge pan (fresh)	⇩	⇩ This habitat most sensitive to inundation and salinity changes, dieback at 5 ppt. Dieback and formation of dry bare saline areas.

Table 4.24 Similarity (%) compared to Reference of abundance for different macrophyte habitats

HABITAT	Pres	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9	Sc10
Submerged macrophytes⇩	96	96	96	96	96	96	96	96	96	96	96
Intertidal salt marsh ⇩	91	91	91	91	91	91	91	91	91	91	91
Open pan (saline)	104⇧	97⇩	108⇧	108⇧	112⇧	112⇧	112⇧	101⇧	115⇧	100⇧	106⇧
Halophytic floodplain ⇩	61	62	60	60	60	60	60	61	59	61	80
Xeric floodplain ⇩	60	61	58	58	58	58	58	60	57	60	79
Reeds and sedges ⇩	74	78	74	74	74	73	72	80	70	78	86
Sedge pan (fresh) ⇩	70	73	69	69	67	67	67	71	67	72	83

4.3.2.3 Score

Projected changes in scores for species richness, biomass and community composition of macrophytes under the various future flow scenarios are summarised in Table 4.25.

Table 4.25 Projected changes in scores for species richness, biomass and community composition of macrophytes under the various future flow scenarios

Score	Pres	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	Sc10	Confi-dence*
1. Species richness# (% similarity in brackets)	(80%)	(90%)	(80%)	(80%)	(80%)	(80%)	(80%)	(90%)	(70%)	(90%)	(90%)	L
2a. Abundance	54	62	50	50	45	46	45	58	41	59	71	M
2b. Community composition	60	80	60	60	60	60	60	80	40	80	80	M
Overall score	54	62	50	50	45	46	45	58	40	59	71	M

*Put confidence in brackets for any scenario where it differs from the general level specified in the last column

Average instantaneous species richness (the number of species expected from a reasonably comprehensive once-off survey, not the cumulative total from exhaustive sampling)

4.3.3 Invertebrates

4.3.3.1 Description and explanation of changes

An explanation of the projected changes in invertebrate community composition and abundance under the various future flow scenarios is provided in Table 4.26.

Table 4.26 Projected changes in invertebrate community composition and abundance under the various future flow scenarios.

Scenario 1	Although lowflows are slightly higher than present day, floods are less frequent. No change predicted for species richness, but zooplankton and subtidal benthic biomass will increase marginally as less frequent flooding will lead to reduced flushing from the system. Floodplain sediments salinate and compact, as will higher intertidal areas – droughts now last for up to 8 years at a time. Because of changes in the sediment salt load, there will also be a small change in community composition at higher intertidal levels and on the floodplain.
Scenario 2	Marginal increase in marine dominance and a further decrease in floods – droughts now up to 11-12 years. Increase in channel invertebrate biomass, but a further decrease in the floodplain infauna biomass.
Scenario 3	Floods unchanged from Scenario 2, but a further increase in lowflows (37.2% of the time) leading to increased biomass of the channel fauna.
Scenario 4	In this scenario, lowflows extend for longer compared to the previous scenario (now 41.9% of the time). Increased channel biomass compared to previous scenario. Flooding impacts reduced.
Scenario 5	Floods reduced and a further increase in lowflows (now 51% of the year). Channel biomass will increase further. Floods also further reduced – less flushing of plankton.

Scenario 6	Significant increase in lowflows (82% of the time), further marine dominance and increased channel biomass of invertebrates. Floods unchanged.
Scenario 7	Salinity distribution similar to present because of similar lowflows. Channel biomass of invertebrates similar to present. Flooding more frequent and similar to present 3.5% reduction compared to 10%) – greater flushing of zooplankton and subtidal benthos and better floodplain inundation.
Scenario 8	Although MAR similar to Scenario 6, lowflows slightly more that Scenario 5 (now 54% of the year). Channel biomass of invertebrates unchanged from Scenario 5. Flooding more frequent and similar to present (6.5% reduction compared to 10%).
Scenario 9	Similar to present state, but higher lowflows will lead to lower salinity downstream. Conditions more similar to natural.
Scenario 10	Reducing some of anthropogenic impacts will marginally improve habitat for invertebrates, but many cannot be reduced (port development, dredging effects, etc).

4.3.3.2 Summary of changes

Biomass is the main factor influenced by changing salinity, flood regimes and increased tidal range after dredging of the new mouth. The extent of floodplain inundation during floods is the main driver of change in biomass of invertebrates living there.

Carid shrimps will benefit from increased *Zostera* coverage (reduced flooding), but turbidity increases. Thus, kept at 10% increase for all scenarios.

Intertidal biomass mainly linked to Zone A – area of least change. The new mouth has also lead to a greater tidal range on average, leading to a greater intertidal area, although higher intertidal levels likely to experience increased salt loading over time as flood frequency is now lower – kept at 10% intertidal biomass overall. Change in sandy subtidal biomass linked to disappearance of former mouth channel and banks (1 km) when the new deeper mouth was established, as well as coarser sediments caused by stronger tidal currents in the lower estuary (coarser sediments less favourable for the infauna) – kept at 25% change for all scenarios.

Table 4.27. Summary of the changes in invertebrate species richness and in the biomass of the various groups of invertebrates under the future flow scenarios.

	Pres	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**	**Sc 5**	**Sc 6**	**Sc 7**	**Sc 8**	**Sc 9**	**Sc 10**
Invertebrate species richness	0%∆	0%∆	0%∆	0%∆	0%∆	0%∆	0%∆	0%∆	0%∆	0%∆	0%∆
Copepod biomass	55%⇧	57%⇧	60%⇧	62%⇧	64%⇧	66%⇧	70%⇧	50%⇧	54%⇧	52%⇧	52%⇧
Mysid biomass	55%⇧	57%⇧	60%⇧	62%⇧	64%⇧	66%⇧	70%⇧	50%⇧	54%⇧	52%⇧	52%⇧
Carid shrimps biomass	10% ⇧	10% ⇧	10% ⇧	10% ⇧	10% ⇧	10% ⇧	10% ⇧	10% ⇧	10% ⇧	10% ⇧	10% ⇧
Intertidal biomass	10%⇧	10%⇧	10%⇧	10%⇧	10%⇧	10%⇧	10%⇧	10%⇧	10%⇧	10% ⇧	15% ⇧

Sandy subtidal biomass	25% ⇩	25% ⇩	25% ⇩	25% ⇩	25% ⇩	25% ⇩	25% ⇩	25% ⇩	25% ⇩	25% ⇩	25% ⇩
Muddy subtidal biomass	10%⇧	10%⇧	10%⇧	10%⇧	10%⇧	10%⇧	10%⇧	5%⇧	5%⇧	5%⇧	10%⇧

4.3.3.3 Score

Projected changes in scores for species richness, biomass and community composition of invertebrate fauna of the Berg estuary under the various future flow scenarios are summarised in Table 4.28.

Table 4.28. Projected changes in scores for species richness, biomass and community composition of invertebrate fauna of the Berg estuary under the various future flow scenarios

Score	Pres	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	Sc10	Conf.
1. Species richness# (% similarity in brackets)	100% (100)	100% (100)	100% (100)	100% (100)	100% (100)	100% (100)	100% (100)	100% (100)	100% (100)	100% (100)	100% (100)	H
2a. Abundance	45	43	40	38	36	34	30	50	46	55	57	M
2b.Community composition	50	48	45	43	41	39	35	55	51	55	55	L
Overall score	45	43	40	38	36	34	30	50	46	55	57	L

* Confidence levels for scenarios that differ from the general level specified in the last column are included in brackets

Average instantaneous species richness (the number of species you would expect to record in a reasonably comprehensive once-off survey, not the cumulative total from exhaustive sampling)

4.3.4 Fish

4.3.4.1 Description and explanation of changes

An explanation of the projected changes in fish community structure and abundance under the various future flow scenarios is provided in Table 4.29.

Table 4.29 Projected changes in fish community composition and abundance under the various future flow scenarios

Scenario 1	Reduced lowflows and flood frequency mean greater marine dominance and increased productivity (increased phytoplankton, benthic microalgae, zooplankton) and provision of additional food for some species (particularly filter feeders, zooplanktivorous species, benthic invertebrate feeders, and herbivores) with a concomitant increase in abundance of these groups in the system. However, reductions in freshwater habitat at the head of the estuary will most likely result in further reductions and possible loss of estuarine resident species. Reductions in water quality (particularly oxygen) will have a negative impact on many fish species. Further loss of intertidal and shallow subtidal habitat will affect juveniles of many species and adults of some resident species. Changes in floodplain vegetation and invertebrate biomass do not significantly affect indigenous fish in the system, as they do not make much use of this habitat. Assume no change in anthropogenic impacts. In this scenario, duration of summer lowflows moderately increased from Reference (+13%), floods reduced by 15%, intertidal reduced by 35%, and water quality is poor; enhanced productivity (phytoplankton, benthic microalgae and zooplankton biomass) provides additional food for filter feeders and zooplanktivorous species. No change in instantaneous species richness, overall increase in abundance of fish relative to PD, and further change in community composition.
Scenario 2	A marginal increase in marine dominance as a result of increased duration of summer low flows and a further reduction in floods, and water quality (reduced oxygen due to reduced flushing), productivity increased through. Enhanced trajectory of change for fish as described above (reduction in instantaneous species richness, overall increase in abundance of fish relative to PD, and further change in community composition).
Scenario 3	Floods as for Scenario 2, but increased incidence in lowflows and marine dominance. Enhanced trajectory of change for fish as described above (reduction in instantaneous species richness, overall increase in abundance of fish relative to PD, and further change in community composition). No significant change in fish community relative to Sc 2.
Scenario 4	Further reduction in flooding, no change in incidence of lowflows rel. to Sc 3, no change in extent of marine dominance. Enhanced trajectory of change for fish as described for Sc 1 and 2 (reduction in instantaneous species richness, overall increase in abundance of fish relative to PD, and further change in community composition).
Scenario 5	Further reduction in flooding but occurrence of low flow conditions reduced, slight increase in marine dominance. No change in instantaneous species richness but slight reduction in fish biomass. No significant change in community structure.
Scenario 6	Floods as for Scenario 5, occurrence of low flow conditions more frequent than Sc5 but less than Sc 4; increase in marine dominance relative to all previous scenarios. Enhanced trajectory of change for fish as described for Sc 1 and 2 (reduction in instantaneous species richness, overall increase in abundance of fish relative to PD, and further change in community composition).
Scenario 7	Magnitude and frequency of floods between PD and Sc1, incidence of lowflows as for PD but magnitude increased (min summer lowflow = 0.9 m^3s^{-1}), thus extent of marine dominance reduced in upper reaches. Increase in instantaneous species richness, reduction in filter feeder biomass (improvement towards natural) but no significant change in community structure.
Scenario 8	Change in magnitude and frequency for floods as for Sc4-6, incidence of low flows as for 6, but extent of marine dominance increased due to reduced magnitude of lowflows

	(summer lowflow = 0.15 m^3s^{-1}). Loss of freshwater habitat at the head of the estuary leads to further loss of estuarine resident fish species dependent on this habitat and increase in biomass of filter feeding species.
Scenario 9	Magnitude and frequency of floods and occurrence of lowflows as for PD but extent of marine dominance reduced due to increased magnitude of lowflows (Dec =2.0 m^3s^{-1}, Jan =1 m^3s^{-1}.5, Feb = 1.0 m^3s^{-1}, Mar=1.0 m^3s^{-1} and April = 3 m^3s^{-1}). Species richness as for PD, biomass of filter feeders reduced, increase in abundance of resident species.
Scenario 10	Flows as for Sc 9 but channel has been rehabilitated and water quality has improved due to reduced nutrient inputs. Instantaneous species richness as for PD, biomass of filter feeding species reduced, increase in abundance of resident species.

4.3.4.2 Summary of changes

Projected changes in biomass of the various groups of fish in the Berg estuary under the future flow scenarios are summarized in Table 4.30.

Table 4.30 Change in biomass for estuary associated fish species relative to present day:

	Pres	**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**	**Sc8**	**Sc9**	**Sc10**
Category Ia (Estuary resident)	23%⇧	20%⇧	26%⇧	23%⇧	32%⇧	33%⇧	32%⇧	22%⇧	35%⇧	10%⇩	10%⇩
Category Ib (Estuary resident)	18%⇧	15%⇧	26%⇧	18%⇧	32%⇧	33%⇧	32%⇧	16%⇧	35%⇧	10%⇧	10%⇧
Category IIa (Estuary dependent marine migrant)	90%⇩	90%⇩	90%⇩	90%⇩	90%⇩	90%⇩	90%⇩	90%⇩	90%⇩	80%⇩	80%⇩
Category IIb (Estuary associated marine migrant)	33%⇧	30%⇧	36%⇧	33%⇧	45%⇧	40%⇧	42%⇧	32%⇧	43%⇧	20%⇧	10%⇧
Category IIc (Estuary associated marine migrant)	33%⇧	30%⇧	36%⇧	33%⇧	45%⇧	40%⇧	42%⇧	32%⇧	43%⇧	20%⇧	10%⇧
Category III (Marine migrant)	25%⇧	25%⇧	36%⇧	25%⇧	45%⇧	40%⇧	42%⇧	27%⇧	43%⇧	15%⇧	10%⇧

	Pres	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	Sc10
Category IV (Euryhaline freshwater species)	100% ⇩	100% ⇩	100% ⇩	100% ⇩	100% ⇩	100% ⇩	100% ⇩	100% ⇩	100% ⇩	100% ⇩	100% ⇩

4.3.4.3 Score

Projected changes in scores for species richness, biomass and community composition of fish fauna of the Berg estuary under the various future flow scenarios are presented in Table 4.31.

Table 4.31. Projected changes in scores for species richness, biomass and community composition of fish fauna of the Berg estuary under the various future flow scenarios

Score	Pres	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	Sc10	Confi-dence*
1. Species richness# (% similarity in brackets)	56	56	45	45	45	45	45	56	35	56	56	56
2a. Abundance	85	88	82	81	75	79	77	86	76	95	95	85
2b.Community composition	87	87	87	87	87	87	87	87	87	87	87	87
Overall score	56	56	45	45	45	45	45	56	35	56	56	56

* Confidence levels for scenarios that differ from the general level specified in the last column are included in brackets
# Average instantaneous species richness (the number of species you would expect to record in a reasonably comprehensive once-off survey, not the cumulative total from exhaustive sampling)

4.3.5 Birds

4.3.5.1 Description and explanation of changes

An explanation of the projected changes in avifauna on the Berg estuary under the various future flow scenarios is provided in Table 4.32.

Table 4.32 Projected changes in fish community composition and abundance under the various future flow scenarios

Present	There has been a loss in the degree of flooding relative to present day, which has affected the attractiveness of the floodplain for breeding birds, and the length of time that birds occupy the floodplain areas. Intertidal area is significantly reduced to less than two-thirds remaining in original condition, affecting the most numerous group on the estuary, the waders. Artificial saltpans have increased suitable habitat for flamingos and other species. Areas of reed beds have decreased substantially, possibly having a negative effect on some skulking rallid and heron species. There has been no change in the general productivity of the system, but densities of benthic invertebrates have increased by 10%, counteracting the impact of loss of intertidal area, and numbers of fish have decreased slightly, to the detriment of piscivorous groups.
Scenario 1	The flows associated with this scenario are akin to the conditions measured in the Berg River Estuary Baseline Study (2007). Hydrological conditions are slightly closer to natural than the present day scenario, making the estuary more favourable for waterfowl than under present conditions. Intertidal conditions are also more favourable for waders. Fish are slightly more abundant than under present conditions, and more favourable for piscivores.
Scenario 2 - 8	These scenarios represent a range of conditions all with more modified hydrological regimes than the present. Intertidal conditions remain relatively unchanged from the present, but there are no significant changes in productivity, invertebrate abundance or fish abundance. Conditions approach those of Scenario 1 in Scenario 7.
Scenarios 9 and 10	In Scenario 9, flooding is similar to present conditions, and macrophytes and fish are closer to present and natural than in the other scenarios. In Scenario 10, intertidal habitats are slightly improved, fish abundance increases due to reduced fishing pressure. There is a slight decrease in disturbance due to management of people.

4.3.5.2 Summary of changes

Projected changes in abundance relative to present day of the various groups of birds on the Berg estuary under the future flow scenarios are summarized in Table 4.30.

Table 4.33 Change in abundance relative to present day for various groups of birds under the future flow scenarios

	Pres	**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**	**Sc8**	**Sc9**	**Sc10**
Piscivorous waterfowl	-17%	-14%	-26%	-26%	-35%	-35%	-35%	-17%	-35%	-17%	-14%
Omnivorous waterfowl	-25%	-19%	-33%	-33%	-41%	-41%	-41%	-25%	-41%	-25%	-25%
Herbivorous waterfowl	-44%	-37%	-50%	-50%	-56%	-57%	-58%	-40%	-59%	-41%	-35%
Piscivores	-14%	4%	-23%	-23%	-34%	-34%	-33%	-14%	-36%	-18%	4%
Greater Flamingo (inverts)	-6%	-6%	-6%	-6%	-6%	-6%	-6%	-6%	-6%	-6%	-2%

	Pres	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	Sc10
Lesser Flamingo (Phytoplankton)	325%	325%	325%	325%	325%	325%	325%	325%	325%	325%	325%
Waders (Inverts)	-32%	-29%	-32%	-32%	-32%	-32%	-32%	-32%	-32%	-32%	-27%
Gulls and terns (Piscivores)	-15%	-4%	-15%	-15%	-16%	-16%	-15%	-15%	-18%	-18%	3%

4.3.5.3 Score

Projected changes in scores for species richness, abundance and community composition of avifauna on the Berg estuary under the various future flow scenarios are presented in Table 4.31.

Table 4.34. Projected changes in scores for species richness, abundance and community composition of avifauna on the Berg estuary under the various future flow scenarios.

Score	Pres	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	Sc10	Confi-dence*
1. Species richness# (% similarity in brackets)	82	87	79	79	71	71	79	82	79	87	87	M
2a. Abundance	82	86	80	80	78	77	77	83	77	81	87	M
2b.Community composition	84	86	84	84	83	83	83	90	83	89	94	M
Overall score	82	86	79	79	71	71	77	82	77	81	87	M

* Confidence levels for scenarios that differ from the general level specified in the last column are included in brackets

Average instantaneous species richness (the number of species you would expect to record in a reasonably comprehensive once-off survey, not the cumulative total from exhaustive sampling)

4.4 Economic value of the Berg estuary

Impacts of the various flow scenarios examined in this study on economic value of the Berg estuary was estimated only for turnover in the real estate sector, visitor expenditure, and the nursery value of the estuary, as these three components contributed more than 99% of the Total Economic Value of the estuary (see Section 3.3) are presented in Table 4.35. In order to estimate impacts on turnover in the real estate sector and visitor expenditure, respondents in the questionnaire survey conducted in Vedrif at the mouth of the estuary, were asked to evaluate a series of hypothetical scenarios regarding the condition of the Berg Estuary. Note These were not related to the scenarios assessed in the larger RDM study but were simply designed to tease out the relative influence of various attributes on total of economic of the estuary. These attributes included numbers of birds on the estuary, abundance of angling fish, reed bed area and intertidal salt marsh area. A model was then constructed using the four variables in continuous form. Overall utility (on a scale of 0 to 10) for the estuary was described by the model as follows:

Utility score = -0.46 + 0.006*Saltmarsh area (ha) + 2.35*Angling fish (% diff to present day) + 0.0003*Birds (numbers) + 0.0007*Reed bed area (ha).

The variance explained by the model was relatively low, but the model itself was highly significant ($P<0.001$). The co-efficients for all four variables were also significant, with birds and angling fish being highly significant ($p<0.0001$).

Many of the respondents indicated that if their preferred scenario occurred it would have a positive impact on either their property value, in the case of home owners, or the amount of time spent in the area, in the case of visitors. In all, 30% of permanent residents, 45% of holiday home owners, and 21% of visitors indicated a positive impact (as opposed to no change). Property owners estimated an average increase in property value of 10% and visitors an average of 15% increase in the time spent in the area per unit increase in utility. A larger percentage (33% of permanent residents, 58% of holiday home owners, and 25% of visitors) indicated that if their least preferred scenario came about it would decrease property value, in the case of property owners, or decrease the amount of time spent in the area, in the case of visitors. Property owners estimated an average decrease in property value of 11% and visitors an average of 21% decrease in the time spent in the area per unit decrease in utility. Based on the above models, the various RDM Scenarios were evaluated in terms of their utility scores. The resultant scores range from 6.84 – 7.51, but only resulted in about a predicted 5% increase in the use of the estuary and an increase of R800 000 in estimated recreational turnover between the lowest (Sc 2/9) and highest (Sc 10) scoring scenarios (Table 4.35).

Table 4.35. Contributions to the total estimated value of the Berg estuary from turnover in the real estate sector, recreational turnover, and nursery value as estimated from this study for the Present Day (PD) and under the various future scenarios (Sc1-10). All values in 2005 Rands. Note that subsistence and existence value have been excluded from this total owing to the small contribution from these components.

Scenario	Estimated real estate turnover (R millions)	Estimated recreational turnover (R millions)	Nursery value (R Millions)	Total Economic Value (R Millions)
PD	48.6	18.3	8.07	75.0
1	49.7	18.8	8.86	77.4
2	49.0	18.3	8.38	75.7
3	49.4	18.6	8.5	76.5
4	49.5	18.6	8.81	76.9
5	49.5	18.6	8.69	76.8
6	49.6	18.7	8.81	77.1
7	49.7	18.8	8.07	76.6
8	49.2	18.4	8.81	76.4
9	49.0	18.3	7.55	74.9
10	50.3	19.1	9.17	78.6

Changes in the abundance of fish in the various estuary dependent categories identified in Section 3.2.1.4 category were estimated by the fisheries species on the team (Barry Clark). According to these data, overall fish biomass in the Berg estuary has increased modestly (~14%) relative to the Reference condition. This was attributed to increased productivity in the estuary owing to higher nutrient inputs and associated increases in microalgae biomass that has benefitted mainly the filter feeding species utilising the estuary. However, many of species important in inshore fisheries in the region are not filter feeding species and have not benefitted in this manner. In fact, many of these species are very low relative to the Reference condition due mostly to anthropogenic influences operating both inside and outside the estuary. The most important of these influences is fishing which has decimated adult populations of these species. Changes in flow under the various future scenarios were nonetheless predicted to have some impact on the abundance of commercially and recreationally important fish species in the estuary, most of which were positive and were associated with an increase in saline (marine type) habitat in the estuary and increases in productivity in the system (increased phytoplankton and zooplankton abundance) (Sc2-Sc6 and Sc8), while increases in flow have the opposite effect (Sc 7 and 9) unless this is coupled with a concerted effort to reduce existing non-flow related anthropogenic impacts on the system (e.g. reduction in illegal gill net fishing and restoration of degraded habitats in the estuary, Sc 10) (Table 4.35).

Total estimated value for the Berg estuary for these three components examined for the future flow scenarios is R75.0 million per annum at present. This value increases marginally under most of the future scenarios (aside from Scenario 9), due to increases in all components of value under these scenarios up a maximum of R78.6 million per annum under Scenario 10. Under Scenario 9, modest increases in real estate turnover are offset by the lack of any change in recreational utility and a reduction in nursery value. It should be noted that all of the changes in value are all very small relative to the overall value of the system (all <5%), and should be treated with caution given that they are all less than the confidence limits surrounding these value estimates.

4.5 Ecological reserve categories (ERC) associated with runoff scenarios

The individual EHI scores, as well as the corresponding ERC for the different scenarios are provided in Table 4.36.

Table 4.36 EHI score and corresponding ERC for the different runoff scenarios

VARIABLE	WEIGHT	PD	Runoff SCENARIO									
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Hydrology	*25*	72	76	72	71	67	63	61	72	61	80	80
Hydrodynamics/mouth condition	*25*	90	90	90	90	90	90	90	90	90	90	90
Water quality	*25*	40	41	41	41	41	40	38	45	36	49	59
Physical habitat alteration	*25*	59	68	62	62	61	61	61	61	61	61	71
Habitat health score	***50***	**65**	**69**	**66**	**66**	**65**	**64**	**63**	**67**	**62**	**70**	75
Microalgae	*20*	**75**	75	74	74	74	74	74	75	74	75	80
Macrophytes	*20*	**54**	62	50	50	45	46	45	58	40	59	71
Invertebrates	*20*	**50**	43	40	38	36	34	30	50	46	55	55
Fish	*20*	**56**	56	45	45	45	45	45	56	35	56	56
Birds	*20*	**78**	85	76	76	71	71	72	80	71	79	87
Biotic health score	***50***	63	64	57	57	54	54	53	64	53	65	70
Estuarine Health Index Score		64	66	62	61	59	59	58	65	58	67	72
Ecological Reserve Category (ERC)		**C**	**C**	**C**	**C**	**D**	**D**	**D**	**C**	**D**	**C**	**C**

4.6 Recommended Ecological Water Requirement Scenario

The evaluation of the simulated runoff scenarios is used to derive the recommended EWR. The recommended EWR is defined as the scenario (or a slight modification thereof) that represents the highest reduction in river inflow that will keep the Estuary in the recommended ERC.

The Berg River Estuary has been targeted as a Desired Protected Area (DWAF 2008). Thus, according to the guidelines for assigning a recommended ERC, the ERC should be a Category A or the Best Attainable State (BAS). Alternatively, the ERC guidelines for a ‘highly important estuary’, the next category down from “Desired Protected Area”, requires that the codnition be improved by at least one category (in this case to a Category B) or BAS.

The feasibility of achieving either a Category A or B was examined through the evaluation of two additional scenarios (Scenarios 9 and 10), in which summer lowflows (the aspect of greatest concern within the flow regime) were elevated (both scenarios) and all practical mitigation measures applied to non-flow related impacts (e.g., e.g. removal of unutilised infrastructure in the lower estuary, reduced agricultural impacts on the floodplain and reduction in application of fertilizers in the catchment and eradication of illegal gill net fishing in the estuary; Scenario 10). None of these measures resulted in an improvement to a Category A or B. Using flow alone, it was possible to elevate the health by only 3% (from 64 to 67%) and a further improvement of 5% was achieved if all the practical mitigation measures were implemented. Thus, the BAS for the estuary is a **Category C.**

Many of the scenarios evaluated resulted a drop in condition in the Berg River Estuary, mainly because summer lowflows were even lower than present. The estuary showed itself to be much less sensitive to reduction in high flows. Given this, and the fact that the condition of the Berg River Estuary is mostly likely declining (i.e. not static) owing to the fact that the Berg River dam was only recently brought on line (i.e. in 2005), and the fact that the system is still adapting to the new flow regime that has been imposed. Once this dam is fully operational, accidental spillages will be curtailed, and the health of the system may well decline further. There is also considerably uncertainty as to the magnitude of the summer lowflows reaching the system due to the absence of a gauging station at the head of the estuary. The extreme sensitivity to reduced summer lowflows is linked to the fact that the upstream extent of saline water penetration has increased considerably in comparison to the Reference condition (viz. from an estimated 35 km upstream to a present 45 km upstream) and to the fact that the estuary narrows rapidly over the section in question, and even more so from this point upstream. Noting also that there considerably uncertainty in respect of the magnitude of the summer inflows to the estuary due to the fact that this is affected by the operation of the system downstream of Misverstand and the extent to which releases are intercepted by irrigators downstream. Streamflows received by the estuary reportedly could vary from less than 0.3 m^3s^{-1} to over 1 m^3s^{-1}!

Given all of the foregoing and following the guideline above, **Scenario 7**, i.e. the Present inflow scenario with marginally reduced minimum summer low requirements of 0.6 x m^3s^{-1} is selected as the recommended EWR Scenario for the Berg River Estuary. The flow distribution is summarised in Table 4.37.

Table 4.37 Summary of the flow distribution for the recommended EWR (Scenario 7 with minimum summer lowflows of 0.6 m^3s^{-1}) for the Berg River Estuary

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	46.97	30.38	14.58	5.30	7.03	8.36	23.43	64.98	120.14	220.34	185.50	139.78
90%ile	22.06	12.70	2.71	1.46	1.24	1.81	7.51	29.83	63.86	114.04	117.06	54.26
80%ile	15.53	8.51	0.93	0.90	0.90	0.90	5.61	13.83	37.23	60.90	85.14	38.81
70%ile	11.56	6.26	0.60	0.90	0.90	0.90	3.91	10.26	31.42	46.06	55.93	32.27
60%ile	9.69	4.88	0.60	0.90	0.90	0.90	2.08	8.59	19.69	36.07	44.29	23.95
50%ile	8.28	4.02	0.60	0.90	0.90	0.90	1.42	6.90	16.13	27.74	28.66	20.15
40%ile	7.56	3.74	0.60	0.90	0.90	0.90	1.00	5.43	11.46	21.97	22.95	15.90
30%ile	6.69	3.31	0.60	0.90	0.90	0.90	0.90	4.33	9.78	17.19	19.04	14.13
20%ile	6.22	2.73	0.60	0.90	0.90	0.90	0.90	3.43	7.75	13.22	15.91	11.00
10%ile	5.22	2.32	0.60	0.90	0.90	0.90	0.90	2.73	6.19	8.81	11.34	8.44
1%ile	3.79	0.60	0.60	0.60	0.60	0.60	0.90	1.49	3.61	4.67	7.28	4.83

Maintaining the *status quo* in respect of the existing summer lowflows is likely to result in continued modification of the Ecological status of the estuary and may ultimately result in the system falling into a Category D. This is highly undesirable and would be associated with the follow negative outcomes:

- Excessive (or nuisance) macroalgal growth during the summer months that will smother invertebrate communities inhabiting intertidal mud and sandflats in the lower estuary, particularly if nutrient inputs from agricultural activities continue in the catchment and fish processing factories at the mouth continue discharging effluent into the estuary. This will have potential negative impacts on bird fauna, recreational usage and aesthetics (i.e. 'loss of value').
- Increase in abundance and occurrence of nuisance macrophytes, notably water hyacinth in the upper estuary and *Enteromorpha* in the lower estuary, with negative impacts on marginal salt marsh vegetation, intertidal invertebrate populations inhabiting sand and mudflats in the lower estuary, bird fauna of the estuary, and recreational usage and aesthetics.
- Reduction in populations of estuarine dependent fish and invertebrate species, particularly those that use the upper reaches of the estuary as a spawning and nursery ground.
- Reduced cueing effect to estuarine dependent invertebrate and fish species, and a possible reduction in diversity and abundance of fish in the estuary.

The above-mentioned are also likely to have a ripple effect on economic good and services provided by the adjacent marine environment, e.g. the marine fisheries. The Berg River Estuary is but one of a few large estuarine systems along the South African west coast where it is considered to play a crucial role in terms of biological functionality to sustain the important fisheries resource. Note that the linkages between the estuary, the marine environment and the fisheries resource are still poorly understood. Some of the key aspects that require further research are highlighted later (refer to Section 6.1.2).

It is therefore strongly recommended that decisions regarding the future state of the Berg River Estuary, carefully consider potential impacts on all uses, both land-based and marine-based activities. This will require effective cooperative governance between the Department of Water Affairs and Forestry, Department of Agriculture and the Department of Environmental Affairs and Tourism (particularly Marine and Coastal Management). Every effort should also be made to implement the measures required to mitigate the non-flow related impacts on the system. These can be summarised as follows:

- Eradicate invasive alien vegetation (especially dense tree stands) from floodplains.
- Remove derelict, redundant and old quays, jetties, wharfs and revetments; and rehabilitate banks to natural sediments. Optimise use of remaining such structures to minimise requirement for more such structures;

- Prohibit dumping of dredge spoil (from lower main channel as well as marina) in inappropriate areas.
- Install additional culverts into road and rail bridge embankments.
- Manage agricultural practises in the estuary to avoid trampling of estuarine vegetation by livestock.
- Manage agricultural practises in the catchment to minimise nutrient (fertilizer) and increased sediment loads from reaching the estuary
- Institute requirements for treatment of fish factory effluent discharged to the estuary to reduce nutrient loading to the system
- Upgrade the sewage treatment works in the catchment to reduce nutrient contribution from this source to the estuary

5 Ecological Specification

The *Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries, Version 2* (DWAF 2008) does not provide guidance on the determination of ecological specifications for estuaries. Therefore, the approach that was applied, and approved by DWA, as part of the Thukela study was followed (DWAF 2004b).

Ecological Specifications are clear and measurable specifications of ecological attributes (in the case of estuaries - hydrodynamics, sediment dynamics, water quality and different biotic components) that define a specific ecological reserve category, in this case a **Category C.** The ecological specifications for the Berg River Estuary are listed in Table 5.1.

Thresholds of potential concern (TPC) are defined as measurable end points related to specific abiotic or biotic indicators that if reached (or when modelling predicts that such points will be reached) prompts management action. In essence, TPCs should provide early warning signals of potential non-compliance to ecological specification (i.e. not the point of 'no return'). This implies that the indicators (or monitoring activities) selected as part of long-term monitoring programme need to include biotic and abiotic components that are particularly sensitive to changes in river inflow. The TPCs associated with each of the ecological specifications are also provided in Table 5.1.

Table 5.1 Ecological Specifications and TPC associated with an Ecological Category C in the Berg River Estuary

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
1 Birds	Retain at least 90% of the baseline species richness, abundance and diversity of the bird community.	1.1 The number of non-passerine waterbird species recorded in counts decreases by more than 15% across five or more annual surveys 1.2 The overall numbers of any of the defined groups decreases relative to the baseline average by more than 15% over a five-year period, after correcting for regional/global population changes. 1.3 The numbers of any species decreases relative to the baseline average by more than 15% over a five-year period, after correcting for regional/global population changes.	Changes in: Salinity Invertebrate biomass/abundance Fish biomass/abundance in smaller size classes Vegetated habitat Mud flats Human disturbance
2 Fish	Retain the full complement of estuarine resident (7 species) and estuary associated marine (5 species) present in the estuary (see Table 3.18 for list) with population sizes sufficient to ensure their persistence in perpetuity. Ensure that exotic freshwater species do not increase to levels where they can exclude any more indigenous species through predation or competitive interactions	2.1 Comprehensive survey of fish in the estuary (40 + sites sampled across full estuary with fine mesh seine net) during summer fails to confirm presence of viable populations of all 15 species list in Table 3.18. 2.2 Abundance of exotic freshwater species increases by more than 50% above present levels	• Reduction in national spawner biomass for estuary associated marine species • Spawning failure due to environmental conditions (marine) • Recruitment failure (e.g. no cues reaching the sea from the estuary) • Habitat change (macrophytes) • Changes in water quality (temperature, salinity, turbidity, dissolved oxygen) • Toxic substances (?) • Change in food availability (microalgae, invertebrates and fish) • Exploitation • Introduction or change in abundance of alien species

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
	Maintain recruitment of adult and juvenile fish at present levels. This requires maintaining sufficient flow for freshwater plume (temperature, salinity and olfactory gradient) entering the sea. This implies that there should be a significant number of 0 -1 year old fish and no missing year classes.	2.3 There are a missing year class within a species	• Reduction in summer lowflow and floods in winter
3 Invertebrates	Retain present species richness, distribution of species and mix (low species abundance, high dominance) in Zones A to the middle reaches of Zone C. One or two species will always be present at high densities compared to others (e.g. *Pseudodiaptomus hessei, Grandidierella* sp.) in these Zones (A to C).	3.1 Species richness increases or decreases by more than 25% in any of the invertebrate categories (zooplankton, Subtidal zoobenthos or Intertidal benthos) in Zones A to C compared to present.	• Changes in variability in intra-annual flow, e.g. loss of high flow pulses that flush the estuary. Reducing lowflows to a level that allows upstream extension of salinity values into Zone D. This would provide additional habitat. In midsummer (2-3 months).
	Indicator species such as Capitella capitata, should not dominate benthic species at any site	3.2 Capitella capitata exceeds 50% abundance of benthic species at any site	• Increase in pollution (low oxygen high organic loading)
	Callianassa kraussi and *Upogebia africana* distribution patterns remain similar to present state.	3.3 Areas of distribution extend upstream or downstream by more than 4-5 km.	• Changes in sediment characteristics along the estuary coupled with salinity increases.

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
4 Macrophytes	Maintain the present distribution (2003-2005) and abundance of the different plant community types and estuarine habitats (intertidal mudflats with *Zostera capensis* 206 ha, intertidal salt marsh 499 ha, open pan 1159 ha, halophytic floodplain 1521 ha, xeric floodplain 919.1 ha, reeds and sedges 586.6 ha and sedge pan 292.5 ha).	4.1 Greater than 10% change in the area covered by different plant community types	• Increase in salinity and reduced flooding influencing water level, inundation depth, depth to groundwater, groundwater salinity and sediment salinity. Increase in turbidity would reduce submerged macrophyte cover. (Details of different plant community type requirements in reports). Increase in human disturbance, grazing, trampling and other agricultural activities.
	Prevent an increase in mats of macroalgae in the lower intertidal reaches	4.2 Percentage cover should not exceed 100% in more than 50% of the quadrats.	• Increase in nutrients in the lower reaches of the estuary. Low flow conditions and reduced flooding.
	Reduce the area covered by water hyacinth (*Eicchornia crassipes*) in the upper reaches by 50% compared to the present state (2003-2005).	4.3 Upper reaches of the estuary with greater than 50% of estuary water channel covered by water hyacinth.	• Reduced flows, lack of flushing and reduced current speeds. Reduced flooding that resets the estuary. High nutrient input from catchment activities and agricultural return flow.
	Prevent an increase in size of the open pan dry areas (1159 ha in 2003-2005)	4.4 Greater than 10 % increase in area.	• Reduction in pattern and size of annual floods.
	Prevent a decrease in size of the sedge pan areas (293 ha in 2003-2005). *Juncus maritimus,* and waterblommetjies *Aponogeton distachyos* are present.	4.5 Greater than 10 % decrease in area. *Juncus maritimus,* and waterblommetjies *Aponogeton distachyos* are absent.	• Reduction in pattern and size of annual floods and increase in salinity.
	Control the spread of invasive aliens in the riparian zone (e.g. *Acacia mearnsii* and *Eucalyptus camaldulensis*)	4.6 Greater than 10 % increase in area covered by invasive plants.	• Disturbance of riparian zone due to human impacts such as ploughing and clearing of natural vegetation.

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
	Maintain intact reed and sedge stands along the banks of the estuary by ensuring that salinity is not greater than 20 ppt for 3 months at 20 km from the month during summer.	4.7 Dieback of reeds and sedges at 20 km and further upstream from the mouth.	• Reduced flow and an increase in saline intrusion.
	Prevent an increase in bare ground in the halophytic and xeric floodplain habitats by maintaining the present day flooding patterns	4.8 Greater than 20% increase in bare ground in halophytic and xeric floodplain habitats	• Change in flooding patterns which influence sediment moisture, sediment salinity, depth to groundwater and groundwater salinity. Increase in human disturbance, grazing, trampling and other agricultural activities.
5 Microalgae	Maintain a low phytoplankton biomass with a small REI (i.e. 10 ppt to river +1 ppt) zone	5.1 Phytoplankton biomass exceeds 15 µg/l chlorophyll a in summer and 10 ug/l chlorophyll a in winter 5.2 Blue-green algae exceeds 10% of phytoplankton cell counts	• Water flow rates falling too low in winter or summer.
	Maintain microalgal group diversity as measured under present state (2004)	5.3 Flagellates cease to be the dominant group and diatoms become less diverse (<10 taxa per site)	• Reduced freshwater inflow rates and high salinity near the upper areas of the estuary.
	Maintain intertidal and subtidal microphytobenthic biomass as measured under present state (2004).	5.4 Benthic microphytobenthic biomass exceed 40 mg/m2 chlorophyll a	• Elevated nutrient in the inflowing freshwater.
	Maintain a low frequency of dinoflagellates	5.5 The frequency of dinoflagellates exceeds 5% of the total phytoplankton counts	• Eutrophication of inflowing river water.

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
6 Water quality	Salinity intrusion should not to cause exceedence of TPCs for fish, invertebrates, macrophytes and microalgae (see above)	6.1 Salinity greater than 20 ppt for longer than 3 months at 20 km upstream from the mouth (brackish saltmarsh, reeds and sedges and invertebrates) – continuously monitored as 25 ppt measured at 11 km Kliphoek (G1H024) 6.2 Salinity of groundwater increases to 45 ppt and depth to water table to 1 m. (Xeric flood plain salt marsh) 6.3 Total dissolved solids (measure of 'salinity') of river inflow exceeds 3500 mg/l (phytoplankton) in river. 6.4 Salinity in estuary exceeds 35 ppt (prevent hyper- salinity) (phytoplankton) 6.5 Salinity greater than 0 ppt occurs above 40 km upstream of the mouth (fish)	• Modification of volumetric of river inflow Quality of agricultural return flow
	System variables (pH, dissolved oxygen and transparency) not to exceed TPCs for biota (see above)	6.6 River inflow: 7 < pH > 8.5 DO <4 mg/l 6.7 Estuary: Secchi disc depth in Zones A and B <1.0 m during low flow (< $1 m^3 s^{-1}$) 7 < pH > 8.5 DO <4 mg/l	• Organic inputs from river and river banks
	Inorganic nutrient concentrations not to cause in exceedance of TPCs for macrophytes and microalgae (see above)	6.8 River inflow (< $1\ m^3 s^{-1}$ – summer): DIN >80 µg/l; DRP > 20 µg/l 6.9 River inflow (>$5\ m^3 \mathbf{s}^{-1}$ – winter): DIN >800 µg/l; DRP >60 µg/l 6.10 Estuary (lowflows < $1\ m^3 \mathbf{s}^{-1}$, summer): DIN >300 µg/l; DRP >100 µg/l in Zones A and B DIN >80 µg/l ; DRP >30 µg/l in Zones C and D 6.11 Estuary (high flows > $5\ m^3 s^{-1}$, winter): DIN >800 µg/l; DRP >60 µg/l in Zones A-D	• Agricultural return flows currently producing high DIN concentrations (>800 µg/l) during high flow (> $5\ m^3 s^{-1}$) (e.g. fertilizers) • Wastewater discharges from seafood processing currently introduce high DRP (> 150 µg/l) (probably also DIN) during summer (typical production period)

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
	Presence of toxic substances not to cause exceedence of TPCs for biota (see biotic components above)	6.12 Trace metals: Concentrations in estuary exceed target values as per *SA Water Quality Guidelines for coastal marine waters* (DWAF 1995). TPCs for trace metals in sediments still need to be established. 6.13 Pesticides/herbicides: Baseline studies to be undertaken before TPCs can be set.	• Inappropriate agricultural practices in catchment (e.g. pesticides/herbicides) • Runoff from urban development along the banks (e.g. trace metals)
7 Hydrodynamics	Maintain a flow regime to create the required habitat for birds, fish, macrophytes, microalgae and water quality	7.1 River inflow distribution patterns differ by more than 10% from that of Scenario 1 (i.e. Present day without BRD) 7.2 River inflow decreases to below 0.5 m^3s^{-1} at any time 7.3 River inflow below 1 m^3s^{-1} persist for longer than 4 months 7.4 Changes in tidal amplitude at 2 km, 11 km, ~40 km and 51 km of more than 10% from present state (2004)	• Modification to inflow at head of estuary (e.g. resulting from additional river water abstraction or dam developments)
8 Sediment dynamics and morphology	Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) so as not to exceed TPCs for biota (see above)	8.1 Long-term river inflow distribution patterns (flood components) differ by more than 10% (in terms of magnitude, timing and variability) from that of the present state (2004) 8.2 Suspended sediment concentration from river inflow deviates by more than 10% of the sediment load discharge relationship to be determined as part of baseline studies (present state 2004), i.e. from that of Present day without Berg	• Modification to inflow at head of estuary (e.g. resulting from additional dam developments)

COMPONENT	ECOLOGICAL SPECIFICATION/RESOURCE QUALITY OBJECTIVE	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
	Changes in sediment grain size distribution patterns not to cause exceedance of TPCs in benthic invertebrates (see above).	8.3 The median bed sediment diameter over/under exceeds by more than 10% the range (envelope) to be determined as part of baseline studies (present state). 8.4 Sand/mud distribution in all reaches change by more than 10% from present state range (envelope) (2004) 8.5 Changes in the channel bathymetry (location of channel banks (say ML contours) and deepest bottom line) in all reaches change by more than 10% from present state (2004) envelope.	• Modification to inflow at head of estuary, mainly in flood regime; • Modification to fluvial sediment input at head of estuary (due to catchment activities, e.g. farming practises leading to additional erosion and sediment load in river)

6 Resource Monitoring Programme

6.1 Baseline data requirements

The status of baseline data currently available for different abiotic and biotic components in the Berg River Estuary, after completion of the Berg River Baseline Monitoring Programme (BRBMP), is summarised in the following section. No new data were collected as part of this RDM study. Data available from the BRBMP are compared with the data requirements as specified for an Ecological Reserve determination on a comprehensive level (DWAF 2008).

6.1.1 Abiotic components

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Series of sediment core samples for the analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) taken every 3 years along the length of an estuary (200 m to 2 km intervals)	Grab samples were collected along the length of the estuary during the Berg River Baseline Monitoring Programme (2004)
Series of cross-section profiles (collected at about 500 to 1000 m intervals) taken every 3 years to quantify the sediment deposition rate in an estuary	40 cross sectional profiles were surveyed in for the BRBMP in 2003, 10 of which were repeated in 2004 and 2005
Set of sediment grab samples (at cross-section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) need to be taken immediately after a major flood	Only one set of grab samples were collected during the BRBMP.
Aerial photographs of estuary (earliest available year as well as most recent)	Detailed aerial photography covering the entire estuary was collected during the BRBMP (2003) for the purposes of compiling a DTM of the estuary
Measured river inflow data (gauging stations) at the head of the estuary over a 5-15 year period	No flow data are available for the Berg River Estuary owing to the lack of a gauging station below Misverstand dam. There are concerns regarding the reliability of the Misverstand flow data. This is crucial primary baseline data set for estuarine reserve determination. It is also required to recalibrate the simulated flow data because there are discrepancies between measured and simulated data at present. See Appendix B for more details on this
Continuous water level recordings near mouth of the estuary	Water level records are available at 3 positions in the estuary (2 km: Laaiplek G1H074, 11km: Kliphoek G1H024, 51 km: Jantjiesfontein G1H023). An additional gauging station is required at ~40 km from the mouth for improved calibration of numerical models due to the extreme length of the system and asymmetrical propagation of tidal waves up the system.
Water level recordings at about 5 locations along the length of the estuary over a spring and a neap tidal cycle (i.e. at least a 14 day period)	Water level records available for 5 stations from ~1990

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Longitudinal salinity and temperature profiles (*in situ*) collected over a spring and neap tide during high and low tide at: - end of low flow season (i.e. period of maximum seawater intrusion) - peak of high flow season (i.e. period of maximum flushing by river water)	Longitudinal salinity and temperature profiles were collected at quarterly intervals in 2003 2004 and 2005over spring low and high tide, and neap low and high tide as part of the BRBMP.
Water quality measurements (i.e. system variables and nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and a neap high tide: - end of low flow season - peak of high flow season	pH, turbidity, dissolved oxygen and inorganic nutrient data were collected at 22 stations up the length of the estuary in the estuary at quarterly intervals in 2005 coinciding with the salinity and temperature survey as part of the BRBMP.
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary	Sediment organic content samples were collected at selected sites as part of the invertebrate surveys in 2003 2004 and 2005 as part of the BRBMP. No data were collected on toxic substances (e.g. pesticides) in sediments of the estuary as part of the BRBMP due to the high costs of such analyses.
Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary	Electrical conductivity, pH, inorganic nutrient data were available from the DWA water quality station at Jantjiesfontein. However, no data on temperature, turbidity or dissolved oxygen are currently available for river inflow. Fish processing factories in the lower reaches of the estuary are a point source of inorganic nutrients to the estuary. Currently no quantitative data are available on such inputs.
Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater	No new data were collected as part of the BRBMP, but this data can be derived from published literature.

6.1.1.1 Biotic Components

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Phytoplankton: Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths. Cell counts of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae Measurements must be taken coinciding with typically high and low flow conditions	Data on phytoplankton and benthic microalgae were collected in August and November 2005 at 14 stations along the estuary as part of the BRBMP.
Benthic microalgae: Intertidal and subtidal benthic chlorophyll-a measurements Epipelic diatoms need to be collected for identification These measurements must to be taken coinciding with a typical high and low flow condition	

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the Reference condition (if available) Available orthophotographs	GIS maps were prepared from 2003 (present state) digital aerial photographs and 1937 (Reference condition).
Number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit	Vegetation surveys were conducted as part of the BRBMP
Permanent transects: - Measurements of percentage plant cover along an elevation gradient - Measurements of salinity, water level, sediment moisture content and turbidity	Permanent vegetation transects were established as part of the BRBMP
Collect a set of six benthic samples each consisting of five grabs. Collect two each from sand, mud and interface substrates. If possible, spread sites for each between upper and lower reaches of the estuary. One mud sample should be in an organically rich area. Species should be identified to the lowest taxon possible and densities (animal/m^2) must also be determined. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides.	Zooplankton, intertidal and subtidal benthos were collected at 10 sampling sites in summer and winter of 2003 2004 and 2005 as part of the BRBMP
Collect two sets of beam trawl samples (i.e. mud and sand). Lay two sets of five, baited prawn/crab traps overnight, one each in the upper and lower reaches of the estuary. Species should be identified to the lowest taxon possible and densities (animal/m^2) must also be determined. Survey as much shoreline as possible for signs of crabs and prawns and record observations. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides.	
Collect three zooplankton samples, at night, one each from the upper, middle and lower reaches of the estuary. Seasonal (i.e. quarterly) data sets for at least one year are required, preferably collected at spring tides.	
Sampling should be representative of small fish (seine nets) and large fish (gill nets). Sampling should be done in all four seasons for the full extent of the system (as far as tidal variation) to allow for predictive capabilities. In a larger estuary (>5 km) sampling can either be at fixed intervals (every 2 km) or have the upper, middle and lower reaches subdivided into at least a further three sections each. The samples should be representative of the different estuarine habitat types, e.g. Zostera beds, prawn beds, sand flats. At least one of the sample sets should be in the 0 to 1 ppt reach of the system.	Seine net and gill net data were collected from 40+ sites up the length of the estuary during summer and winter of 2003 and 2004 and quarterly in 2005 as part of the BRBMP

DATA REQUIRED FOR COMPREHENSIVE LEVEL	CURRENT STATUS
Undertake one full count of all water associated birds, covering as much of the estuarine area as possible. All birds should be identified to species level and the total number of each counted. Monthly data sets for at least one year are required. It this is not possible, a minimum of four summer months and one winter month will be required (decisions on the extent of effort required will depend largely on the size of the estuary, extent of shallows present, as well as extent of tidally exposed areas).	Bi-annual Coordinated Water bird Counts (CWAC) from the Avian Demography Unit at UCT are available for the Berg River Estuary, as well as additional monthly winter count collected during the BRBMP. Monthly counts for a full year were also available for the lower estuary in 1998.

6.1.2 Additional Baseline Data Requirements

The status of baseline studies currently available for the Berg River Estuary are summarised above. Detailed data are available for most abiotic and biotic components. However, there are a number of important data gaps that, if addressed, would improve the confidence of this and any future reserve determination studies. These are listed in Table 6.1.

Table 6.1 Additional baseline data required to increase confidence of Reserve and to set baseline for long-term monitoring in Berg River Estuary

ECOLOGICAL COMPONENT	MONITORING ACTION	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
MACROPHYTES	Monitoring of macrophyte cover along permanent transects used in Boucher and Jones (2007) in relation to flooding, sediment water content, water depth, sediment salinity, depth to groundwater and groundwater salinity.	Initially as frequently as possible to establish baseline conditions in response to floods and thereafter annually at the end of summer to capture extreme conditions.	Entire estuary
MICROALGAE	Phytoplankton: Conduct counts of dominant phytoplankton group.	Quarterly over 1 year, covering four seasons representative of temperature and average river inflow of that season.	Entire estuary (8 stns)
	Benthic microalgae: No additional baseline data are required.	-	-
WATER QUALITY	Baseline data set for pesticides/herbicides accumulation in sediments	Once, at end of low flow period also taking into consideration when spraying occurred	Focus on depositional areas
HYDRODYNAMIC	Water level recordings	Continuous	40 km: New Station
	Flow gauging	Continuous	Head of the estuary. See appendix B for more details on requirements for flow gauging

ECOLOGICAL COMPONENT	MONITORING ACTION	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
SEDIMENT DYNAMICS	Bathymetric survey: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but more detailed in the mouth (vertical accuracy better than 300 mm)	Once-off (to define present state)	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	Once off	Entire estuary - 200 m to 2 km intervals
	Series of sediment core (3 m) samples for the analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations) along the length of estuary (200 m to 2 km intervals). Recommend that isotope analysis in carried out on selected sample to determine the age of sediments	Once-off	Entire estuary 200 m to 2 km intervals
	Velocity cross section data during a neap and spring tide (the same period as the cross section profiles)	Once-off	200 m from mouth
	Daily sampling of suspended sediment (and organic matter) - Required to quantify actual sediment and organic yield and variability entering the estuary from the catchment. (Although sampling of organic input to the estuary from the catchment is not included in current estuarine protocol it is important and this means of quantifying it)	Daily for 5 years	DWA monitoring station at Jantjiesfontein

6.2 Long-term resource monitoring programme

The purpose of long-term monitoring programmes, in this context, is to assess (or audit) whether the Ecological Specifications (defined as part of the Ecological Reserve determination process) are being complied with after implementation of the Reserve. In addition, these programmes can also be used to improve and refine the Ecological Reserve measures (including the Resource Quality Objectives), in the longer-term through an iterative process (Taljaard *et al*. 2003).

Although baseline studies and long-term monitoring programmes have different purposes, it is extremely important that long-term monitoring programmes follow on from similarly structured baseline studies. In essence, the monitoring activities selected for the long-term monitoring programme should be derived from the monitoring activities conducted as part of the baseline studies (in this case the Berg River Baseline Monitoring Programme), but implemented on less intensive spatial and/or temporal scales (Taljaard *et al*. 2003).

Abiotic and biotic indicators considered relevant for a long-term monitoring programme on the Berg River Estuary is listed in Table 6.2. Should the components within the programme need to be prioritised prior to the completion of the baseline studies (when higher confidence will allow for a sensible prioritisation), it was concluded that the emphasis should be placed on monitoring of the abiotic ‘driver’ components.

Table 6.2 Long-term resource monitoring programme proposed for the Berg River Estuary after implementation of the Reserve

ECOLOGICAL COMPONENT	MONITORING ACTION	RELATED TPC (see Table 17)	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
BIRDS	Undertake counts of all water associated birds. All birds should be identified to species level and total number of each counted.	1.1 – 1.2	Winter and summer survey, yearly	Entire estuary
FISH	Conduct fish surveys using both seine and gill nets as primary gear.	2.1 – 2.6	Two years after implementation conduct summer and winter survey, followed by summer and winter survey every 3 years thereafter	Entire estuary (40+ stns)
INVERTEBRATES	Zooplankton: Collect quantitative samples using a flow meter after dark, preferably during neap tides (mid to high tide). Sampling to be done at mid- water level, i.e. not surface. (Include chlorophyll a measurements on benthic microalgae and water column chlorophyll as to establish feeding links)	3.1	Same as for fish	Entire estuary (10-15 stns)
	Benthic invertebrates: Collect (subtidal) samples using a Zabalocki-type Eckman grab sampler with 5-9 randomly placed grabs (replicates) at each station. Collect intertidal samples at spring low tide using core sampling.	3.2	Same as for fish	Entire estuary (10-15 stns)
	Macrocrustaceans: Collected quantitative samples during neap tides (mid to high tide), at the same stations used for zooplankton, using a benthic sled with flow meter.	3.3	Same as for fish	Entire estuary (10-15 stns)

ECOLOGICAL COMPONENT	MONITORING ACTION	RELATED TPC (see Table 17)	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
MACROPHYTES	Use aerial photographs to quantify area covered by different macrophyte habitats and produce a vegetation map. Conduct ground survey to: 1) verify areas covered by different macrophyte habitats 2) check the spread of alien vegetation, 3) check the spread of aquatic weeds (upper reaches) and macroalgae in the lower estuary reaches 4) check the extent of bare ground in the halophytic and xeric floodplain, depth to groundwater and groundwater salinity. 5) Check the distribution of reeds and sedges up the length of the estuary in relation to the longitudinal salinity gradient and the area covered by the sensitive sedge pan habitat. Measurements of macrophyte cover along permanent transects in relation to flooding, sediment water content, water depth, sediment salinity, depth to groundwater and groundwater salinity.	4.1 – 4.8	Annually	Entire estuary
MICROALGAE	Phytoplankton: Conduct water column chlorophyll a measurements and counts of dominant phytoplankton group.	5.1 – 5.3, 5.5	Same as for fish	Entire estuary (8 stns)
	Benthic microalgae: Conduct benthic chlorophyll a measurements	5.4	Same as for fish	Entire estuary (8 stns)
WATER QUALITY	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow	6.6, 6.7 and 6.8	At least monthly	At Jantjiesfontein
	Monitor inorganic nutrient inflow from agricultural return flow in upper reaches (e.g. bore hole sampling)	6.6, 6.7 and 6.8	At least monthly	3-5 stns along upper banks
	Collected longitudinal salinity and temperature profiles (*in situ*)	6.1 – 6.5	Continuous *in situ* salinity probe To be measured when biotic surveys require information for interpretation	At 11km: Kliphoek (G1H024), new gauge at 40 km
	Water quality measurements taken along the length of the estuary (surface and bottom samples) for salinity, pH, dissolved oxygen, suspended solids/turbidity and inorganic nutrients.	6.1 – 6.9		Entire estuary (10-15 stns)
	Baseline data set for pesticides/herbicides accumulation in sediments	6.13	Every 3 – 6 years	Focus on depositional areas

ECOLOGICAL COMPONENT	MONITORING ACTION	RELATED TPC (see Table 17)	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
HYDRODYNAMICS	Water level recordings	8.6	Continuous	2 km: Laaiplek (G1H074), 11km: Kliphoek (G1H024), 51 km: Jantjiesfontein G1H023) New gauge at 40 km
	Improved Flow gauging of lowflow (< 5 m^3s^{-1})	7.1 – 7.3 and 8.1	Continuous	Near Misverstand
	Aerial photographs of estuary (spring low tide)	4.1 – 4.4 and 8.5	Annually	Entire estuary
SEDIMENT DYNAMICS	Bathymetric survey: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but more detailed in the mouth (vertical accuracy better than 300 mm)	8.5	Every 3-6 years, depending on time scale of dominant sedimentation/erosion processes in an estuary, as well as after flood events.	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	8.3 - 8.4		Entire estuary
	Daily sampling of suspended sediment (and organic matter)	8.2	Daily	Sishen-Saldanha train bridge

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APPENDIX A

AVAILABLE INFORMATION AND DATA

Data availability on sediment dynamics, hydrodynamics and water quality

DATA REQUIRED	AVAILABILITY	COMMENT
Simulated monthly runoff data (at the head of the estuary) for present state, Reference conditions and the selected future runoff scenarios over a 50 to 70 year period	77-year data set provided by Aurecon Consulting Engineers	Very low confidence in the baseflows during low flow season
Simulated flood hydrographs for present state, Reference conditions and future runoff scenarios: • 1:1, 1:2, 1:5 floods (influencing aspects such as floodplain inundation) • 1:20, 1:50, 1:100, 1:200 year floods (long-term sediment dynamics, equilibrium, budget)	Not available at the Berg Estuary	
Aerial photographs of estuary (earliest available year as well as most recent)	2003, 1998, 1986, 1971, 1960, 1942, 1938	Need updated set
Continuous water level recordings near mouth of the estuary	2 km: Laaiplek (G1H074), 11km: Kliphoek (G1H024), 51 km: Jantjiesfontein G1H023	Need new station: 40 km
Mouth observations	N/A	
Longitudinal salinity and temperature profiles (in situ) collected over a spring and neap tide during high and low tide at: end of low flow season (i.e. period of maximum seawater intrusion) peak of high flow season (i.e. period of maximum flushing by river water)	Oct 1975; Aug 1976; Sep1989; Jan/Feb 1990; Aug 1995, Feb 1996; Mar 1996; Nov 2002 – Nov 2005 (13 sampling surveys)	Eagle and Bartlett 1984; Taljaard et al 1992; Slinger and Taljaard 1996; Slinger et al 1996; DWAF 2007
Water quality measurements (i.e. system variables, and nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at: • end of low flow season • peak of high flow season	Oct 1975; Aug 1976; Sep1989; Jan/Feb 1990; Aug 1995, Feb 1996; Mar 1996; Feb, May, Aug, Nov 2005	Eagle and Bartlett 1984; Taljaard et al 1992; Slinger and Taljaard 1996; Slinger et al 1996; Clark and Taljaard 2007)
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary.	No data	Measurements required for sediments up the length of the estuary
Water quality (e.g. system variables, nutrients and toxic substances)measurements on river water entering at the head of the estuary	1976 to 2007 (Jantjiesfontein); 1976-2008 (Die Brug, Misverstand)	Jantjiesfontein - G1H023Q01 Misverstand, Die Brug - G1H031Q01
Water quality (e.g. system variables, nutrients and toxic substances)measurements on near-shore seawater	Available data	DWAF 1995; DWAF 2007

Data availability on microalgae

DATA REQUIRED	AVAILABILITY	COMMENT
Chlorophyll *a* measurements taken at 5 stations at the surface, 0.5 m and 1 m depths. Cell counts of dominant phytoplankton groups i.e. flagellate, dinoflagellates, diatoms and blue-green algae. Measurements must be taken coinciding with typically high and low flow conditions.	Phytoplankton Chl-a: Early 1980's 1989/1990.	Branch and Day 1984; Slinger and Taljaard 1994.
Intertidal and subtidal benthic chlorophyll *a*	Benthic microalgal Chl-	Branch and Day 1984;

measurements taken at 5 stations (at least). Epipelic diatoms need to be collected for identification. These measurements must to be taken coinciding with a typical high and low flow condition (in temporarily closed estuaries measurements must include open as well as closed mouth conditions).	a: Early 1980's and 1992.	Adams and Bate (unpub. data).
Simultaneous measurements of flow, light, salinity, temperature, nutrients and substrate type (for benthic microalgae) need to be taken at the sampling stations during both the phytoplankton and benthic microalgal surveys.	Associated environmental variables: Early 1980's 1989/1990.	Branch and Day 1984; Slinger and Taljaard 1994.

Data availability on macrophytes

DATA REQUIRED	AVAILABILITY	COMMENT
Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the Reference condition (if available) Available orthophoto maps	Detailed vegetation map	DWAF (2007)
Number of macrophyte habitat types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit.	Mostly available	DWAF (2007)
Permanent transects: - Measurements of percentage plant cover along an elevation gradient	2003-2005 study period Transects (19) and cover data Transect data (6) McDowell (1993)	DWAF (2007) O'Callaghan 1994a, b
- Measurements of salinity, water level, sediment moisture content and turbidity	No sediment or groundwater salinity data	
Aerial photographs of the estuary (ideally 1:50 000 scale) reflecting the present state, as well as the Reference condition (if available) Available orthophoto maps	Available 2004	

Data availability on invertebrates

DATA REQUIRED	AVAILABILITY	COMMENT
Compile a detailed sediment distribution map of the estuary Obtain a detailed determination of the extent and distribution of shallows and tidally exposed substrates. During each survey, collect sediment samples for analysis of grain size [1] and organic content [2] at the six benthic sites.	Good spatial and temporal data (BRBMP). Branch and Day (1984)	No historical data pre-1984

DATA REQUIRED	AVAILABILITY	COMMENT
Surveys to determine salinity distribution pattern along the length of the estuary, as well as other system variables (e.g. temperature, pH and dissolved oxygen and turbidity) are required for different seasons and for different states of the tide [3] Seasonal (summer winter) physico-chemical data are also required for each of the six benthic sampling sites	Good spatial and temporal data (BRBMP). Taljaard et al 1992; Slinger and Taljaard 1996; Slinger et al 1996; Branch and Grindley (1984); Grindley (1981).	No historical data pre-1992
Collect a set of six benthic samples each consisting of five grabs. Collect two each from sand, mud and interface substrates. If possible, spread sites for each between upper and lower reaches of the estuary. One mud sample should be in an organically rich area. Species should be identified to the lowest taxon possible and densities (animal/m^2) must be determined. Seasonal (summer winter) data sets for at least one year are required, preferably collected at spring tides.	Good spatial and temporal data Monitoring programme). Branch and Day (1984) Bickerton 1990's unpublished report; Kaletjta (1992 1993); Kalejta and Hockey (1991 1994).	No historical data pre-1984
Collect two sets of beam trawl samples (i.e. mud and sand). Lay two sets of five, baited prawn/crab traps overnight, one each in the upper and lower reaches of the estuary. Species should be identified to the lowest taxon possible and densities (animal/m^2) must be determined. Survey as much shoreline as possible for signs of crabs and prawns and record observations. Seasonal (summer winter) data sets for at least one year are required, preferably collected at spring tides.	No data	
Collect three zooplankton samples, at night, one each from the upper, middle and lower reaches of the estuary. Seasonal (summer winter) data sets for at least one year are required, preferably collected at spring tides.	Good spatial and temporal data (BRBMP).	No historical data pre-2003

Data availability on fish

DATA REQUIRED	AVAILABILITY	COMMENT
In a small estuary (<5km) collect at minimum three sets of samples from the lower, middle and upper reaches of the estuary. The samples should be representative of the different estuarine habitat types, e.g. Zostera beds, prawn beds, sand flats. At least one of the sample sets need to be in the 0 to 10 ppt reach of the estuary. Sampling should be representative of small fish (seine nets) and large fish (gill nets). In a larger estuary (>5km) sampling can either be at fixed intervals (every 2km) or have the upper, middle and lower reaches subdivided into at least a further three sections each. The samples should be representative of the different estuarine habitat types, e.g. Zostera beds, prawn beds, sand flats. At least one of the sample sets should be in the 0 to 1 ppt reach of the system. Sampling should be representative of small fish (seine nets) and large fish (gill nets). Sampling should be done during both the low and the high flow season for the full extent of the system (as far as tidal variation) to allow for predictive capabilities.	Good spatial and temporal data available from 1992 onwards - Bennett (1993), Clark *et al.* (2009), BRBMP	No historical data prior to 1992

Data availability on birds

DATA REQUIRED	AVAILABILITY	COMMENT
Undertake one full count of all water associated birds, covering as much of the estuarine area as possible. All birds should be identified to species level and the total number of each counted. Seasonal (summer winter) data sets for at least one year are required. It this is not possible, a minimum of four summer months and one winter month will be required (decisions on the extent of effort required will depend largely on the size of the estuary, extent of shallows present, as well as extent of tidally exposed areas).	Mid-summer and mid-winter CWAC count data for the period 1994 to present. Monthly count data for 2001 (Murison and Hockey 2002). Spring (Sep, Oct, Nov) count data for 2005 (DWAF 2007). Earlier counts are available for the lower estuary (Velasquez et al. 1998).	Count data are all broken down into 13 counting areas of the estuary. Information is very detailed, but is relatively recent. Spring count data are in short supply.

APPENDIX B:
MEASUREMENT OF STREAMFLOWS IN THE LOWER BERG DOWNSTREAM OF MISVERSTAND

Measurement of streamflows in the Lower Berg downstream of Misverstand

Anton Sparks, Mike Shand and Karl Reinecke

Purpose

The purpose of this fieldtrip, undertaken on the 5th February 2010, was to document the current operation of the system and to locate a suitable streamflow measuring site for the summer lowflows close to the estuary.

Current operation

Releases are made from the Misverstand Dam to supply irrigators located downstream. Since 2006, the water releases from Misverstand have/had been measured at gauge G1H075. Currently, Henk van der Westhuizen from the Morester farm measures the level of the water using a staff gauge plate located near one of his pump stations and when the water level drops below about 700mm he asks for additional releases from the Misverstand Dam (see Addendum Figure 2). According to some irrigators, the pumps from Broodkraal are switched on in summer and have a significant effect on streamflows. Their capacity is about $0.9m^3s^{-1}$. Broodkraal only has a winter water right but apparently, their pumps are sometimes used in summer when the water in the Broodkraal Dam becomes too saline for irrigation.

The unused streamflows bypassing the irrigators and entering the estuary are not measured which makes it impossible to establish whether the inflows to the estuary are insufficient / excessive and to compare the ecological response of the estuary with the water actually received.

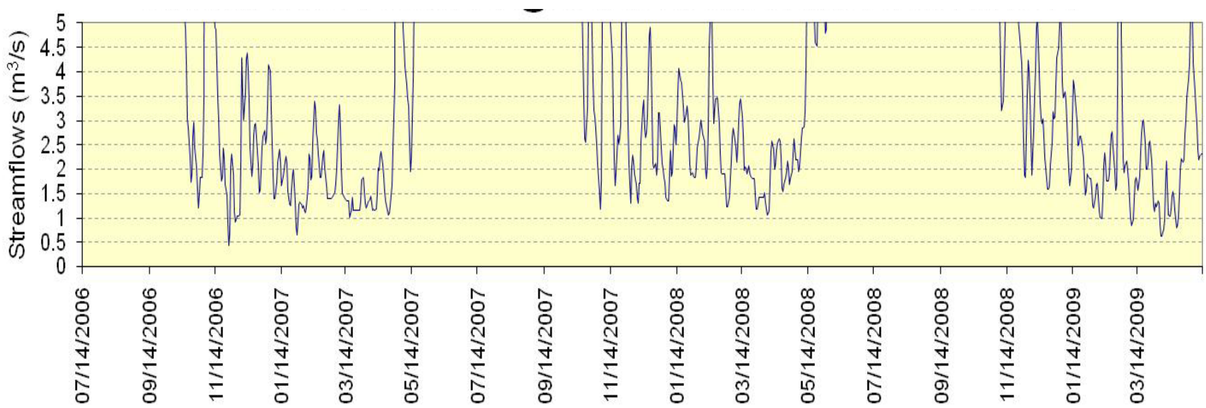
At the time of the fieldtrip the level at Henk van de Westhuizen's gauge plate was relatively high, namely 1.0m and the streamflows at Klipheuwel and at Klipbank / Doornboom were measured by water meter gauging to be about $1.5m^3s^{-1}$ (see Addendum Table 1). The releases over the preceding period from 3rd to 5th February from Misverstand were recorded at G1H075 to be about 2.6 - $2.7m^3s^{-1}$ and therefore about $1.2m^3s^{-1}$ was being abstracted between Misverstand and Doornboom situated immediately upstream of the estuary as shown on Addendum Figure 3. According to the local irrigators about 138 ha are currently irrigated downstream of Doornboom (see Addendum Figure 4), which would translate to a water demand of about 0.12 m^3s^{-1} [138ha x 8000 m^3/ha/season x 1/(100days*24*60*60secs/season = 0.12 m^3s^{-1}]. This means that about $1.3m^3s^{-1}$ should be entering the estuary. The summer releases from Misverstand at G1H075 appear to vary between 1 and 3 m^3s^{-1} (see Addendum Figure 1).

Addendum Table 1 Determination of streamflows at Klipheuwel and Klipbank / Doornboom

Station	Horiz dist (m)	Water depth (m)	Velocity (mS^{-1})	Sectional Flow (m^3S^{-1})	Total Flow (m^3S^{-1})	Temperature (degrees Centigrade)	TDS (mS/cm)
Klipheuwel	12.7	0.00	0.00		1.49007	25.8	489
	12.0	0.34	0.16	0.00952			
	11.0	0.44	0.39	0.10725			
	10.0	0.45	0.37	0.16910			
	9.0	0.43	0.33	0.15400			
	8.0	0.63	0.30	0.16695			
	7.0	0.67	0.25	0.17875			
	6.0	0.70	0.32	0.19523			
	5.0	0.68	0.31	0.21735			
	4.0	0.73	0.26	0.20093			
	3.0	0.67	0.00	0.09100			
	2.0	0.51	0.00	0.00000			
	1.5	0.00	0.00	0.00000			
Klipbank / Doornboom	8.1	0.00	0.00		1.47205	27.7	652
	8.0	0.03	0.00	0.00000			
	7.5	0.20	0.00	0.00000			
	7.0	0.38	0.22	0.01595			
	6.5	0.58	0.46	0.08160			
	6.0	0.62	0.49	0.14250			
	5.5	0.62	0.60	0.16895			
	5.0	0.62	0.59	0.18445			
	4.5	0.62	0.54	0.17515			
	4.0	0.58	0.50	0.15600			
	3.5	0.58	0.49	0.14355			
	3.0	0.53	0.48	0.13459			
	2.5	0.49	0.50	0.12495			
	2.0	0.48	0.27	0.09336			
	1.5	0.40	0.12	0.04290			
	1.0	0.14	0.00	0.00810			
	0.7	0.00	0.00	0.00000			

It was beyond the terms of reference to reconcile this abstraction with the scheduled areas. However, if the abstraction downstream were a constant 1.3 m^3s^{-1} then the flow released to the estuary would vary between 0 and 1.7m^3s^{-1} with an average of about 0.8m^3s^{-1}, before taking account of any additional and possibly illegal abstraction by Broodkraal which would reduce the streamflows reaching the estuary.

Addendum Figure 2 Morester Pump station



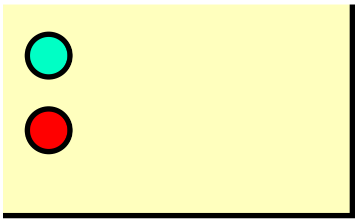
Addendum Figure 3 Streamflows measured at G1H075 m^3s^{-1} of Misverstand Dam

Addendum Figure 4 Possible allocations located downstream of Doornboom / Klipbank crossing

Streamflow Gauging Sites

Four potential sites to gauge summer flows were visited as shown in Addendum Figure 5. The photographs taken at these sites are included as Addendum Figure 6 to Addendum Figure 10.

The most downstream site visited, Klipbank/Doornboom could probably be used for low flow measurement during summer. As the name implies, the left bank (when facing downstream) appears to be located on a "klipbank" (see Addendum Figure 10) and there is a slight fall downstream of the causeway (see Addendum Figure 9). There could be a problem with siltation on the left half of the causeway though it appears as though the left half located on the "Klipbank" is higher than the right half and will normally be dry in summer. The 18 or so larger pipes on the right-hand side appear to remain clear of silt. A level recorder could be placed upstream of the causeway and streamflow gaugings should be used to derive a rating table. The position of the silt upstream of the causeway should be photographed at the start of summer and streamflow gauging should be undertaken if necessary to check the validity of current rating table. Discussions with the local irrigators and the CSIR confirmed that site is beyond the tidal reach during summer, though during high flows in winter there may be some backwater effect.



Addendum Figure 5 Location of river crossings

Addendum Figure 6 Looking upstream from Klipheuwel. Section used for stream flow measurement is shown in yellow).

Addendum Figure 7 Moravia / Morester crossing from upstream (left) and downstream (right)

Addendum Figure 8 Tuinhof / Breekmeur from left bank

Addendum Figure 9 Klipbank / Doornboom looking upstream towards crossing

Addendum Figure 10 **Site used for stream flow measurement downstream of the Klipbank / Doornboom crossing. Section used for stream flow measurement is shown in yellow).**

Recommendations

The construction of a low flow measuring station in the Lower Berg is necessary to improve the management of the system. This might be achieved by installing an automatic water level recorder at Klipbank / Doornboom and to rate the section using stream flow measurements. The rating would need to be checked at the start of summer in case the sandbanks had shifted and changed the stream flow characteristics. The level recorder should be linked into DWA'S real-time SCADA system to assist with the management of releases from Voëlvlei Dam and Misverstand Weir.

A meeting should be held between DWA and the irrigators to identify any illegal summer abstractions. Releases from Misverstand should be compared with the allocations downstream of the dam, including the estuary.

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