P H 000/00/1102

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

DIRECTORATE OF WATER RESOURCES PLANNING

BREEDE RIVER BASIN STUDY

INTERMEDIATE DETERMINATION OF RESOURCE DIRECTED MEASURES FOR THE BREEDE RIVER ESTUARY

NINHAM SHAND CONSULTING SERVICES

MBB

JAKOET & ASSOCIATES

DEPARTMENT OF
WATER AFFAIRS AND FORESTRY

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INTERMEDIATE DETERMINATION OF
RESOURCE DIRECTED MEASURES
FOR THE BREEDE RIVER ESTUARY

Final

MAY 2003

CSIR : Ematek
P O Box 320
Stellenbosch
7600
(021) 888 2495
phuizing@csir.co.za

TITLE	:	**Intermediate Determination of Resource Directed Measures for the Breede River Estuary**
AUTHOR	:	**S Taljaard**
PROJECT NAME	:	**Breede River Basin Study**
PROJECT NO.	:	**8718**
REPORT STATUS	:	**Final**
DWAF REPORT NO.	:	**PH 00/00/1102**
DATE	:	**Second Draft : March 2002** **Final: May 2003**

Approved for CSIR

....

P HUIZINGA

Approved for MBB Consulting Engineers, Jakoet & Associates, Ninham Shand (Pty) Ltd in association

....

M J SHAND
Study Leader

DEPARTMENT OF WATER AFFAIRS AND FORESTRY
Directorate : Water Resources Planning

Approved for Department of Water Affairs and Forestry

....

F A STOFFBERG
Chief Engineer : Water Resources Planning South

....

J A VAN ROOYEN
Director : Water Resources Planning

This project was co-ordinated by:

Mr Piet Huizinga

This report was compiled by:

Ms Susan Taljaard

Specialist inputs were provided by:

Mr Piet Huizinga (Physical dynamics)
Ms Lara van Niekerk (Physical dynamics)
Ms Susan Taljaard (Water quality)
Prof Guy Bate (Microalgae)
Dr Janine Adams (Macrophytes)
Prof Tris Wooldridge (Invertebrates)
Mr Steve Lamberth (Fish)
Dr Jane Turpie (Birds)

This report was submitted to:

Ninham Shand Consulting Engineers

This report will be printed and published by:

Ninham Shand Consulting Engineers (on behalf of the Department of Water Affairs and Forestry)

CSIR Report ENV-S-C 2002-020/A

This report is to be referred to in bibliographies as :

Department of Water Affairs and Forestry, South Africa. 2003. *Intermediate Determination of Resource Directed Measures for the Breede River Estuary*. Prepared by S Taljaard of CSIR as part of the Breede River Basin Study. DWAF Report No. P H 00/00/1102

BREEDE RIVER BASIN STUDY

INTERMEDIATE DETERMINATION OF RESOURCE DIRECTED MEASURES FOR THE BREEDE RIVER ESTUARY

EXECUTIVE SUMMARY

RESERVE DETERMINATIONS UNDERTAKEN FOR THE BREEDE RIVER BASIN STUDY

Environmental sustainability forms one of the cornerstones of the National Water Act. In recognition of this, and to provide the information that would be required to ascertain the availability of water at particular locations in the Breede River catchments and to set a Preliminary Reserve in the Breede Water Management Area, a considerable portion of Study resources was directed toward determining the ecological water requirements of the aquatic ecosystems in the catchments of the Breede River.

Reserve determinations were carried out for the following components of the Reserve :

- Groundwater, documented in Report PH 00/00/1202 *Groundwater Reserve Determination.*
- The Papenkuils Wetland, documented in Report PH 00/00/1402 *Papenkuils Wetland Intermediate (Ecological) Reserve Determination (Low Confidence).*
- Riverine water quantity, documented in Report PH 00/00/1302 *Ecological Reserve Determination for Six Representative Sites using the Building Block Methodology*.
- Riverine water quality, documented in Reports PH 00/00/3402 *Ecological Reserve Determination (Water Quality)*, and PH 00/00/3602 *Ecological Reserve Determination (Water Quality) – Recalculation of the Water Quality Reserve*.
- The Breede River Estuary (this report).

The geographical spread and confidence levels of the determinations were planned to deliver, as far as present knowledge and available resources permitted, Reserve determinations commensurate with the management needs of the Breede River catchments. The Study findings represent scientific estimates of the ecological water requirements of the aquatic ecosystems in the Breede River catchments. The socio-economic implications of the implementation of Reserves at the recommended levels (Ecological Management Categories) should therefore be carefully considered prior to the setting of a preliminary Reserve. Before a comprehensive Reserve can be set, a separate stakeholder consultation process must first take place.

Numerous interrelations exist between the different components of the Reserve in the Breede River Basin. These had to be taken into account to provide an accurate reflection of current and future water availability. This information will also be required when setting a Preliminary Reserve, and to manage the system accordingly. Relatively simple integration procedures were therefore developed during the course of the Study, and the findings of this work are reported on in the *Main Report* of the Study (Report PH 00/00/3102).

Very little experience has thus far been gained in the implementation and management of Reserves in South Africa, and little is known about the effectiveness of the ecological water requirements (EWRs) in achieving the recommended ecological management categories. In recognition of the limited experience available, further study work was approved to explore the implications that the system-wide implementation of recommended EWRs may have on water availability in the Basin. This work is also documented in the *Main Report*.

RESERVE DETERMINATION FOR THE BREEDE RIVER ESTUARY

Location

The Breede River Estuary stretches roughly from 10 km north-west of Malgas to the town of Witsand at the mouth of the Breede River. Tidal influence extends beyond the pont at Malgas to approximately 52 km upstream of the mouth. The estuary enters the sea through a permanently open mouth located at the southern end of an extensive sand spit. The channel of the estuary is incised in the coastal plain and depths of 3 to 6 m are common over the first 28 km. The mouth of the Breede River Estuary is permanently open because of the volumes of tidal exchanges and the still relatively high run-off of the system. It is considered highly unlikely that the mouth will close under present day conditions.

Present Condition

The Breede River Estuary is the largest of the few permanently open estuaries on the South African coast. The large freshwater input creates a salinity gradient in the estuary along which different plants and animals are distributed, leading to a high biodiversity. Although the fresh water entering the estuary is only of "average" water quality, the ecological condition of the estuary is presently classified as "good", and is associated with a Present Status Category of B (largely natural, with few modifications).

Ecological importance is an expression of the value of a specific estuary to maintaining ecological diversity and functioning of estuarine systems on local and wider scales. The Estuarine Importance Score for the Breede River Estuary, based on its Present State, is considered to be 'highly important'. This rating is derived from an assessment of the following characteristics (arranged in order of contribution to the overall rating of the Breede River Estuary):

- Functional importance
- Habitat diversity
- Biodiversity importance
- Estuary size
- Zonal type rarity

Recommended Ecological Reserve Category and Ecological Flow Requirements

According to the protocol for estuarine Reserve determination (Appendices E3 and E4 of the *Resource Directed Measures for Protection of Water Resources: Estuarine Ecosystem Component*, DWAF 1999), the Ecological Reserve Category should be :

- Because the Breede River Estuary is highly important, the recommended Ecological Reserve Category should be elevated to one category above the Present Status Category, which implies a Category A or, if not possible,
- Best attainable state, with Category B the minimum requirement.

The largest factor that has contributed to the change from an un-impacted system to its present condition is the large reduction in inflows due to upstream development. A large re-allocation of water, already abstracted in the catchment, would therefore be required to improve the present condition of the Estuary to match its ecological importance. As it was assumed unlikely that large volumes of water could be re-allocated to the estuary and being within the rules of the protocol (i.e. minimum score to be allocated to a 'highly important' estuary is Category B), the specialist team recommended a Category B ERC for the Breede River Estuary.

The methodology for estuarine Reserve determination is based on assessments of the effects that a range of modified runoff sequences could have on the biotic and abiotic components of the estuarine ecosystem. The Reserve is a runoff sequence that allows the maximum benefit for upstream users while not reducing the Status Category below that specified.

A 'Limited Future' scenario, which provided a mean annual inflow to the estuary of 954 million m^3/a, was considered as meeting the conditions for the recommended ERC of B. A 'Moderate Future' scenario, which reduced inflow to the estuary to 863 million m^3/a, and two 'High Future' scenarios (with inflows of 772 million m^3/a and 649 million m^3/a) were found to impact on the estuary in a way that would reduce the classification to C. On this basis, the Reserve for Water Quantity for an ERC of B was determined as 954 million m^3/a (53.4% of natural MAR), and 649 million m^3/a for an ERC of C (36.4% of natural MAR).

At the workshop, the specialist team concluded that the largest factor that contributed to the change in the state of the Breede River Estuary from the Reference Condition to its Present State (putting it in a Category B) was the large reduction in river inflow. Therefore, to improve the Breede River Estuary's ERC from a Category B to a Category A, a large amount of water, already abstracted in the catchment by dams, will have to be re-allocated to the estuary. It was assumed unlikely that large volumes of water could be re-allocated to the estuary such that would elevate the ERC to a Category A.

The implications of the recommended Reserve for future water availability in the Breede River catchments are described in the *Main Report* (Report PH 00/00/3102) of the study. Estimates of the yields available from new developments after provision of ecological water requirements have shown that previous assessments of water resources development potential in the Breede Basin will probably have to be downscaled dramatically. Reserve requirements have become the critical aspect in terms of water availability, and will greatly affect the further availability of water from the Breede River.

In terms of total system yield, it was found that the EWRs of the lower reaches of the Breede River would limit the basin-wide amount of surplus water that would be available for further abstraction and use during the dry summer months, while the requirements of the Estuary limit the quantities of water that are available for storage during some of the high runoff winter months. Unlike many other developed coastal systems, the EWRs of the Lower Breede River and its Estuary are of the same order of magnitude. Selection of a lower ecological Reserve category for only one of these two components would therefore not significantly increase the yield potential of the system.

Reserve for Water Quality

It is considered that the prevailing water quality of inflows to the head of the estuary (as measured over the period 1994 to 1999) is unlikely to deteriorate the ERC of the estuary beyond a Category B. Using the precautionary approach, the Reserve for Water Quality at the head of the estuary, is therefore estimated as the median water quality concentrations measured at the Swellendam Monitoring Station (H7H006Q01) over the period 1994 to 1999.

Resource Monitoring Programme

To improve the confidence of this Intermediate Reserve determination of the Breede River Estuary, the following monitoring surveys were recommended:

Abiotic components:

1. Atypical rain patterns during the study period, prevented specialists from measuring the extreme extent of saline intrusion typically encountered during low flow periods in the Breede River Estuary. To improve confidence, particularly for the low flow period, salinity distribution patterns, as well as water quality conditions at such times still need to be monitored.

2. The levels of water quality variables, such as suspended solids and toxic substances (e.g. pesticides and herbicides) in inflowing river water need to be established for the Present State.

3. Reference Conditions for water quality variables need to be derived by specialists conducting the river component.

Biotic Components:

1. To improve confidence of the predictions that need to be made in Reserve determinations requires more data on the relationships between different biotic and abiotic variables. This requires in-depth research – a cross-sectional analysis across different states or systems to determine these relationships. Some of these issues are being addressed in a Water Research Commission Project aimed at improving information requirements and understanding in terms of determination of Reserves.

2. The utilisation of microphytobenthos need to be better established, i.e. "Who eats what" is not well understood.

3. Plant habitat monitoring: Area of intertidal flats should distinguish *Zostera* bed, and area of unvegetated sandflat versus mudflat.

4. The extent to which macrophytes in the Breede River Estuary rely on groundwater needs to be established.

5. Phytomicrobenthos species and biomass assays need to be conducted to determine the extent of species change with seasons.

6. Monitoring the distribution of fringing macrophytes along the banks of the estuary, particularly *Phragmites australis.* If average salinity increases in an upstream direction, dieback of macrophytes may occur as a consequence. Sampling should be undertaken during the wet and dry seasons.

7. Monitor distribution and abundance (hole counts) of intertidal macrobenthos, particularly large burrowing forms. If average salinity increases in an upstream direction, more suitable conditions provided by higher salinity values may allow colonisation of new intertidal banks by some species. At the same time, subsurface sediment samples should be collected at high, mid and low tide levels for particle size analysis.

8. For fish, four sampling exercises at 25 sites from the mouth to 40 km upstream during spring, summer, autumn and winter need to be undertaken. At least one sampling exercise needs to be done over a complete weather cycle or 7 days to get some idea of the short-term responses of fish to changes in flow.

9. To improve confidence and to evaluate performance in the long term, the following would be required for birds: all water birds need to be counted in the different estuarine sections described in this report during late summer (Feb-Mar) (essential), midwinter (Jun-Jul) (important), and spring (Sep) (could be important) at spring low tides. Also, birds in the lower estuary should be counted in one low tide period, the upper estuary in one day (the following day at low tide), with the count being done on days of low human disturbance.

BREEDE RIVER BASIN STUDY

INTERMEDIATE DETERMINATION OF RESOURCE DIRECTED MEASURES FOR THE BREEDE RIVER ESTUARY

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INTERMEDIATE DETERMINATION OF RESOURCE DIRECTED MEASURES FOR THE BREEDE RIVER ESTUARY

INTRODUCTION

BACKGROUND

Further development of the water resources of the Breede River system are being considered by the Department of Water Affairs and Forestry (DWAF), i.e. further abstraction of water from the Breede River and its main tributary the Riviersonderend. This includes additional schemes for irrigation of agricultural land and possibly also the transfer of water to the Cape Town metropolitan area. Detailed investigations on the viability of the developments are being undertaken by Ninham Shand Consulting Engineers and MBB Consulting Engineers as main consultants to DWAF. The investigations on the influence of river inflow on the environmental aspects of the Breede River Estuary was co-ordinated by the CSIR, acting as sub-consultant.

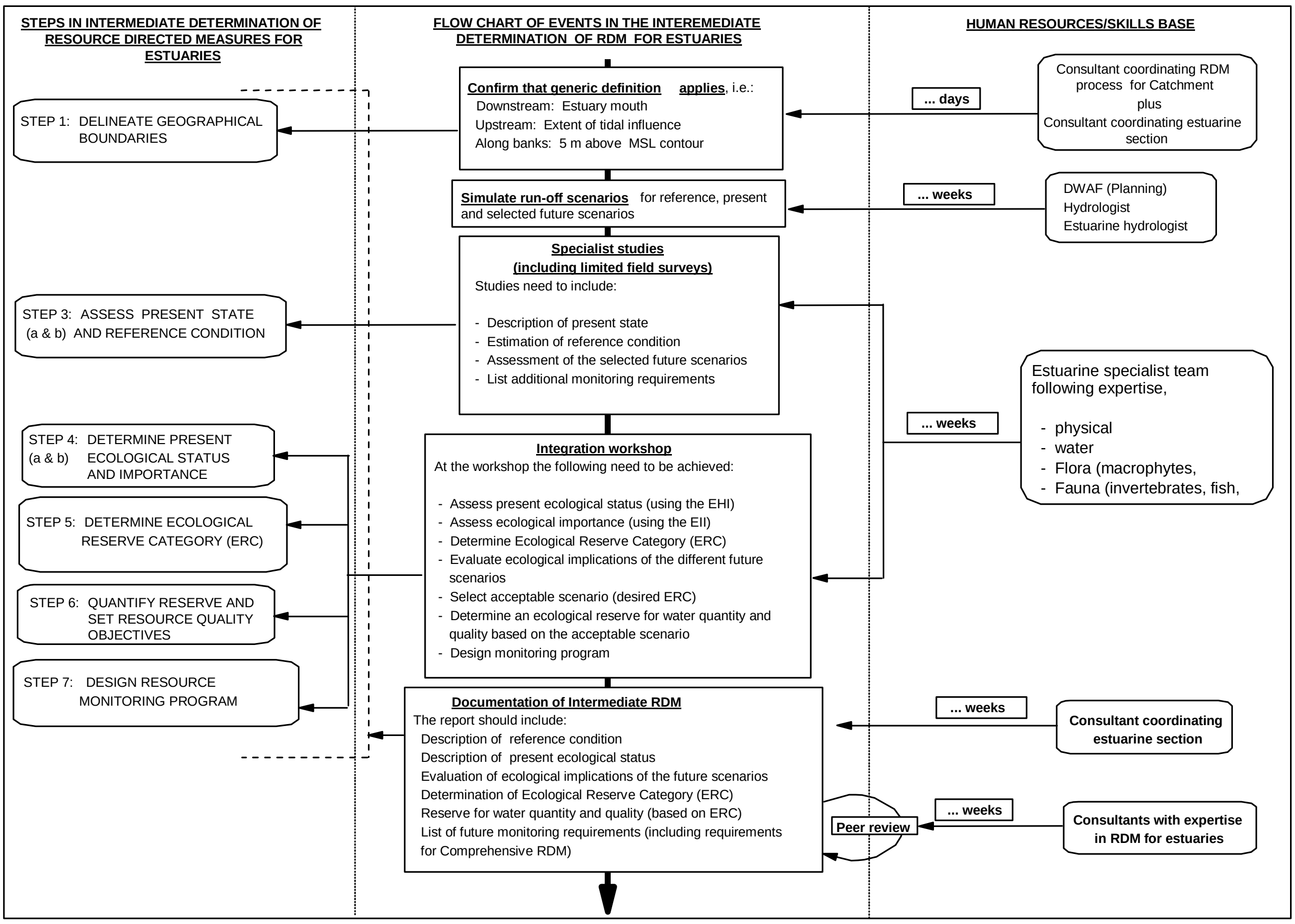
The specialist team appointed for this project was as follows:

TEAM MEMBER	ROLE/EXPERTISE	CONTACT DETAILS
Mr Piet Huizinga	Project co-ordination	CSIR, Stellenbosch phuizing@csir.co.za
Susan Taljaard	Preparation of Intermediate RDM Report	CSIR, Stellenbosch staljaar@csir.co.za
Piet Huizinga	Physical dynamics (including hydrodynamics and sediment dynamics)	CSIR, Stellenbosch phuizing@csir.co.za
Lara van Niekerk		CSIR, Stellenbosch lvnieker@csir.zo.za
Ms Susan Taljaard	Water quality	Department of Zoology, UPE zladdb@zoo.upe.ac.za
Prof Guy Bate	Microalgae	DEM, Port Elizabeth btagcb@mweb.co.za or btagcb@upe.co.za
Dr Janine Adams	Macrophytes	Department of Botany, UPE btajba@upe.ac.za
Prof Tris Wooldridge	Invertebrates	Department of Zoology, UPE zlathw@zoo.upe.ac.za
Mr Steve Lamberth	Fish	Marine and Coastal Management, DEAT lamberth@sfri.wcape.gov.za
Dr Jane Turpie	Birds	Private Consultant jturpie@botzoo.uct.ac.za

In addition to the specialist team listed above, the following people also attended the RDM Workshop held in Stellenbosch on 25 and 26 June 2001:

TEAM MEMBER	ROLE	CONTACT DETAILS
Mr Mike Luger	Representative of consultants for the Breede River Basin Study	Ninham Shand Consulting Engineers, Cape Town mluger@shands.co.za
Ms Barbara Weston	DWAF representative	Social and Environmental Services, DWAF ded@dwaf.pwv.gov.za
Ms Mpume Mthembu	DWAF representative	Social and Environmental Services, DWAF deq@dwaf.pwv.gov.za
Ms Toni Belcher	DWAF representative	Western Cape Regional Office, DWAF BelcheA@dwaf-wcp.wcape.gov.za
Ms Tohvo Ndiitwani	DWAF representative	Western Cape Regional Office, DWAF NdiitwT@dwaf-wcp.wcape.gov.za
Dr Dirk van Driel	Observer	Scientific Services Branch, City of Cape Town dvandriel@cmc.gov.za
Mr Tommy Bornman	Observer	Department of Botany, UPE btbtgb@upe.ac.za

A flow chart of events for the Intermediate determination of RDM as proposed in *Resource Directed Measures for Protection of Water Resources: Estuarine Ecosystem Component* (www-dwaf.pwv.gov.za/idwaf/Documents) is provided below:



For the Intermediate Determination of RDM for the Breede River Estuary the following process was followed:

1. Field studies were undertaken by specialists

2. Specialists prepared draft reports for each of the abiotic and biotic components that included:

   - Description of natural conditions
   - Description of Present State
   - Identification of changes that occurred from the natural to present
   - Identification of changes that may occur as a result of four future development scenarios.

   (Although no additional funding was available to specialists to convert the original budgeted EFR study into the format required for Intermediate RDM determination, specialists were requested to, as far as possible, present their information in the required format proposed in the RDM methodology for estuaries).

3. A 2-day workshop was held in Stellenbosch. The workshop agenda was as follows:

   - Presentation of individual specialist reports
   - Discussion on the Present State and Reference Condition of the Estuary (Step 3)
   - Determination of Present Status category using the Estuarine health index (Step 4a)
   - Determination of Ecological Importance (Step 4b)
   - Set Ecological Reserve Category (Step 5)
   - Set Reserve for Water Quantity and Water Quality (Step 6a and b)
   - Preliminary discussion on Resource Quality Objectives for the Breede River Estuary (Step 6c)
   - Recommendation on future monitoring requirements (Step 7)

4. A draft Intermediate RDM Report for the Breede River Estuary was produced and circulated to the specialists for comments and inclusion of additional information.

5. Comments from the Department of Water Affairs and Forestry and Ninham Shand Consulting Engineers were included in the final Intermediate RDM Report on the Breede River Estuary.

ASSUMPTIONS AND LIMITATIONS

The following assumptions and limitations need to be taken into account for this study:

a. As decided at an RDM Integration Meeting, held in Pretoria on 19 July 2001, the term Ecological Management Class (EMC) has been changed to Ecological Reserve Category (ERC).

b. The study was initially planned as an Estuarine Freshwater Requirement study (EFR) and not an Intermediate Determination of Resource Directed Measures (RDM). The initial study, therefore, was aimed at providing only an estimate of the freshwater requirements of the estuary (as a percentage of MAR), and did not include aspects required under the RDM methodology, such as the allocation of an Ecological Reserve Category (ERC), setting the Reserve for Water Quality or setting of the Resource Quality Objectives (RQO). The DWAF, however, did provide additional funding to extend the workshop from a one-day to a two-day workshop.

c. Because this project originally started off as an EFR study, this report has not been peer reviewed, as is required in the protocol for the Intermediate determination of Resource Directed Measures for estuaries (EFR studies did not require peer review). Comments on this RDM Report, however, were received from Ninham Shand Consulting Engineers (Colin Carter) and these are attached as Appendix I.

d. This was the third time that the Intermediate level of *Resource Directed Measures for Protection of Water Resources: Estuarine Ecosystem Component,* as developed by DWAF, has been applied. This study thus also had a secondary aim of pilot testing the intermediate RDM methodology for estuaries (proposed revisions to the methodology is attached as Appendix B).

e. For the purposes of this study, the River-Estuary-Interface (REI) zone, i.e. the productive zone at the interface between seawater and freshwater, is defined as the sector of the estuary where salinities are less than 10 ppt. However, in subsequent studies it became apparent that the REI zone may be different for the different biotic components and the definition, therefore, may requires further refinement in future.

f. Criteria for confidence limits attached to statements <u>throughout this report</u> are as follows:

LIMIT	DEGREE OF CONFIDENCE
40%	If no data were available for the Breede River Estuary or similar estuaries, i.e. low confidence
60%	If limited data were available for the Breede River estuary or other similar estuaries, i.e. medium confidence
80%	If sufficient data were available for the Breede River Estuary on a particular issue, i.e. high confidence

g. This study provides details on the recommended <u>Ecological Reserve</u>, i.e. the water needs of the aquatic ecosystem. A comprehensive determination of RDM would need to take into account a public participation process to determine the Management Class which could effect the final Ecological Reserve. Thereafter, other user requirements (in terms of water quality) would be incorporated to establish the Resource Quality Objectives. Therefore, specific needs relating to other water uses, such as the water quality requirements for recreational use (e.g. *Eschericia coli* levels) were not included in this Intermediate determination of RDM.

h. The Determination of the Reserve for Water Quantity for Ecological Reserve Categories (ERC) higher and lower than the recommended ERC was not part of the original Terms of Reference for this project. This was added later and has therefore not been reviewed by the entire specialist team, as required by the Protocol.

i. The Reserve for Water Quantity and Water Quality is set at the head of the Breede River Estuary (about 52 km upstream of the mouth). However, the closest gauging station (H7H006-A01) and water quality monitoring station (H7H006Q01) is at Swellendam (about 102 km upstream of the mouth). The Buffeljags tributary enters the river downstream of this point and, as a result, input from its catchment also needs to be included (gauging station at Eenzaamheids Buffeljags Dam Station – H7H013-A01). For compliance monitoring, after implementation of the Reserve, correlations will have to be established in order to be able extrapolate data from these existing monitoring stations to the head of the estuary, unless the monitoring programme of the DWAF is expanded to include flow gauging and water quality monitoring at the head of the estuary.

STEP 1:

DELINEATION OF GEOGRAPHICAL BOUNDARIES

STEP 1 : DELINEATION OF GEOGRAPHICAL BOUNDARIES

The Breede River Estuary stretches roughly from 10 km above Malgas to the town of Witsand some 220 km east of Cape Town (Figure 1). Tidal influence extends beyond the pont at Malgas to approximately 52 km upstream of the mouth. The estuary enters the sea through a permanently open mouth located at the southern end of an extensive sand spit. The channel of the estuary is incised in the coastal plain and depths of 3 to 6 m and even more are common over the first 28 km. The mouth of the Breede River Estuary is permanently open because of the length of the estuary and the still relatively high run-off of the system. It is considered highly unlikely that the mouth will close under present day conditions.

For the purposes of the Intermediate Determination of RDM for the Breede River Estuary, the geographical boundaries are defined as follows (Figure 1) (Gauss Conform Projection, Clarke 1880 spheroid):

- **Downstream boundary :** The estuary mouth (20^o 50' 40" E; 34^o 24' 30" S).
- **Upstream boundary :** The head of tidal influence, approximately 52 km from the mouth (20^{o}30' 40" E; 34^o 15' 00" S).
- **Lateral boundaries :** The 5 m contour above MSL along the banks, a delineation that could be readily referenced from an ortho-photograph of the area. Because the banks of the estuary are steep in most places, a shift of the lateral boundaries to a lower or higher level is not likely to markedly alter the lateral area of the estuary (refer to 1:10 000 ortho-photographs).

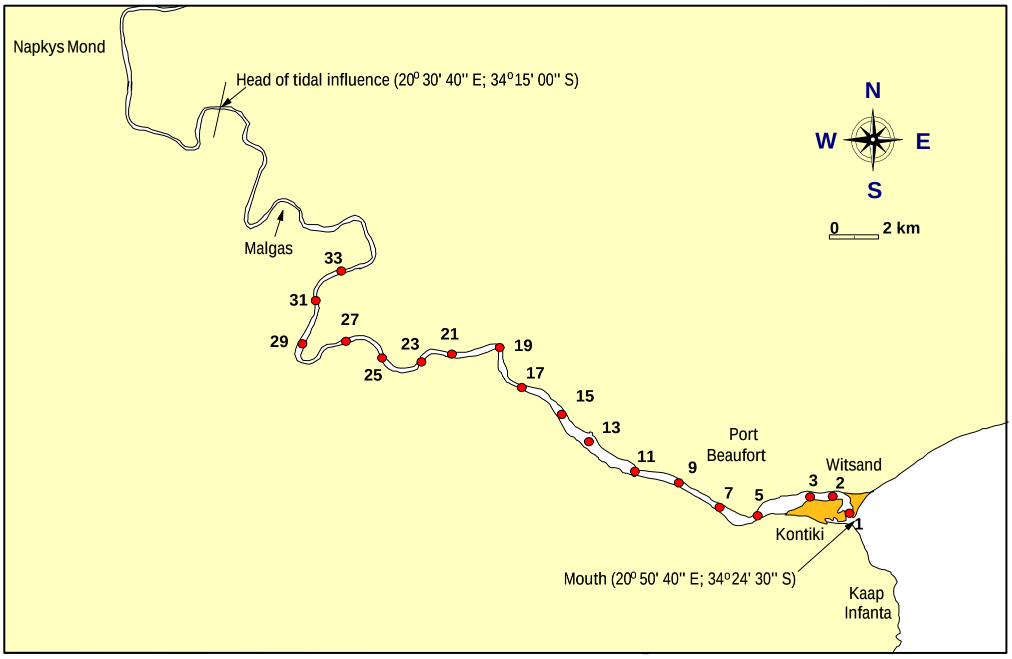


Figure 1 : Geographical boundaries of the Breede River Estuary

STEP 3:

ASSESSMENT OF PRESENT STATE AND REFERENCE CONDITION

STEP 3 : ASSESSMENT OF PRESENT STATE AND REFERENCE CONDITION

STEP 3a : ASSESSMENT OF PRESENT STATE

Abiotic Components

a. River inflow characteristics under the Present State

Floods

Ninham Shand was not able to provide such flood information. It was therefore attempted to obtain a first impression by analysing the frequency and magnitude of the highest monthly flows in the simulated monthly datasets for the different scenarios. In the table below, the 13 highest monthly flows for the reference (naturalised) conditions obtained from the datasets of simulated monthly flows are listed and these are compared with the flows in the same months for the present day scenario. It is likely that during a month with such a high average flow a major flood with a much higher peak flow would have occurred. Therefore this analysis gives only an indication of the occurrence of major floods under the different scenarios.

YEAR/MONTH	SIMULATED RUNOFF SCENARIOS	
	Reference	**Present**
June 1942	321	194
July 1954	344	240
August 1954	303	260
August 1955	344	271
June 1957	337	244
August 1962	565	436
August 1974	744	577
May 1977	313	230
June 1977	310	211
July 1977	352	328
August 1977	367	352
August 1986	338	310
July 1991	314	227
Average	**381**	**99**
% of Reference	**100**	**78.4**

The highest average monthly flows have been reduced by 21,6 per cent at present compared to reference conditions.

Monthly flow distributions

Monthly-simulated runoff data for Present State, over a 64-year period (1927 to 1990), are provided in Table 1. The Present MAR is 1034 x 10^6 m^3 (58.9% of the natural MAR). A summary of flow distribution (mean monthly flows in m^3/s) for the Present State, derived from the 64-year simulated data set, is provided below:

MONTH	1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	130.459	65.518	47.999	32.569	24.531	22.561	20.562	16.315	12.797	9.175	4.656
Nov	115.069	48.385	33.629	17.890	12.212	9.720	7.953	6.262	5.457	4.028	3.115
Dec	37.941	16.484	8.726	6.737	5.833	4.838	4.308	3.985	3.645	3.133	2.351
Jan	86.460	6.889	5.039	4.248	3.419	2.987	2.556	2.376	1.922	1.257	0.690
Feb	54.612	20.178	7.353	3.403	1.895	1.590	1.304	0.957	0.752	0.544	0.361
Mar	28.989	18.103	11.475	7.582	5.712	4.121	2.173	1.195	0.781	0.492	0.322
Apr	156.164	54.698	17.876	12.837	8.757	6.915	4.677	2.267	1.270	0.657	0.101
May	191.151	95.545	48.215	34.118	21.358	16.098	11.904	5.785	3.042	1.306	0.000
Jun	223.552	137.248	72.121	56.261	40.598	27.501	19.835	16.494	13.243	5.266	0.212
Jul	275.355	141.192	91.586	74.453	59.273	47.823	39.137	26.051	20.623	14.541	7.796
Aug	488.804	189.215	109.520	82.788	71.792	57.275	42.914	35.847	32.434	20.828	13.627
Sep	145.384	111.565	70.372	60.094	44.203	37.045	33.036	27.717	23.915	17.935	13.944

TABLE 1 : MONTHLY RUNOFF DATA (in m^3/s) FOR PRESENT STATE, SIMULATED OVER A 64-YEAR PERIOD

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1927	1.97	7.90	2.79	1.09	0.49	13.20	3.46	0.00	49.57	10.97	21.10	27.42	11.66
1928	8.83	48.60	17.27	2.47	0.94	5.13	6.94	8.24	15.41	76.96	71.26	21.82	23.66
1929	9.39	3.98	7.66	4.46	31.13	18.52	4.14	2.67	2.05	6.46	35.94	56.80	15.27
1930	23.77	7.37	3.82	3.43	1.53	5.29	69.77	40.06	9.50	59.89	103.97	44.60	31.08
1931	65.64	17.58	34.48	11.63	32.69	4.28	0.87	11.75	21.45	32.98	21.88	141.31	33.04
1932	50.58	7.70	4.31	1.81	1.08	1.11	0.64	2.47	55.89	100.96	68.18	26.16	26.74
1933	11.30	9.68	4.27	4.97	3.68	3.96	1.12	1.25	8.81	20.18	41.55	42.20	12.75
1934	90.47	40.79	6.77	2.41	1.98	1.27	7.04	25.49	25.06	39.63	39.90	28.24	25.75
1935	11.37	11.53	4.83	2.52	0.99	0.48	0.16	3.20	3.75	20.31	42.44	42.64	12.02
1936	17.59	100.95	41.86	5.98	1.61	9.92	4.87	7.22	56.07	94.13	30.09	19.24	32.46
1937	8.82	7.07	9.24	6.54	0.96	6.73	14.23	28.25	13.24	20.83	29.00	31.62	14.71
1938	16.34	12.10	5.88	2.30	20.26	21.01	7.62	15.92	5.89	13.74	94.37	42.09	21.46
1939	9.19	3.81	2.75	0.60	26.00	12.05	14.22	5.07	25.28	20.87	14.02	15.73	12.47
1940	7.32	26.20	6.25	2.97	0.69	0.23	38.03	93.17	147.44	74.37	72.45	147.97	51.42
1941	53.97	14.74	4.78	6.23	1.79	0.84	0.54	40.64	194.92	35.77	47.88	15.31	34.78
1942	17.05	6.11	14.77	45.05	15.21	5.78	6.21	4.30	17.62	48.81	75.83	71.60	27.36
1943	25.46	47.88	12.71	3.00	0.67	2.38	1.99	40.31	113.46	39.01	79.69	74.76	36.78
1944	32.57	8.63	3.66	1.94	0.46	0.38	1.07	96.56	162.80	244.33	171.49	33.76	63.14
1945	91.49	30.17	4.21	2.53	0.75	32.71	13.36	2.54	3.32	8.58	18.81	60.08	22.38
1946	21.34	3.59	2.27	0.74	0.50	26.81	10.20	4.67	5.00	75.20	34.92	24.69	17.49
1947	18.25	8.28	3.99	2.38	0.79	8.67	6.34	15.10	13.73	46.79	18.14	67.58	17.50
1948	137.55	40.10	3.62	2.28	0.59	0.41	7.77	2.08	11.17	22.89	34.79	29.09	24.36
1949	25.33	139.12	35.64	2.69	1.13	0.41	18.23	0.33	0.29	75.82	18.77	39.47	29.77
1950	23.23	46.84	11.15	32.65	10.02	2.50	13.13	2.81	79.94	57.97	33.14	46.08	29.95
1951	22.19	10.99	3.14	1.90	1.04	0.63	0.63	24.73	16.16	44.33	134.15	112.72	31.05
1952	32.58	90.77	19.15	3.65	1.42	0.49	70.39	50.91	16.53	93.09	51.73	24.29	37.92
1953	24.64	18.01	5.59	2.35	0.55	0.96	12.80	137.59	79.19	240.18	260.56	69.56	71.00
1954	19.76	5.82	4.40	5.14	82.58	21.89	1.67	0.00	27.45	96.68	271.84	48.25	48.79
1955	46.28	12.24	3.77	2.72	0.75	3.96	2.04	20.33	57.98	60.96	88.40	22.49	26.83
1956	21.46	6.01	6.28	3.20	18.97	5.97	2.26	103.39	244.41	243.21	196.81	69.13	76.76
1957	101.20	18.72	4.29	2.65	1.90	6.61	3.87	121.34	58.19	12.80	56.73	23.35	34.30
1958	15.96	5.43	3.27	4.23	5.56	4.65	66.36	168.01	27.55	64.67	97.73	34.86	41.52
1959	61.51	13.75	3.91	3.06	0.91	2.16	1.92	16.28	49.00	17.20	12.95	11.62	16.19
1960	6.23	4.36	6.51	7.04	2.70	1.32	2.27	10.05	18.48	21.72	49.49	68.04	16.52
1961	23.78	6.02	3.13	2.48	2.45	9.96	9.41	0.51	165.70	63.70	436.68	123.60	70.62
1962	126.29	57.34	11.49	4.43	1.48	17.14	9.19	17.84	19.43	36.19	113.52	26.72	36.76
1963	16.10	9.76	5.62	5.36	6.32	15.77	6.89	1.37	80.09	47.70	82.17	32.27	25.78
1964	22.93	29.16	7.79	3.74	2.35	7.75	8.43	25.34	16.89	23.95	33.28	16.11	16.48
1965	43.81	28.68	8.28	5.10	1.57	1.38	1.37	1.28	18.05	55.49	98.62	52.86	26.37
1966	13.06	3.05	2.88	1.20	1.75	4.52	150.51	77.85	105.66	35.86	33.24	26.10	37.97
1967	28.44	9.43	4.27	2.83	0.54	0.63	4.38	43.76	59.12	76.23	71.93	21.12	26.89
1968	60.89	14.90	4.57	3.67	1.28	0.92	8.79	5.45	15.99	16.13	20.71	28.85	15.18
1969	34.29	4.15	2.40	1.60	3.68	1.21	0.00	3.46	38.75	42.37	79.90	37.19	20.75
1970	16.00	4.77	3.79	1.08	4.42	6.10	21.04	15.07	13.24	103.79	117.67	33.15	28.34
1971	8.74	17.88	6.34	2.41	3.61	2.24	5.43	14.40	18.87	14.73	36.50	27.75	13.24
1972	9.17	4.30	2.81	0.86	0.19	0.47	0.70	0.00	0.08	68.74	29.01	17.38	11.14
1973	12.41	4.49	5.65	2.35	19.99	7.77	0.81	21.36	44.13	19.24	577.55	110.25	68.83
1974	37.58	9.96	4.29	3.81	0.79	0.77	4.87	48.00	26.58	53.42	67.81	33.01	24.24
1975	20.37	6.67	3.55	1.71	1.89	5.91	9.34	5.82	166.97	90.58	38.35	20.38	30.96
1976	32.15	79.82	19.67	9.53	18.15	7.56	43.67	230.56	211.30	328.19	352.30	55.91	115.73
1977	21.98	11.86	8.38	4.14	0.95	0.76	10.04	13.40	4.87	10.38	46.40	38.33	14.29
1978	21.57	6.11	6.39	3.23	33.77	11.09	0.58	12.54	41.06	26.06	44.80	34.96	20.18
1979	40.50	6.28	3.50	5.00	1.54	0.61	4.63	9.81	15.34	14.46	19.17	16.51	11.45
1980	13.89	60.47	17.22	156.97	38.19	13.12	49.11	21.34	11.99	55.64	106.85	103.90	54.06
1981	24.02	6.96	6.73	4.73	1.13	5.43	165.79	66.80	29.86	26.01	31.38	36.90	33.81
1982	21.58	5.47	4.85	1.22	2.08	1.01	0.26	43.43	92.41	164.10	57.82	81.64	39.66
1983	26.40	8.16	4.49	2.01	1.49	20.11	3.88	131.02	30.17	76.48	34.99	143.86	40.26
1984	65.24	16.60	7.51	12.34	8.91	19.61	17.64	17.23	63.90	150.13	147.09	35.62	46.82
1985	52.95	39.01	10.12	4.70	1.75	2.97	8.61	17.43	22.90	59.60	310.62	112.13	53.57
1986	24.09	8.64	3.78	3.38	0.50	0.50	32.52	60.02	51.47	44.70	114.59	60.24	33.70
1987	17.83	3.16	5.31	1.50	0.52	1.65	16.33	21.37	36.85	30.14	41.07	67.18	20.24
1988	14.31	3.37	3.55	1.34	0.71	12.73	57.09	33.46	30.75	47.94	72.86	143.47	35.13
1989	73.75	38.83	5.53	3.01	3.38	2.04	80.05	48.54	67.41	120.34	61.94	15.61	43.37
1990	10.95	3.71	4.31	2.83	1.70	0.79	0.96	9.45	58.67	227.94	63.51	96.18	40.08
< 0.5	0	0	0	0	3	7	3	4	2	0	0	0	
0.5 - 3.0	1	0	6	33	41	23	17	9	1	0	0	0	
3.0 -10.0	8	34	46	26	8	20	22	11	7	2	0	0	
10.0 - 20.0	16	13	9	2	5	9	10	12	16	9	6	8	
> 20.0	39	17	3	3	7	5	12	28	38	53	58	56	

b. ***Sedimentation/erosion characteristics under the Present State*:**

The reduction in the occurrence and magnitude of major floods will result in a reduction in the flushing of sediments during such floods, which indirectly can result in long-term ongoing sedimentation in the estuary. The flushing of sediments during floods has probably significantly been reduced between reference and present conditions.

Confidence: 40%

c. ***Prevailing abiotic conditions under different inflows of freshwater (referred to as Abiotic States)***

Based on the assessments and evaluations conducted for this specialist report, five Abiotic States were derived for the Breede River Estuary, of which the occurrence and duration varies depending on river inflow rate. These states are:

- State 1: Strongly freshwater dominated
- State 2: Freshwater dominated with significant saline intrusion in lower reaches
- State 3: Marine and freshwater influence on the estuary is balanced, with a well-developed REI zone
- State 4: Marine dominated, where the REI zone is variable, depending on the flow rate and duration
- State 5: Strongly marine dominated, with no REI zone.

Typical abiotic characteristics prevailing during each of these states are listed on the following pages.

ABIOTIC STATE 1: Strongly freshwater dominated

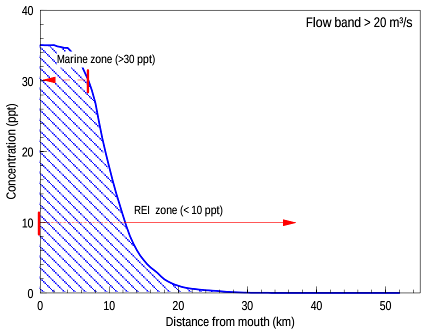
Typical flow patterns: > 20 m³/s
Confidence: 60%

State of the mouth: Wide open
Confidence: 80%

Flood plain inundation patterns: N/A
Confidence: -

Amplitude of tidal variation (indicative of exposure of inter-tidal areas during low tide): 0.9 (neap tide) to 1.5 m (spring tide)
Confidence: 60%

Salinity distributions in the estuary:



Confidence: 60%

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

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	**Middle salinity ranges**	**< 10 ppt (REI zone)**
Temperature (°C)	15 – 17 (winter)		
pH	8	7 - 8	7 - 8
Suspended solids (mg/l)	< 10	Because of flocculation SS should be less than in the <10ppt zone, but may still be higher than in the >30 ppt zone	Depend on levels in river inflow, which is expected to increase during winter (no data available)
Dissolved oxygen	Well oxygenated through estuary		

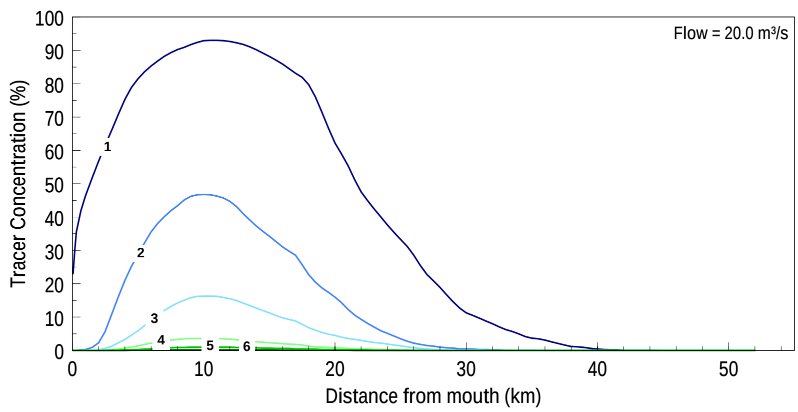
Confidence: 60%

Nutrients:

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	**Middle salinity ranges**	**< 10 ppt (REI zone)**
Nitrite-N (mg/l) Nitrate-N (mg/l)	< 0.1	0.1 – 0.4	0.2 – 0.5
Total Ammonia-N (mg/l)	Low	0.02 – 0.07	< 0.02
Reactive phosphate-P (mg/l)	0.04	0.015 – 0.025	< 0.02
Reactive Silicate –Si (mg/l)	0.15	0.15 – 1.50	1.50 – 2.00

Confidence: 60%

Retention times of water masses: A model simulation over a 6-week period indicated that the maximum retention was in the region 5 to 15 km upstream from the mouth - after about 2 weeks less than 50% of the original water mass remained.



Confidence: 40%

ABIOTIC STATE 2: Fresh water dominated, with saline intrusion

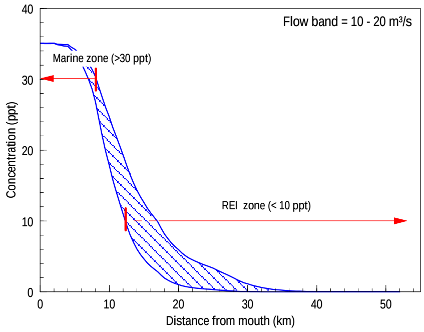
Typical flow patterns: 10 - 20 m^3/s
Confidence: 60%

State of the mouth: Wide open
Confidence: 80%

Flood plain inundation patterns: N/A
Confidence: -

Amplitude of tidal variation (indicative of exposure of inter-tidal areas during low tide): 0.9 (neap tide) to 1.5 m (spring tide)
Confidence: 60%

Salinity distributions in the estuary:



Confidence: 60%

Temperature, pH, dissolved oxygen and SS/turbidity:

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	**Middle salinity ranges**	**< 10 ppt (REI zone)**
Temperature (°C)	15 – 17 (winter)		
pH	8	7 - 8	7 - 8
Suspended solids (mg/l)	< 10	Because of flocculation SS should be less than in the <10ppt zone, but may still be higher than in the >30 ppt zone	Depend on levels in river inflow, which is expected to increase during winter (no data available)
Dissolved oxygen	Well-oxygenated throughout the estuary		

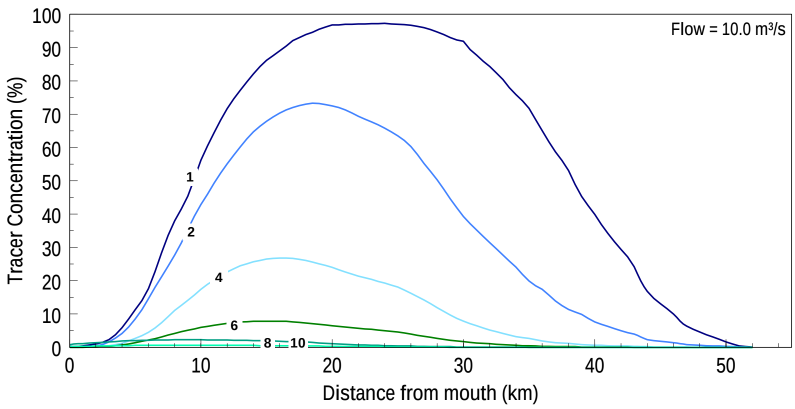
Confidence: 60%

Nutrients:

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	**Middle salinity ranges**	**< 10 ppt (REI zone)**
Nitrite-N (mg/l) Nitrate-N (mg/l)	< 0.1	0.1 – 0.4	0.2 – 0.5
Total Ammonia-N (mg/l)	Low	0.02 – 0.07	< 0.02
Reactive phosphate-P (mg/l)	0.04	0.015 – 0.025	< 0.02
Reactive Silicate –Si (mg/l)	0.15	0.15 – 1.50	1.50 – 2.00

Confidence: 60%

Retention times of water masses: A model simulation over a 10-week period indicated that the maximum retention was in the region 15 to 25 km upstream from the mouth - after 2 to 4 weeks less than 50% of the original water mass remained.



Confidence: 60%

ABIOTIC STATE 3: Balanced marine and freshwater influence, well-developed REI

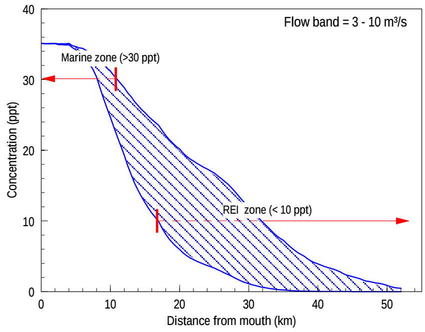
Typical flow patterns: 3 - 10 m^3/s
Confidence: 60%

State of the mouth: Open
Confidence: 80%

Flood plain inundation patterns: N/A
Confidence: -

Amplitude of tidal variation (indicative of exposure of inter-tidal areas during low tide): 0.9 (neap tide) to 1.5 m (spring tide)
Confidence: 60%

Salinity distributions in the estuary:



Confidence: 60%

Temperature, pH, dissolved oxygen and SS/turbidity:

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	**Middle salinity ranges**	**< 10 ppt (REI zone)**
Temperature (°C)	21 – 25 (summer)		
pH	8	7 - 8	7 - 8
Suspended solids (mg/l)	< 10	< 10	< 10
Dissolved oxygen	Well oxygenated throughout the estuary		

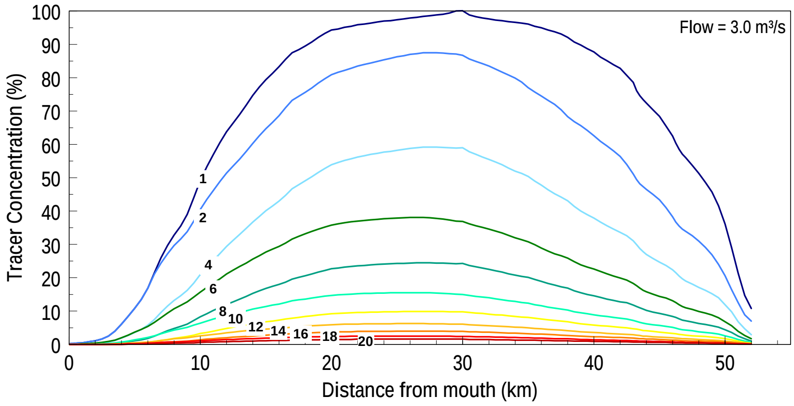
Confidence: 60%

Nutrients:

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	**Middle salinity ranges**	**< 10 ppt (REI zone)**
Nitrite-N (mg/l) Nitrate-N (mg/l)	< 0.1	0.02 – 0.17	0.02 – 0.20
Total Ammonia-N (mg/l)	Low	0.02 – 0.07	< 0.02
Reactive phosphate-P (mg/l)	0.040	0.015 – 0.025	< 0.02
Reactive Silicate –Si (mg/l)	0.15	0.15 – 0.90	0.70 – 1.20

Confidence: 60%

Retention times of water masses: A model simulation over a 20-week period indicated that the maximum retention was in the region 15 to 35 km upstream from the mouth - after about 4 weeks only 50% of the original water mass remained.



Confidence: 60%

ABIOTIC STATE 4: Marine dominated (REI varies and are smaller than for State 3)

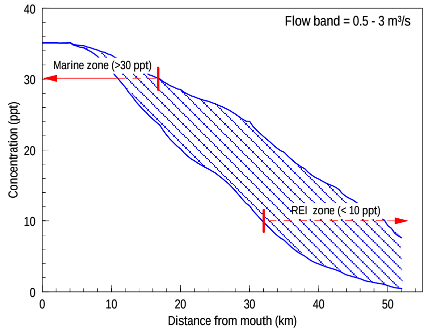
Typical flow patterns: 0.5 - 3 m^3/s
Confidence: 40%

State of the mouth: Open
Confidence: 80%

Flood plain inundation patterns: N/A
Confidence: -

Amplitude of tidal variation (indicative of exposure of inter-tidal areas during low tide): 0.9 (neap tide) to 1.5 m (springtide)
Confidence: 60%

Salinity distributions in the estuary:



Confidence: 40%

Temperature, pH, dissolved oxygen and SS/turbidity:

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	**Middle salinity ranges**	**< 10 ppt (REI zone)**
Temperature (°C)	21 – 25 (summer)		
pH	8	7 - 8	7 - 8
Suspended solids (mg/l)	< 10	< 10	< 10
Dissolved oxygen	Oxygenated throughout the estuary		

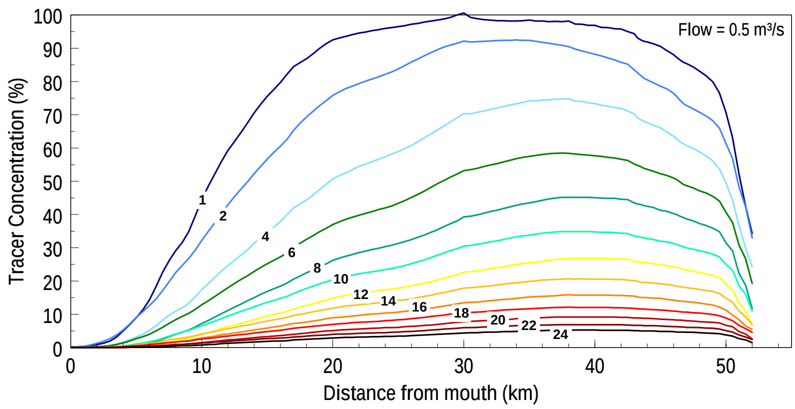
Confidence: 60%

Nutrients:

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	**Middle salinity ranges**	**< 10 ppt (REI zone)**
Nitrite-N (mg/l)	< 0.1	0.02 – 0.17	0.02 – 0.20
Nitrate-N (mg/l)			
Total Ammonia-N (mg/l)	Low	0.02 – 0.07	< 0.02
Reactive phosphate-P (mg/l)	0.04	0.015 – 0.025	< 0.02
Reactive Silicate –Si (mg/l)	0.15	0.15 – 0.90	0.70 – 1.20

Confidence: 60%

Retention times of water masses: A model simulation over a 24-week period indicated that the maximum retention was in the region 30 to 50 km upstream from the mouth where, already after about 6 weeks, only 50% of the original water mass remained.



Confidence: 40%

ABIOTIC STATE 5: Strongly marine dominated (no REI)

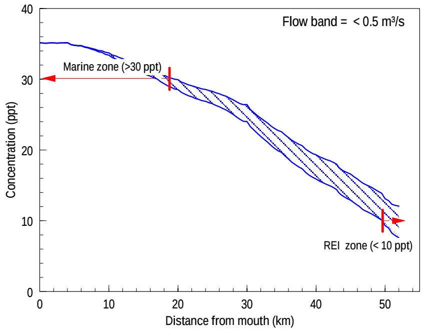
Typical flow patterns: < 0.5 m^3/s
Confidence: 40%

State of the mouth: Open
Confidence: 80%

Flood plain inundation patterns: N/A
Confidence: -

Amplitude of tidal variation (indicative of exposure of inter-tidal areas during low tide): 0.9 (neap tide) to 1.5 m (spring tide)
Confidence: 60%

Salinity distributions in the estuary:



Confidence: 40%

Temperature, pH, dissolved oxygen and SS/turbidity:

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	**Middle salinity ranges**	**< 10 ppt (REI zone)**
Temperature (°C)	21 – 25 (summer)		
pH	8	7 - 8	7 - 8
Suspended solids (mg/l)	< 10	< 10	< 10
Dissolved oxygen	Oxygenated	Although no data are available, bottom water in these salinity ranges may start to show reduced oxygen levels owing to limited flushing.	

Confidence: 40%

Nutrients:

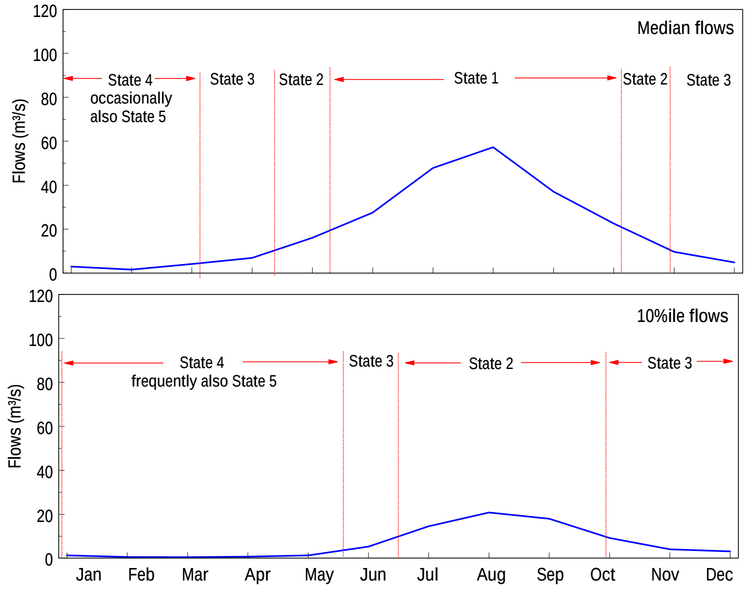
VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	**Middle salinity ranges**	**< 10 ppt (REI zone)**
Nitrite-N (µg/l)	< 0.10	0.02 – 0.20	0.02 – 0.20
Nitrate-N (µg/l)			
Total Ammonia-N (µg/l)	Low	0.02 – 0.07	< 0.02
Reactive phosphate-P (µg/l)	0.04	0.015 – 0.025	< 0.02
Reactive Silicate –Si (µg/l)	0.15	0.15 – 1.20	0.70 – 1.20

Confidence: 40%

Retention times of water masses: None available for this state

Confidence: -

To estimate the occurrence and duration of the different Abiotic States during the Present State, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively:



- Under the Present State, the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)	
Months	Duration
Nov – Apr	6 months

DROUGHTS (10%ile)	
Months	Duration
Oct – Jul	9 months

- The average, as well as the maximum distances (in km), at which certain salinities penetrate during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)		
SALINITY (ppt)	**DISTANCE FROM MOUTH (km)**	
	Average	**Maximum**
30	9	12
20	16	26
10	28	37

DROUGHTS (10%ile)		
SALINITY (ppt)	**DISTANCE FROM MOUTH (km)**	
	Average	**Maximum**
30	11	22
20	25	42
10	39	None

- The average and maximum salinities at the head of the estuary (about 52 km from the mouth) during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Salinities (ppt) at head of estuary	
Average	Maximum
<1	~3

DROUGHTS (10%ile) Salinities (ppt) at head of estuary	
Average	Maximum
~2	~14

- The average and maximum salinities at 12 km from the mouth during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
20	4 - 5
30	None

DROUGHTS (10%Ile) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
20	6 - 7
30	6

c. *Human interferences affecting abiotic components under the Present State:*

Structures: There are three major dams on the Riviersonderend and the Breede River: the Theewaterskloof Dam built in 1980, which has a capacity of 433 x 10^6 m^3, the Brandvlei Dam built in 1926 with a capacity of 304 x 10^6 m^3 and the Kwaggaskloof Dam, built in 1975 with a capacity of 171x 10^6 m^3. Additionally, there are several smaller dams in the catchment and many farm dams. The mean annual run-off (MAR) of the river reaching the estuary has as a result been reduced by approximately 42 per cent from 1785 x 10^6 m^3 under reference (or natural) conditions to 1034 x 10^6 m^3 at present. **Confidence:** 80%
Human exploitation (consumptive or non-consumptive): Not applicable to Abiotic components **Confidence:** -
Point/diffuse source discharges affecting WQ (e.g. dump sites, storm water, sewage discharges, etc): **Nutrients:** Agricultural activities are probably the cause of elevated nitrate concentrations in the winter months **Toxic substances:** No measured inputs. Pesticides and herbicides may become an issue associated with agriculture activities in the catchment. **Confidence:** 60%

Biotic Components

a. *Microalgae*

Present State of microalgae in the Breede River Estuary is:

Biomass distribution: No reason to suspect other than normal. Biomass may be higher than pristine because of agricultural activities in the catchment but no information is available on the nutrient status from large fauna under pristine conditions. **Confidence:** 60%
Species diversity, richness and rarity (e.g. provide details on endemic and Red Data species): Species diversity high, up to 70+ species identified at some stations. This is higher than in most estuaries. Other stations have between 30-40 species at each station, which is about average. **Confidence:** 80%
Seasonal and inter-annual variability, as well as flood situations and drought conditions: The system is likely to be very variable between years and seasons. The present condition must be approximately average for wet seasons. No data available on which to decide except that farm dams will be present which will have reduced certain seasonal flow. Unlikely to have had much impact on the microalgae except that mineral nutrients would have been reduced due to vegetation growth in the dams **Confidence:** 60%
Assessment of the relationship to other nearby estuarine and marine systems: A beautiful large, rich system. Possibly one of the very few in South Africa that fluctuates seasonally from a river mouth to a true estuary. One of the largest systems on the Cape south coast and therefore very valuable ecologically. The absence of dams will result in there being natural species migrations far inland, to support natural freshwater ecosystems. **Confidence:** 60%
Local/regional/national importance of the estuary in terms of the biotic component.: Very important because of its size and the relatively unique nature of winter high flow and summer low flow. **Confidence:** 60%

Important abiotic and biotic components that may influence microalgae in the Breede River Estuary are:

<u>State of the mouth</u>: Should remain open at all times due to the unique biological position it fills. Closed mouth is followed by a drop in phytoplankton and benthic production that are supported by fresh water inflow. **Confidence:** 60%
<u>Flood plain inundation</u>: None according to local opinion. Very small localised flood plains are present. N/A to microalgae. **Confidence:** 60%
<u>Exposure of intertidal areas during low tide</u>: The size of the intertidal areas is not large because the estuary is confined to a natural valley with fairly steep sides. Intertidal benthic microalgae community will disappear if there is no intertidal area. **Confidence:** 60%
<u>Salinity distribution in the estuary (including the size of the REI)</u>: Seawater mixes with fresh water to produce an area of optimal phytoplankton productivity (REI). In the case of phytoplankton, it is not the presence/absence of the mixing zone that is important; it is the duration that it exists that is important. The Breede River Estuary is a unique system with a huge REI because of the high freshwater flow and the very large tidal wedge. Likely size of the REI requires to be calculated in order to make comparisons with other systems .The REI may occur out to sea when fresh water flow is greater than 11 $m^3.s^{-1}$ **Confidence:** 60%
<u>Other water quality (system variables, nutrients and toxic substances) constituents</u>: The flow on all sampling occasions was high. The Breede drains an extensive agricultural region. This may cause elevated fertiliser components at times. The natural geology would probably produce oligotrophic river water under natural conditions. The likelihood, therefore, is that mineral nutrients will be low to moderate. Water hyacinth (*Eichhornia crassipes*) was present in the upper estuary, indicating that some plant growth minerals had been removed from the water before it entered the estuary. Microalgal growth increases in response to increased mineral content, provided they are not flushed out of the estuary before they have had time to divide. **Confidence:** 60 %
<u>Other biotic components</u>: Very extensive reeds beds will provide a great deal of epiphytic diatom material that will add substantially to the amount of food available to primary consumers. **Confidence:** 40%

Human interferences having a **direct** influence on microalgae in the Breede River Estuary are:

<u>Structures</u>: Human influences will have a small influence on microalgae, i.e. very large number of fishermen and boats. Boats may alter species diversity slightly, but unlikely to have any adverse effect on the phytomicrobenthos. **Confidence:** 60 %
<u>Human exploitation (consumptive or non-consumptive):</u> Very small effect if any. See above for reasons. **Confidence:** 40 %
<u>Flood plain and catchment development</u>: Catchment well developed but largely agriculture. The effect is to increase biomass because of increased mineral (nutrient) input. Unknown to what extent by comparison with large herbivore effect. **Confidence:** 40%

b. *Macrophytes*

Present State of macrophytes in the Breede River Estuary is:

Biomass distribution: *Zostera* beds cover approximately 6 ha in the lower reaches of the estuary, intertidal salt marsh 20.5 ha and supratidal salt marsh 30 ha. Extensive reed beds characterise the middle and upper reaches of the estuary and begin approximately 10 km from the mouth of the estuary. **Confidence:** 80%
Species diversity, richness and rarity (e.g. provide details on endemic and Red Data species): Six of the nine possible plant community types occur in the Breede Estuary. There are 23 dominant macrophyte species and the largest salt marsh (Green Point) has high species richness. Intertidal saltmarsh occurs in permanently open estuaries. Only 18 % of South African estuaries are permanently open and therefore intertidal saltmarsh can be considered rare. **Confidence:** 80%
Seasonal and inter-annual variability, as well as flood situations and drought conditions: Large floods can uproot the submerged macrophyte *Zostera* and thus influence the distribution and abundance of this species. During drought the cover / abundance of supratidal marsh would be reduced as these plants are largely dependent on rain as a source of freshwater. **Confidence:** 80%
Assessment of the relationship to other nearby estuarine and marine systems: Nearby permanently open estuaries are the Heuningnes, Duiwenhoks and Kafferkuils. In Coetzee *et al*. (1997) the Duiwenhoks and Kafferkuils received higher botanical importance scores than the Breede Estuary mainly because of the larger intertidal salt marsh and seagrass (*Zostera capensis*) areas. As a result of its high freshwater input, the Breede Estuary is more of a fresh / brackwater system and the abundance of small marshes characterized by brackish species is probably unique to this estuary. **Confidence:** 80 %
Local/regional/national importance of the estuary in terms of the biotic component: The Breede Estuary has the fifth highest botanical importance score for estuaries in South Africa. It shares this position with other permanently open estuaries that have high species rich. **Confidence:** 80 %

Important abiotic and biotic components that may influence macrophytes in the Breede River Estuary are:

State of the mouth: An open mouth is important as it maintains the intertidal plant community types i.e. intertidal salt marsh and *Zostera* beds. Salt marsh plants occur in distinct zones up the shore along a tidal inundation gradient. If the mouth closes the plants found in these zones would die. **Confidence:** 80 %
Exposure of intertidal areas during low tide: Tidal flushing is important for salt marsh nutrient exchanges and for maintaining the zonation and diversity of salt marsh plants. **Confidence:** 80 %
Sediment characteristics (including sedimentation): Intertidal salt marsh is associated with high silt content and supratidal salt marsh with high clay content. Accumulation of sediments in the upper estuary would promote the growth and expansion of *Phragmites* (common reed). Marine sedimentation and smothering has been cited as the reasons for the decrease in the area covered by the seagrass *Zostera capensis*. **Confidence:** 80 %
Salinity distribution: A longitudinal salinity gradient increases biotic diversity as salt marsh colonizes the lower saline reaches and reeds and sedges occur in the brackish middle and upper reaches. If the salinity is altered the growth and distribution of specific species will change. **Confidence:** 80 %
Other water quality parameters (be as specific as possible): Nutrient enrichment can increase growth and encroachment of reeds into the main estuary channel. **Confidence:** 80 %
Other biotic components: N/A **Confidence:** -

Human interferences that have a **direct** influence on macrophytes in the Breede River Estuary are:

Structures: Some jetties and slipways in the upper reaches of the estuary have resulted in the permanent removal of reeds. **Confidence:** 80 %
Human exploitation (consumptive or non-consumptive): Exploitation of bait species can disturb the *Zostera* beds. In the upper reaches of the estuary agricultural activities have resulted in the removal of reeds. **Confidence:** 80 %
Floodplain and catchment development: Cattle grazing on the supratidal marsh at Green Point has altered the growth form of the dominant plant, *Sarcocornia pillansii* in some areas. The intertidal marsh showed signs of erosion, possibly as a result of the heavy boating activity in this region. Boating and stirring up bottom sediments could also impact the submerged macrophytes (*Zostera capensis* and *Potamogeton pectinatus*), reducing both cover and biomass. **Confidence:** 80 %

c. Invertebrates

Present State of invertebrates in the Breede River Estuary is:

Biomass distribution: **Hyperbenthos and Zooplankton**: Previous studies undertaken by Grindley (quoted in Carter 1983) indicated a depauperate estuarine zooplankton fauna. The two surveys undertaken in 2000 support these conclusions. *Pseudodiaptomus hessei* and *Acartia natalensis* were present in low numbers (abundance may exceed 100000 per cubic metre of water, while numbers >10000 per cubic metre of each species are frequently recorded in estuaries). *A. longipatella* was not present in samples. Mysid shrimps were also poorly represented and were restricted to the lower estuary (numbers sometimes exceed 10000 per cubic metre of water, while numbers > 500 - 1000 per cubic metre are common). **Larger invertebrates associated with the hyperbenthos**: The river prawn *Palaemon capensis* (found in brackish waters of south coast estuaries) appeared in abundance along the estuary margins in association with reeds (*Phragmites australis* extending upstream from the Power line or about 12 km from the mouth). Because of their close association with reeds, quantification of prawns is difficult. These prawns probably play an important role in energy transfer, contributing to the energy requirements of juvenile fish utilising the estuary as a nursery area (e.g. dusky cob). A second species of river prawn (*Macrobrachium* sp.) migrates to the estuary in summer, where it also lives in association with the fringing vegetation in the upper estuary. *Macrobrachium* species typically utilise brackish water habitats for breeding purposes, returning to rivers during winter. The species present in the Breede is unknown to date, and could not be identified by the South African Museum in Cape Town from a specimen supplied by Lamberth (pers. communication). **Interrtidal invertebrates:** In earlier studies undertaken by Day et al. (1981), no sandprawn (*Callianassa kraussi*) were recorded in the estuary, while pencil bait (*Solen* sp) and bloodworm (*Arenicola loveni*) occurred in patches only near the mouth. Currrently, all three species are present, although numbers are not high. By contrast, small polychaetes and mudprawn (*Upogebia africana*) are extremely abundant. The latter species occurs in the lower estuary only (below the power line) where intertidal mudbanks occur. It is likely to be a very important food organism for benthic feeding fish. **Confidence**: 80%
Species diversity, richness and rarity (e.g. provide details on endemic and Red Data species): No invertebrate species endemic to the Breede estuary were identified, although bloodworm (*Arenicola loveni*) occurs in relatively few estuaries. *Upogebia africana* is restricted to tidal estuaries. The status of the *Macrobrachium* species is unknown. **Confidence:** 80%
Seasonal and inter-annual variability, as well as flood situations and drought conditions Interannual variability will be directly linked to freshwater runoff and the degree of river dominance. Zooplankton is not likely to become well established because of strong tidal currents that characterize the estuary, irrespective of the size of the REI. Under drought conditions, some of the hyperbenthic species (living in close association with the substrate) such as mysids may become more abundant in the estuary. The carid shrimps (*Palaemon* and *Macrobrachium* species) move from freshwater to the brackish zone of estuaries to breed at the end of winter, but no details on specific requirements are known. **Confidence:** 60%
Assessment of the relationship to other nearby estuarine and marine systems: Comparison with adjacent estuaries is difficult, mainly due to limited sampling and different sampling techniques used. Nevertheless, Carter & Brownlie (1990) recorded relatively low zooplankton biomass in the Kafferkuils and Duiwenhoks (except for the mouth station in the former estuary). No zooplankton records are available for the Heuningnes estuary (Bickerton 1984). Bloodworm (Arenicola loveni) and three other bait organisms also occur in the three estuaries, although biomass appears variable variable and relatively low. **Confidence:** 60%

Continued…

Local/regional/national importance of the estuary in terms of the biotic component: The Breede is considered one of the most important southern Cape estuaries because of its size and importance to biota. Coupled to its high botanical rating (5th highest rating of South African estuaries, Adams & Colloty, this report series), the Breede supports a rich invertebrate fauna, particularly in the intertidal. Turpie *et al*. (2001) rank the Breede among the top 20 estuaries in South Africa for conservation importance **Confidence:** 80%

Important abiotic and biotic components that may influence invertebrates in the Breede River Estuary are:

State of the mouth: An open tidal mouth is critical for the conservation status of the estuary. Coupled to this condition, is the presence of the extensive sandbank inside the mouth that provides specialist habitat for sand-loving species. Patches of *Zostera* in more sheltered areas (upstream from the mouth) provide specialist habitat for some invertebrate species. The invertebrate fauna of the sandbank is probably very dynamic in character, with abundance linked to the constantly changing conditions on the sandbank (e.g. erosion and expansion of the sandbank according to flood cycles) and water salinity in the lower estuary. **Confidence:** 80%
Flood plain inundation: - **Confidence: -**
Exposure of intertidal areas during low tide: Extensive intertidal areas in the lower estuary support a rich and abundant infauna that is zoned along the intertidal gradient. Large numbers of benthic feeding birds utilise exposed banks at low tide, utilising specific levels according to distribution of important food items. At high tide, foraging fish utilise the same area according to food preference. It is important that both sand- and mudbanks extend along the estuarine salinity gradient since the combination of substrate particle size and salinity (particularly), determine the composition of the community living in the intertidal. If salinity increases in an upstream direction for extended periods, structure and abundance of the community will change. **Confidence:** 80%
Salinity distributions in the estuary (including the size of the REI): The size of the REI in the Breede is important with regard to the specialist habitat it provides for larger invertebrates such as river prawns. Available information suggests that prawns require brackish water conditions for breeding purposes. In addition, the large REI ensures that the reed beds (*Phragmites australis*) extend relatively far downstream and this provides extensive habitat for river prawns. If salinity increases in an upstream direction (higher salinity values become more common upstream), available habitat is likely to decrease in area. After spawning, prawn larvae probably undergo further development in the upper estuary (although specific requirements are not known), so that increasing upstream salinity values may impact negatively on recruitment to the adult population (prawn larvae may have specific salinity requirements). **Confidence:** 60%
Other water quality (system variables, nutrients and toxic substances) constituents: - **Confidence: -**
Other biotic components: - **Confidence: -**

Human interferences that have a **direct** influence on invertebrates in the Breede River Estuary are:

Structures: There are no apparent human structures that directly influence invertebrates, although jetties may have some influence in the upper half of the estuary. The presence of jetties requires the permanent removal of reeds (and therefore specialist habitat). **Confidence:** 60%
Human exploitation (consumptive or non-consumptive): Bait exploitation probably affects intertidal invertebrates directly, both through removal of organisms and trampling by diggers as bait is collected. Unsubstantiated information provided by residents suggests that some bait organisms decrease considerably after the summer holiday season, particularly bloodworm (*Arenicola loveni*). Liddle (1997) quotes numerous examples of the reduction in invertebrate fauna after bait collecting. **Confidence:** 60%
Flood plain and catchment development: The construction of barriers across rivers probably reduces migration success of some invertebrates, particularly those returning upstream after the breeding season (*Palaemon capensis* and *Macrobrachium* sp. are two examples). This aspect requires further research. **Confidence:** 60%

d. *Fish*

Present State of fish in the Breede River Estuary is:

Biomass distribution: On the whole, the majority of completely and partially estuarine dependent species were most abundant from 5-20 km from the mouth in salinities ranging from 0-20 ppt and water clarity less than 100 cm. Non estuarine dependent marine species were most often in the lower 5 km at salinities higher than 20 ppt whereas most freshwater tolerant and catadromous species were further than 20 km from the mouth in salinities of 0-1 ppt.

Confidence: 80%

Species diversity, richness and rarity (e.g. provide details on endemic and Red Data species): A total of 59 species from 30 families have been recorded from the Breede Estuary. Twenty-five (42 %) are southern African endemics. The estuary is an important nursery area for dusky kob *Argyrosomus japonicus* and white steenbras *Lithognathus lithognathus*, the stocks of both of which have a $SBR_{f=0}$ = 6% and are collapsed. The Breede is one of five permanently open out of a total of eight estuaries along the south coast from Cape Agulhas to Mossel Bay. It is the largest of the eight and accounts for 43 % of the total estuarine area within this region. Its importance lies in its size and its situation in a region of high endemicity close to the warm temperate, cool temperate transition zone the latter which has only six permanently or semi permanently open estuaries in the entire stretch of coastline between the Gariep River and Cape Agulhas.

Confidence: 80%

Seasonal and inter-annual variability, as well as flood situations and drought conditions: Upstream distribution of the species caught during the summer and winter survey was largely a reflection of the estuarine-dependence category to which they belong. Category Ib species which breed only in estuaries were largely confined to the REI zone and showed a shift from 25-40 km upstream during summer to 5-15 km during winter. Category Ib species that have marine and estuarine breeding populations were largely confined to the lower reaches of the estuary in salinities of 20-35 ppt. The exception in this group was *Caffrogobius,* which ranged throughout the estuary during both seasons but with the bulk of the population showing a distinct downstream shift from 10-20 km to 0-10 km from the mouth during winter.

Category IIa species which are entirely dependent on estuaries as a juvenile habitat showed various responses between summer and winter. *Rhabdosargus holubi* and *Lithognathus lithognathus* showed a downstream shift of approximately 10 km during winter. *Argyrosomus japonicus* and *Lichia amia* were spread throughout the estuary during summer but disappeared from catches during winter, probably a reflection of their overall low abundance rather than their absence from the system *Pomadasys commersonnii* displays an interesting seasonal response to higher flow in that most of the population appears to move upstream during the winter months to 20-40 km from the mouth.

Partially estuarine dependent species (II b & IIc), were spread throughout the estuary during summer but concentrated in the lower 10 km during winter. The facultative catadromous *Myxus capensis* was found above 20 km in 0 ppt during both seasons and has also been recorded 100 km upstream shoaling with ***Mugil cephalus.***

Juvenile catadromous eels use summer freshettes and floods to recruit into the estuary and migrate upstream.

Confidence: 80%

Assessment of the relationship to other nearby estuarine and marine systems: The estuary provides a vital nursery function, and 40 % of the estuary nursery habitat on the south coast. There is constant migration of adult fish into and out of the Breede from, and to, adjacent estuaries and surfzones. Adults that spend their juvenile phase in the estuary have been found to disperse throughout the SA coastline.

Confidence: 80%

Local/regional/national importance of the estuary in terms of the biotic component: In terms of fish the Breede Estuary has a biodiversity and overall importance score of 90 % which places it within the top percentile of all estuaries in South Africa

Confidence: 80 %

Important abiotic and biotic components that may influence fish in the Breede River Estuary are:

State of the mouth: A permanently open mouth facilitates year round recruitment of larval and juvenile fish and migration of adults into and out of the estuary. Depending on the duration and season of mouth closure, the estuary would lose a substantial component of the fish community. **Confidence:** 60 %
Flood plain inundation: Not applicable **Confidence:** -
Exposure of intertidal areas during low tide: No mudskippers here **Confidence:** -
Salinity distributions in the estuary (including the size of the REI): Species diversity ranges from low diversity (dominated by freshwater species) high abundance, under strong freshwater inflow to high diversity low abundance under a balanced marine/freshwater input, to low diversity (dominated by marine species) high abundance under strong marine influence **Confidence:** 60 %
Other water quality (system variables, nutrients and toxic substances) constituents: Low to medium nutrient levels lead to low benthic diatom and phytoplankton production therefore lack of filter feeders and species that actively select phytoplankton. **Confidence:** 60 %
Other biotic components: System appears to be driven by detritus from the *Phagmites* beds, perhaps one of the reasons for the relatively high abundance of detritus feeders such as the mullet species. **Confidence:** 60 %

Human interferences that have a **direct** influence on fish in the Breede River Estuary are:

Structures: Bank stabilisation and slipway construction in parts of the upper reaches of the estuary have removed large portions of limited shallow marginal foraging area. **Confidence:** 60 %
Human exploitation (consumptive or non-consumptive): Recreational angling removes 40 t and illegal netting 5 t of fish from the estuary each year. There appears to be a strong negative correlation between boat traffic and fish abundance and/or catchability within the estuary. **Confidence:** 60 %
Flood plain and catchment development: Refer to abiotic report. Dams and other instream obstacles hinder upstream migration of catadromous species **Confidence:** 60 %

e. Birds

Present State of birds in the Breede River Estuary is:

Biomass distribution: Most biomass in first 10km: 95% of birds in lower estuary in summer, 68% in winter **Confidence:** 80%
Species diversity, richness and rarity (e.g. provide details on endemic and Red Data species): Relatively high diversity: 48 waterbird species recorded. Red data species: African Black Oystercatcher, Caspian Tern (both in low numbers). **Confidence:** 80%
Seasonal and inter-annual variability, as well as flood situations and drought conditions Strong seasonal variability: Total of 1900 birds in summer, 379 in winter. Also variability associated with tidal phase due to availability of mudflat area. **Confidence:** 80%
Assessment of the relationship to other nearby estuarine and marine systems: Probably some interchange of birds with neighbouring estuaries. Marine species (cormorants, gulls, terns) move into the estuary from surrounding coastal areas. Egyptian geese move between the estuary and agricultural fields. **Confidence:** 80%
Local/regional/national importance of the estuary in terms of the biotic component: Fairly high due to overall numbers and diversity of birds in the context of all South African estuaries. **Confidence:** 80%

Important abiotic and biotic components that may influence birds in the Breede River Estuary are:

State of the mouth: Not applicable, since the mouth does not close. **Confidence:** 80%
Flood plain inundation: Not significant, since estuary is a drowned valley, ie steep-sided **Confidence:** 80%
Exposure of intertidal areas during low tide: Very important for birds, since the avifauna is dominated by intertidally foraging birds, especially waders. This study shows that change in area exposed between spring and neap tides has a marked influence on bird numbers. **Confidence:** 80%
Salinity distributions in the estuary (including the size of the REI): Has a significant impact on certain bird species that tend to stay in freshwater habitats (e.g. rails, certain waterfowl), but these birds are not numerous in the estuary. **Confidence:** 80%
Other water quality (system variables, nutrients and toxic substances) constituents: These only have an indirect influence, through their impact on bird food supplies (plants, invertebrates & fish) **Confidence:** 80%
Other biotic components: These are the most important components that influence birds (availability of suitable plants, invertebrates, fish). Not all aspects of these relationships are well understood, but we have a good gut feel for them (see report for detailed analysis) **Confidence:** 60-80%

Human interferences that have a **direct** influence on birds in the Breede River Estuary are:

Structures: Jetties provide perches and roosting sites for birds. They are particularly important for Kingfishers and Reed Cormorants. **Confidence:** 80%
Human exploitation (consumptive or non-consumptive): People on mudflats decrease foraging areas available to birds through direct disturbance, and reduce food available to invertebrate feeders and piscivores through bait collection and fishing. Boating also disturbs birds, especially in the upper estuary. **Confidence:** 80%
Flood plain and catchment development: Developments affecting the availability of wetland habitats and grain would influence the regional populations of some of the birds that frequent the estuary. **Confidence:** 80%

STEP 3b : ASSESSMENT OF REFERENCE CONDITION

Abiotic Components

a. River inflow characteristics

Floods

Refer to the Assessment of the Present State (Step 3a).

Monthly flow distributions

Monthly-simulated runoff data for the Reference Condition, over a 64-year period (1927 to 1990), are provided in Table 2. The MAR under the Reference Condition was 1785 x 10^6 m^3.

A summary of flow distribution (mean monthly flows in m^3/s) for the Reference condition, derived from the 64-year simulated data set, is provided below:

MONTH	1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	158.932	85.748	64.854	50.683	41.626	38.337	36.348	31.065	27.026	22.176	19.082
Nov	138.147	68.130	52.649	33.690	30.400	25.397	22.060	19.225	16.933	14.916	11.477
Dec	59.568	32.405	22.042	15.849	14.532	12.612	11.388	10.587	9.470	8.800	6.046
Jan	111.280	15.375	10.963	9.206	8.173	6.623	5.715	5.597	5.434	4.852	3.726
Feb	84.199	36.430	17.063	9.704	7.930	6.146	5.453	4.844	3.905	3.544	2.998
Mar	45.452	26.115	20.652	14.581	11.951	9.640	8.003	5.529	4.698	3.324	1.858
Apr	186.977	84.958	44.601	29.230	22.334	16.966	14.217	10.446	8.013	5.269	3.158
May	292.024	180.408	97.353	69.089	54.640	42.429	37.688	27.829	20.706	15.642	5.896
Jun	327.049	239.358	154.698	132.459	95.324	73.599	57.191	45.807	35.626	20.945	9.476
Jul	347.328	212.407	163.158	137.806	112.115	101.913	84.546	67.214	53.756	39.097	22.244
Aug	631.810	218.223	164.191	141.620	122.035	98.286	83.347	74.610	60.521	54.900	30.466
Sep	201.414	148.398	120.631	90.414	77.525	69.035	56.725	50.555	43.938	37.383	29.665

b. Changes in occurrence and variability of Abiotic States in the Breede River Estuary under Reference Conditions

To estimate the occurrence and duration of the different Abiotic States during the Reference Condition, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively:

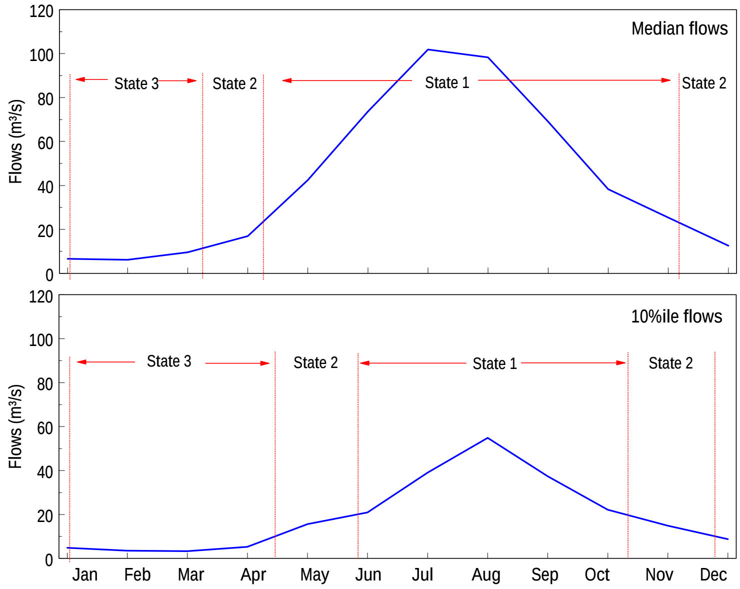


TABLE 2 : MONTHLY RUNOFF DATA (in m^3/s) FOR REFERENCE CONDITION, SIMULATED OVER A 64-YEAR PERIOD

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	19.73	22.34	8.78	5.66	3.73	22.73	9.87	2.93	135.91	55.15	60.61	68.53	34.66
1928	23.12	61.22	26.83	5.72	3.59	10.86	23.92	37.26	46.83	150.91	122.34	39.74	46.03
1929	21.77	12.70	17.27	10.18	47.11	26.03	9.70	7.70	8.61	24.44	79.66	128.36	32.79
1930	38.87	22.03	9.44	8.21	6.02	10.12	115.85	67.19	23.89	92.12	168.82	86.87	54.12
1931	90.67	33.50	46.62	18.97	51.02	10.75	4.54	45.06	58.20	91.00	50.01	185.25	57.13
1932	69.05	19.32	10.03	4.95	4.75	3.96	3.19	26.27	155.92	187.03	119.08	47.14	54.22
1933	26.92	20.98	10.36	8.87	9.87	9.30	4.58	27.26	39.00	49.53	81.50	83.79	31.00
1934	115.19	60.39	15.76	5.52	6.71	5.54	21.99	68.77	63.09	81.43	69.80	53.70	47.32
1935	23.66	28.12	11.39	8.31	4.95	4.18	3.11	29.97	19.35	75.89	99.90	73.92	31.90
1936	30.93	120.09	68.42	12.09	5.32	20.44	17.88	40.93	153.81	176.07	51.58	36.99	61.21
1937	23.51	17.42	16.66	14.69	4.44	11.42	33.27	57.76	37.05	47.46	64.26	73.60	33.46
1938	30.54	25.49	12.73	5.61	36.92	30.58	19.04	53.62	21.94	33.66	145.71	65.64	40.12
1939	21.38	13.61	7.90	4.39	43.01	20.64	45.86	30.73	83.84	53.20	32.91	36.49	32.83
1940	20.69	46.32	15.65	11.40	5.51	3.01	78.10	188.11	244.41	137.99	130.90	227.46	92.46
1941	76.04	31.44	12.56	11.47	6.12	3.22	3.56	89.87	321.08	60.20	84.25	30.67	60.87
1942	30.00	16.66	25.72	57.77	23.49	14.00	17.09	16.82	54.65	104.71	141.46	103.61	50.50
1943	42.35	65.69	23.83	5.65	3.36	6.76	8.43	77.85	227.57	83.16	128.04	101.65	64.53
1944	50.67	23.52	10.59	4.81	3.19	2.11	7.84	179.69	268.44	280.06	189.66	51.03	89.30
1945	108.49	47.15	10.19	4.97	3.65	45.50	22.52	15.71	15.09	31.51	55.19	130.41	40.86
1946	37.65	13.56	5.79	3.20	2.83	45.42	19.17	21.91	20.52	165.62	75.15	41.90	37.73
1947	33.10	20.29	8.96	5.58	3.83	17.76	16.38	43.95	40.24	101.77	41.34	139.32	39.38
1948	160.31	57.10	8.84	5.06	3.18	1.84	20.37	18.90	31.28	62.62	79.89	68.41	43.15
1949	41.06	168.89	54.37	5.38	3.10	1.87	43.76	8.76	12.31	183.48	36.93	93.20	54.43
1950	38.51	68.02	24.18	45.44	18.88	5.83	37.13	17.88	185.86	104.46	59.95	90.10	58.02
1951	40.22	31.74	9.49	5.11	5.25	3.57	4.88	63.62	46.00	101.60	215.58	173.85	58.41
1952	50.57	118.04	35.80	6.80	4.34	2.53	123.84	118.29	39.11	157.03	96.25	39.32	65.99
1953	36.96	33.03	13.01	5.52	3.72	4.75	30.24	244.07	141.82	344.42	303.16	89.37	104.17
1954	36.93	18.73	11.13	8.82	126.66	32.28	8.44	7.64	70.74	177.79	344.35	66.49	75.83
1955	63.94	31.16	10.69	5.71	4.44	8.06	6.52	54.95	141.96	114.33	128.42	45.30	51.29
1956	36.33	17.38	13.74	6.57	35.29	13.66	10.46	204.67	337.21	274.38	219.35	88.38	104.78
1957	120.01	35.43	9.87	4.61	8.12	12.81	11.04	180.72	94.14	25.70	111.47	41.38	54.61
1958	31.00	18.10	7.75	9.15	12.01	9.20	101.65	279.34	45.47	80.36	147.45	54.06	66.29
1959	79.13	28.66	9.23	6.31	3.95	6.63	8.13	41.73	119.09	39.09	26.30	27.96	33.02
1960	17.98	11.77	11.69	15.67	6.93	5.08	10.31	32.88	56.94	53.59	96.67	127.75	37.27
1961	39.43	17.12	7.52	6.42	8.23	17.23	28.70	14.77	292.12	110.65	565.61	151.01	104.90
1962	158.12	78.44	24.03	8.41	4.85	24.69	14.10	27.87	35.32	104.21	201.38	47.06	60.71
1963	27.38	22.46	14.73	10.20	17.29	22.97	14.44	17.49	161.64	97.07	139.65	55.90	50.10
1964	38.16	49.68	16.94	6.90	9.16	20.67	26.64	71.96	45.85	53.86	67.40	35.39	36.88
1965	59.37	43.79	19.17	10.58	5.28	16.40	13.03	16.60	68.24	122.79	147.29	81.59	50.34
1966	24.98	10.99	6.20	4.04	4.94	8.63	186.41	97.55	187.30	67.31	59.90	47.21	58.79
1967	44.23	25.30	10.62	5.68	3.38	2.52	15.50	97.22	131.30	137.72	120.83	39.35	52.80
1968	87.23	29.41	11.95	8.02	5.86	3.82	23.40	15.61	35.83	39.11	54.78	71.63	32.22
1969	57.54	15.29	7.03	5.47	9.69	5.17	3.31	31.73	95.62	103.69	143.02	69.54	45.59
1970	32.60	15.86	11.79	5.31	12.08	14.38	46.25	25.52	29.50	161.52	168.19	48.84	47.65
1971	19.92	31.58	11.39	5.52	8.79	5.44	11.80	54.90	51.62	34.33	63.91	50.75	29.16
1972	20.41	17.79	9.39	4.39	3.53	6.85	11.29	7.78	9.99	151.63	80.37	48.70	31.01
1973	25.76	14.85	15.19	8.26	28.33	10.27	6.17	39.42	101.19	54.34	744.54	142.30	99.22
1974	54.88	30.65	12.59	7.80	5.44	5.15	16.84	119.48	76.46	112.48	118.24	52.60	51.05
1975	33.94	21.06	12.64	5.65	7.16	12.08	14.52	23.06	269.10	160.31	68.46	38.19	55.51
1976	50.78	118.16	41.03	16.34	22.93	12.91	66.83	313.63	310.63	352.27	367.76	75.14	145.70
1977	37.47	28.82	22.73	10.77	5.73	5.55	22.42	27.42	15.51	18.51	104.53	67.73	30.60
1978	43.47	22.19	15.28	6.67	37.40	18.87	6.34	40.96	97.78	70.36	85.55	76.72	43.47
1979	63.45	24.16	9.22	11.26	6.32	3.98	15.86	40.47	54.92	47.81	58.83	37.04	31.11
1980	31.07	78.34	42.00	202.39	59.26	22.92	63.42	45.93	33.78	135.74	171.90	182.06	89.07
1981	39.33	19.28	17.79	10.16	7.01	13.07	187.95	77.60	67.42	67.48	57.68	60.03	52.07
1982	34.47	16.41	13.40	5.60	9.22	9.84	6.38	116.84	187.18	243.71	81.76	116.06	70.07
1983	43.08	21.29	11.03	5.73	8.97	34.54	14.16	242.00	63.74	137.79	60.39	177.01	68.31
1984	82.02	36.32	21.59	23.04	16.92	36.19	32.81	33.07	133.94	223.28	159.33	54.09	71.05
1985	66.23	63.96	34.80	12.75	6.18	9.44	29.12	40.46	89.82	121.51	338.19	127.49	78.33
1986	41.77	27.79	10.64	7.57	3.75	4.63	47.44	108.19	112.76	90.10	161.53	77.73	57.82
1987	36.42	14.15	15.50	4.31	4.15	7.99	42.81	43.13	77.95	66.40	96.05	99.87	42.39
1988	32.55	15.59	10.56	5.52	5.63	26.15	87.90	61.39	83.90	102.06	132.38	186.12	62.48
1989	82.30	68.18	15.11	6.42	12.76	9.42	89.20	88.32	132.30	183.66	85.89	35.47	67.42
1990	27.10	15.07	12.78	9.71	10.11	5.44	6.76	45.75	153.88	314.72	83.12	114.32	66.56
< 0.5	0	0	0	0	0	0	0	0	0	0	0	0	
0.5 - 3.0	0	0	0	0	1	5	0	1	0	0	0	0	
3.0 -10.0	0	0	15	46	45	28	18	4	2	0	0	0	
10.0 - 20.0	3	21	35	14	7	16	18	8	4	1	0	0	
> 20.0	61	43	14	4	11	15	28	51	58	63	64	64	

- Under the Reference Condition, the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)	
Months	Duration
Jan – Mar	3 months

DROUGHTS (10%ile)	
Months	Duration
Dec - Apr	5 months

- The average, as well as the maximum distances (in km), at which certain salinities penetrate during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)		
SALINITY (ppt)	DISTANCE FROM MOUTH (km)	
	Average	Maximum
30	7	9
20	12	14
10	19	22

DROUGHTS (10%ile)		
SALINITY (ppt)	DISTANCE FROM MOUTH (km)	
	Average	Maximum
30	9	11
20	15	20
10	26	31

- The average and maximum salinities at the head of the estuary (about 52 km from the mouth) during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Salinities (ppt) at head of estuary	
Average	Maximum
<1	<1

DROUGHTS (10%ile) Salinities (ppt) at head of estuary	
Average	Maximum
<1	<1

- The average and maximum salinities at 12 km from the mouth during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
20	Move past with tide
30	None

DROUGHTS (10%Ile) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
20	3
30	None

c. In the absence of changes brought about by anthropogenic influences (identified under the Present State [Step 3a]), reference condition abiotic characteristics (the Reference Condition of the estuary) would have differed from its Present State as follows

Structures: The river inflow would have been that predicted for the Reference Condition **Confidence:** 80%
Human exploitation (consumptive or non-consumptive): N/A **Confidence:** -
Point/diffuse source discharges affecting WQ: Nutrients: Nitrate inputs during winter would have been lower. Pesticides and herbicides would not have been an issue. **Confidence:** 60%

Biotic Components

The following assessments are based on the predicted abiotic characteristics of the Breede Estuary for the Reference Condition (refer to pages 25 to 27) and excluding **direct** human impacts on biotic components identified under the Present State (Step 3a).

a. *Microalgae*

For microalgae the Reference Condition would have differed from the Present State as follows:

<u>Species diversity, richness and rarity</u>: Under natural conditions the important ecological considerations are what was happening out at sea. Under reference conditions there were some periods in summer where the estuary existed but for most of the time the system was a river mouth. Diversity would not likely have been much different to today. The dominant species would likely have changed due to the altered mineral content of the freshwater (agriculture) and the increase in marine intrusion. No evidence exists to indicate that the altered mineral content is detrimental or beneficial to microalgae. Species richness likely to be relatively unchanged. Unlikely that any very rare species would have been removed. **Motivation:** There is very little information in this regard for phytomicrobenthos and phytoplankton. Not likely that any differences would be functionally significant within the estuary but the big difference is out at sea. This should be seen at the national and international level as a potentially serious cumulative impact. **Confidence:** 40%
<u>Biomass distribution:</u> Unlikely to be big change in distribution except that the reduction in annual and seasonal water flow would have made what was a strong river mouth, a bit more estuarine. Uncertain whether biomass would be higher or lower. **Motivation:** The intertidal and subtidal areas are unchanged. Flow characteristics are unlikely to have changed enough to affect this component strongly. The productivity of the nearshore marine areas would have been higher under reference conditions. **Confidence:** 60%
<u>Seasonal variability and community composition:</u> Only very small changes are likely to have occurred. **Motivation:** Seasonal effects are marginal in the case of microalgae as far as we know, because there are not great temperature differences between winter and summer. **Confidence:** 40%

b. *Macrophytes*

For macrophytes the Reference Condition would have differed from the Present State as follows:

<u>Species diversity, richness and rarity</u>: No change. **Motivation**: Although there has been a reduction in flow the same plant community types and species would be present. **Confidence:** 80 %
<u>Biomass distribution</u>: Larger reed beds with greater biomass may have characterized the reference condition. Pondweed (*Potamogeton pectinatus*) would have been more abundant. **Motivation:** The reeds occur from 12 km upstream from the mouth of the estuary to the tidal head. Under reference conditions 20 ppt salinity would not have occurred at the 12 km site. Now 20 ppt occurs for 4-5 months of the year. This higher salinity would reduce the growth and abundance of reeds as long as their roots are not located in brackish water (<20 ppt). Pondweed grows optimally in a salinity less than 10 ppt. Under reference conditions the 10 ppt zone would have extended to 22 km upstream. Under present conditions this zone now starts at 37 km so overall 15 km of potential habitat has been lost. **Confidence:** 60 %
<u>Seasonal variability and Community composition:</u> Little change. **Motivation:** Although the duration of the high flow winter season has been reduced this is expected to have little impact on the macrophytes. **Confidence:** 60 %

c. *Invertebrates*

For invertebrates the Reference Condition would have differed from the Present State as follows:

Species diversity, richness and rarity: Under the reference condition, species diversity and richness were probably similar to present day conditions, although the presence of some species on the intertidal sandbank near the mouth may have been more variable over time. **Motivation**: Freshwater dominance extending far downstream may have resulted in salinity values falling below threshold levels for some species. During dry years, salinity would have extended further upstream, enabling recolonisation of the lower estuary by some species. For some benthic invertebrates, deep scour holes would have trapped pockets of more dense water, providing refugia at times. **Confidence:** 80%
Biomass distribution: The biomass of some estuarine endemic invertebrates species is likely to have been less under natural conditions **Motivation:** River dominance would have extended further downstream and persisted for longer, particularly during high rainfall years. This would negatively affect some species, particularly during the breeding season. Larval forms are usually less tolerant of low salinity water compared to adults. Examples are sandprawn (*Callianassa kraussi*) and probably mudprawn (*Upogebia africana*). **Confidence:** 80%
Seasonal variability and Community composition: Populations of some estuarine species is likely to have fluctuated more between seasons compared to the present. By contrast, brackish water species probably extended further downstream at times. **Motivation**: Because the estuary would have been less affected by freshwater abstraction, river dominance was probably greater during the wet season, affecting those species relatively intolerant of salinity fluctuations. **Confidence:** 80%

d. Fish

For fish the Reference Condition would have differed from the Present State as follows:

Species diversity, richness and rarity: Possibly slightly higher due to presence of species that prefer low or zero salinities. **Motivation:** System was more river dominated **Confidence:** 60 %
Biomass distribution: Abundance was 6 % lower than present **Motivation**: Based on salinity preferences and densities of fish in various salinity ranges under present day conditions. The higher salinity zones were smaller in area than present. **Confidence**: 60 %
Seasonal variability and Community composition: Estuarine breeders and catadromous species were 15-25 % more abundant than present **Motivation:** Preferred salinities of the REI zone were more extensive during reference conditions **Confidence:** 60 %

e. Birds

For birds the Reference Condition would have differed from the Present State as follows:

Species diversity, richness and rarity: Small changes have occurred. **Motivation:** At least one species has disappeared from the estuary, and four others will have appeared since the Reference Condition prevailed, due to range expansions into the Western Cape. The African Black Oystercatcher appears to be declining. **Confidence:** 80%
Biomass distribution: Biomass not likely to have changed much, perhaps a slight decrease has occurred relative to Reference Condition. The distribution of biomass would have been predominantly in the lower estuary during both winter and summer. **Motivation**: Current conditions may favour more waders than reference condition, but human disturbance has probably contributed to greater losses. Egyptian geese would have been largely absent from the estuary in the Reference Condition. **Confidence:** 60%
Seasonal variability and Community composition: A marked change in community composition has probably occurred in certain groups. **Motivation:** Reference Condition probably had fewer of certain species of waders and more of certain species of waterfowl, and there have been additional changes in composition due to human disturbance and range expansion. Appearance and now predominance of Egyptian geese changes the community composition markedly. **Confidence:** 60%

STEP 4

DETERMINATION OF PRESENT STATUS CATEGORY AND ESTUARINE IMPORTANCE

STEP 4 : DETERMINATION OF PRESENT STATUS CATEGORY AND ESTUARINE IMPORTANCE

STEP 4a : DETERMINATION OF PRESENT STATUS CATEGORY

For the determination of RDM, the Present Status Category is determined using the Estuarine Health Index (EHI) described in detail in Appendix E3 of the *Resource Directed Measures for Protection of Water Resources: Estuarine Ecosystem Component* (www-dwaf.pwv.gov.za/idwaf/Documents). Details regarding the individual scoring systems are included in this report.

The EHI is sub-divided into:

The Habitat Health score determined by Abiotic variables (*hydrology, hydrodynamics and mouth condition, water quality, physical habitat alteration and human disturbance of habitat and biota*)

The Biological Health score determined by Biotic variables (*microalgae, macrophytes, invertebrates, fish and birds*)

The scores are 'percentage deviation' of the Present State from the Reference Condition, e.g. if the Present State is still the same as the Reference Condition, then the score is 100.

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. Reduction from natural MAR (%)	42.1	For some permanently open estuaries, such as the Breede River Estuary, critical low flow cut-offs are not easily definable. Changes in MAR, as a reflection in the reduction in flows, were therefore considered a more suitable indicator of change	80%
b. Decrease in mean annual frequency (%) of floods	21.6	Using average monthly flows of greater than 300 m^3/s	40%
Hydrology score	**66**		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of mouth closure, e.g. over a 5 or 10 year period	100	Not applicable to the Breede River Estuary	80%
Hydrodynamic score	100		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	75	Breede River Estuary used to be a freshwater dominated system where significant marine influence was limited to 3 of the 12 months of the year (i.e. State 3). Under Present Conditions, significant, and far stronger marine influence in the estuary occurs for 6 of the 12 months of the year.	60%
2a. Nitrate and phosphate concentration in the estuary	80	Nitrate concentrations in river inflows may have increased owing to agricultural activities in the catchment. No Reference Condition data on river inflows are available to confirm this.	40%
2b. Suspended solids in inflowing freshwater	80	Although agricultural activities in the catchment have probably led to higher suspended solid concentrations in river inflows, vegetation along the banks acts as a sediment trap.	40%
2c. Dissolved oxygen in inflowing freshwater	100	There are no available data, or any other evidence, that indicate reduction in DO levels in the freshwater inflows.	80%
2d. Levels of toxins	90	Pesticides and herbicides associated with agricultural activities could be an issue, but no data or any other evidence are available to confirm this.	40%
Water quality score	**78**		

Physical habitat alteration

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1a. Change in the inter- tidal exposed area (%)	100	No marked changes observed	80%
1b. Change in the sand fraction relative to total sand and mud (%)	75	Due to reduction in river inflows, particularly floods, an increase in marine sediments (i.e. sands) is expected in the lower reaches. Due to stronger seawater intrusion, flocculation of muds may now occur over larger areas.	40%
2. Change in sub-tidal area of the estuary: e.g. bed or channel modification, canalisation	100	No marked changes	80%
3. Migration barriers, bridges, weirs, bulkheads, training walls, jetties, marinas	90	There are a number of small jetties along the entire estuary, particularly in the lower reaches and near Malgas	80%
Physical Habitat score	**92**		

Human disturbance of habitats and biota

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. Degree of human non-consumptive activity on the estuary, e.g. walking, water-skiing, and associated damage to habitats (e.g. trampling, boating activity).	30	The estuary is used extensively during the summer season for recreational activities.	60%
b. Degree of human consumptive activity (fishing and bait collecting) on the estuary, and associated levels of exploitation and damage to habitats (e.g. digging by bait collectors).	10	Recreational angling removes 40 t and illegal netting 5 t of fish from the estuary each year. There appears to be a strong negative correlation between boat traffic and fish abundance and/or catchability within the estuary.	60%
Human Disturbance score	**18**		

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	Large numbers of taxa are common	40%
2a. Abundance	90	Altered mineral nutrient concentration	60%
2b. Community composition	90	Some species will have changed due to altered minerals	40%
Microalgae score	**90**		

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	No change from Reference Condition	80%
2a. Abundance	80	A predicted decrease in the abundance of *Phragmites australis* (common reed) and *Potamogeton pectinatus* (pondweed) as a result of an increase in salinity.	60%
2b. Community composition	100	No change from Reference Condition	60%
Macrophyte score	**80**		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	Under the Reference Condition, species diversity and richness were probably similar to present day conditions, although the presence of some species on the intertidal sandbank near the mouth may have been more variable over time.	80%
2a. Abundance	90	The biomass of some estuarine endemic invertebrates species is likely to have been less under natural conditions, because river dominance would have extended further downstream and persisted for longer, particularly during high rainfall years. This would negatively affect some species, particularly during the breeding season.	80%
2b. Community composition	80	Populations of some estuarine species are likely to have fluctuated more between seasons compared to the present. Because the estuary would have been less affected by freshwater abstraction, river dominance was probably greater during the wet season, affecting those species relatively intolerant of salinity fluctuations.	80%
Invertebrate score	**80**		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	99	Possible loss of one or two species that prefer lower salinities. Introduced freshwater species in upper reaches	60%
2a. Abundance	80	15-25 % decrease in estuarine breeders & catadromous species. Overall 6 % increase in abundance	60%
2b. Community composition	80	15-25 % decrease in estuarine breeders & catadromous species. 12-20 % increase and decrease in abundance of the four dominant piscivores and benthic feeders	60%
Fish score	**80**		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	At least one species has disappeared from the estuary, and four others will have appeared since the Reference Condition prevailed, due to range expansions into the Western Cape. The African Black Oystercatcher appears to be declining.	80%
2a. Abundance	90	Present Conditions may favour more waders than reference condition, but human disturbance has probably contributed to greater losses. Egyptian geese would have been largely absent from the estuary in the reference state.	60%
2b. Community composition	85	Reference Condition probably had fewer of certain species of waders and more of certain species of waterfowl, and there have been additional changes in composition due to human disturbance and range expansion. Appearance and now predominance of Egyptian geese changes the community composition markedly.	60%
Bird score	**85**		

The individual scores for each of the above components are incorporated into a Habitat health score and Biological health score. This allows for the determination of the Estuarine Health Score:

VARIABLE	SCORE	WEIGHT
Hydrology	66	25
Hydrodynamics and mouth condition	100	20
Water quality	78	20
Physical habitat	92	20
Human disturbance	18	15
HABITAT HEALTH SCORE	**73**	**50**
Microalgae	90	20
Macrophytes	80	20
Invertebrates	80	20
Fish	80	20
Birds	85	20
BIOLOGICAL HEALTH SCORE	**83**	**50**
ESTUARINE HEALTH INDEX (EHI) SCORE	**78***	

The EHI score determined for the Breede River Estuary, based on its Present State, is 78 translating into a Present Status Category of B (see below) (Confidence = 60%)

EHI SCORE	PRESENT STATUS CATEGORY	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

STEP 4b : DETERMINATION OF THE ECOLOGICAL IMPORTANCE OF THE BREEDE RIVER ESTUARY

Ecological importance is an expression of the value of a specific estuary to maintaining ecological diversity and functioning of estuarine systems on local and wider scales. The variables selected for the estuarine importance rating index were:

- Estuary size
- Zonal type rarity
- Habitat diversity
- Biodiversity importance
- Functional importance

Each of the above can be categorised as measures of rarity, abundance or ecological function. The rationale for selecting these variables, as well as further details on the estuarine importance index are discussed in detail Appendix E4 of the *Resource Directed Measures for Protection of Water Resources: Estuarine Ecosystem Component* (www-dwaf.pwv.gov.za/idwaf/Documents).

For this study, the Ecological importance determination of the Breede River Estuary was obtained from the *Estuarine Prioritisation for RDM* project (Turpie *et al.,* 2000, report submitted to Social and Ecological Services, DWAF, Pretoria).

The Estuarine Importance Index scores allocated to the Breede River Estuary, *based on its Present State*, were as follows:

Estuary Size

SCORE	MOTIVATION
100	The estuary falls within the top 10% percentile in terms of size for all South African estuaries. Top percentile scores 100, second top scores 90, and so on.

Zonal Type Rarity

SCORE	MOTIVATION
20	The estuary is one of 29 permanently open estuaries within the Warm South Temperate biogeographical zone. The Zonal Type Rarity index is thus 1/29 = 3, which falls into the lowest 20% percentile in terms of all estuarine ZTR scores. The score assigned is thus 20.

Habitat Diversity

SCORE	MOTIVATION
90	This score is calculated on the basis of the amount of each habitat type present in the estuary in relation to the total area of this habitat in South African estuaries. The score (x ha/x ha) for each habitat is summed to obtain the rarity value. The value obtained falls within the second 10% percentile for the scores generated from.

Biodiversity Importance

SUB-COMPONENTS	SCORE	MOTIVATION
Plants	80	This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as 1/number of estuaries in which the species occurs in South Africa (based on actual records of presence). The summed value obtained falls within the third 10% percentile for the scores generated from all South African estuaries, and is thus assigned a score of 80.
Invertebrates	30	This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as 1/number of estuaries in which the species occurs in South Africa (based on interpolated presence records from species distributions). The summed value obtained falls within the eighth 10% percentile for the scores generated from all South African estuaries, and is thus assigned a score of 30.
Fish	90	This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as 1/number of estuaries in which the species occurs in South Africa (based on actual records of presence). The summed value obtained falls within the second 10% percentile for the scores generated from all South African estuaries, and is thus assigned a score of 90.
Bird	90	This score is calculated by adding rarity scores for each species present in the estuary, where rarity scores for each species are calculated as 1/number of estuaries in which the species occurs in South Africa (based on actual records of presence). The summed value obtained falls within the second 10% percentile for the scores generated from all South African estuaries, and is thus assigned a score of 90.
Biodiversity score	**85.5**	

Functional Importance

SUB-COMPONENTS	SCORE	MOTIVATION
Out welling of detritus and nutrients to the coastal zone	100	The estuary functioned as a river mouth under natural flow conditions, supplying important materials to the nearshore marine environment.
Nursery function for marine fish and crustaceans	100	The estuary is extremely important as a nursery for fish (refer to Appendix G)
Movement corridor for river invertebrates that breed in the marine environment	100	The estuary is extremely important as a movement corridor for river invertebrates that breed in the marine environment (refer to Appendix F)
Stop-over function for migratory birds	0	South Africa is not really a stopover destination for migrants (it is proposed that this be taken out - refer to Appendix B)
Roosting area for marine or coastal birds	50	Roosting area in this estuary is not huge, but substantial numbers of gulls and terns roost in the mouth region
Functional score	**100***	

* Using the maximum score of the above

The individual scores obtained above are incorporated into the final Estuarine Importance Score as follows (for further details on the scoring system, refer to Appendix E4 of the *Resource Directed Measures for Protection of Water Resources: Estuarine Ecosystem Component* - www-dwaf.pwv.gov.za/idwaf/Documents):

CRITERION	SCORE	WEIGHT
Estuary size	100	15
Zonal Rarity Type	20	10
Habitat diversity	90	25
Biodiversity Importance	86	25
Functional Importance	100	25
ESTUARINE IMPORTANCE SCORE	**86**	

The Estuarine Importance Score for the Breede River Estuary, based on its Present State, is 86%, indicating that the estuary is highly important (see below).

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

STEP 5

DETERMINATION OF THE ECOLOGICAL RESERVE CATEGORY

STEP 5 : DETERMINATION OF THE ECOLOGICAL RESERVE CATEGORY

The Ecological Reserve Category (ERC) represents the level of protection assigned to an estuary. In turn, it is again used to determine the Ecological Reserve. The Ecological Reserve Category is used as a proxy for the overall Management Class (MC) in an Intermediate RDM determination. In a comprehensive RDM determination, the MC will be set in a consultative process on the basis of ERC and other socio-economic parameters.

For the Intermediate Determination of the RDM in estuaries the first step is to determine the 'minimum' ERC of an estuary, based on its Present Status Category. The relationship between EHI Score, Present Status Category and ERC is as follows:

EHI SCORE	PRESENT STATUS CATEGORIES	ECOLOGICAL RESERVE CATEGORY
91 – 100	A	A
76 – 90	B	B
61 – 75	C	C
41 – 60	D	D
21 – 40	E	Improve to at least a Category D
0 – 20	F	Improve to at least a Category D

NOTE: Should the Present Status Category 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).

The minimum ERC that could be allocated to an estuary, based on its Present Status Category can, be elevated, depending on:

- The Importance of the estuary (determined in Step 4b above).
- Modifying determinants, i.e. protected area status and desired protected area status. A status of "area requiring high protection" should be assigned to estuaries that are identified as vital for the full and most efficient representation of estuarine biodiversity.

The degree to which the minimum ERC (as derived from the Present Status Category) needs to be set at a higher level compared to the Present Status Category, but this is dependent on the level of importance, level of protection or desired protection and the best attainable state. The rules for allocation of the ERC are as follows:

CURRENT/DESIRED PROTECTION STATUS AND ESTUARINE IMPORTANCE	ECOLOGICAL RESERVE CATEGORY
Protected Area	A or BAS (Best Attainable State)
Desired Protected Area (based on complementarity)	A or BAS
Highly Important	**PES + 1, min B, or BAS**
Important	PES + 1, min C, or BAS
Of low to average importance	PES, min D

According to the rules the recommended Ecological Reserve Category (ERC) for the Breede River Estuary should be (refer to above table):

- Because the Breede River Estuary is highly important (reflected by Estuarine Importance Score of 86), the ERC should be the '*Present Status Category, i.e. B +1'*, which implies a Category A or, if not possible,
- Best attainable state, with Category B the minimum requirement.

At the workshop, the specialist team concluded that the largest factor that contributed to the change in the state of the Breede River Estuary from the Reference Condition to its Present State (putting it in a Category B) was the large reduction in river inflow. Therefore, to improve the Breede River Estuary's ERC from a Category B to a Category A, a large amount of water, already abstracted in the catchment by dams, will have to be re-allocated to the estuary. As it was assumed unlikely that large volumes of water could be re-allocated to the estuary and being within the rules of the protocol (i.e. minimum score to be allocated to a 'highly important' estuary is Category B), the specialist team decided to keep the **recommended ERC of the Breede River Estuary as Category B (Confidence = 60%)**. It should be noted that the PES of the estuary is a low B (scored 78 in the range 76 – 90) and also falls in the lower portion of the 'highly important' ecological importance score range (scored 86% in the range 80 – 100%). It is therefore reasonable to manage the estuary so that it would improve within the B category PES.

STEP 6

QUANTIFICATION OF THE RESERVE AND SETTING OF RESOURCE QUALITY OBJECTIVES

STEP 6 : QUANTIFICATION OF THE RESERVE AND SETTING OF RESOURCE QUALITY OBJECTIVES

STEP 6a : DETERMINATION OF THE RESERVE FOR WATER QUANTITY

EVALUATION OF FUTURE SCENARIOS

The following future development scenarios were used in determination of the Reserve for water quantity:

DEVELOPMENT SCENARIO	MEAN ANNUAL RUN-OFF	SHORT DESCRIPTION
Limited Future	954 x 10^6 m^3	The two schemes associated with the limited development scenario (Michells Pass and Upper Molenaars diversions) are essentially run-of-river diversions of winter flows. Due to the fact that only the Michells Pass scheme relies on limited storage, high flows and very high flows (25% and 5% exceedance levels) are largely unaffected. As can be expected, winter low flows (75% and 95% exceedance levels) are reduced to some extent.
Moderate Future	863 x 10^6 m^3	The further implementation of the Ouplaas scheme in the Molenaars River, and the raising of Buffeljags Dam impact on inflows to the estuary in different ways: Winter low flows are reduced due to the regulation of winter floods in the Molenaars River and the additional storage created at Buffeljags Dam. Winter high flows remain largely unaffected due to the limited storage of the two schemes. The significant reduction of summer high flows is ascribed to the operation of the enlarged Buffeljags Dam.
Bromberg	772 x 10^6 m^3	Even after the provision of instream flow requirements, the implementation of Le Chasseur Dam on the main stem of the Breede River has the potential of severely reducing summer high and low inflows to the estuary. Substantial reductions of early to mid winter low and high flows are caused by the filling of available storage in Le Chasseur Dam. Flows during August and September are the least affected, and corresponds with the time of year when the dam would be full, or near to full. During a prolonged drought, a reduction of flows during this period can also be expected. The Bromberg Future Development scenario has a similar impact although slightly less severe, due to the proposed dams under this scenario being smaller.
Le Chasseur	649 x 10^6 m^3	

LIMITED DEVELOPMENT SCENARIO

Effect of Limited Development Scenario on Abiotic Components

a. River inflow characteristics

Floods

In the table below, the 13 highest monthly flows for the reference conditions obtained from the datasets of simulated monthly flows are listed and these are compared with the flows in the same months for the other scenarios. It is likely that during a month with such a high average flow a major flood with a much higher peak flow would have occurred. Therefore this analysis only gives an indication of the occurrence of major floods under the different scenarios.

YEAR/MONTH	SIMULATED RUNOFF SCENARIOS					
	Reference (Natural)	Present	Limited Development	Moderate Development	Bromberg	Le Chasseur
June 1942	321	194	186	174	162	115
July 1954	344	240	221	213	195	217
August 1954	303	260	222	220	216	224
August 1955	344	271	252	241	239	245
June 1957	337	244	232	210	195	188
August 1962	565	436	428	420	370	424
August 1974	744	577	569	562	525	435
May 1977	313	230	222	211	198	169
June 1977	310	211	201	194	190	197
July 1977	352	328	284	273	274	278
August 1977	367	352	343	312	312	315
August 1986	338	310	297	283	259	285
July 1991	314	227	216	208	183	148
Average	**381**	**99**	**283**	**271**	**255**	**249**
% of Reference	**100**	**78.4**	**74.2**	**71.3**	**66.9**	**65.4**

The relatively small further reduction of floods from the Present Condition, will probably have only minor additional effect on further reduction in flushing of sediments during floods.

Monthly flow distributions

Monthly-simulated runoff data for the Limited Development Scenario, over a 64-year period (1927 to 1990), are provided in Table 3. The MAR for this scenario is 954 x 10^6 m^3 (53.4% of natural MAR). A summary of flow distribution (mean monthly flows in m^3/s) for the Present State, derived from the 64-year simulated data set, is provided below:

MONTH	1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
	123.003	58.931	42.203	27.128	19.824	17.703	14.860	12.231	8.338	5.608	1.952
Nov	115.104	48.469	33.666	18.117	12.362	9.791	7.949	6.321	5.509	4.064	3.277
Dec	38.100	16.345	8.981	6.879	6.283	5.010	4.464	4.100	3.775	3.252	2.496
Jan	86.420	7.510	5.394	4.641	3.861	3.307	2.919	2.568	2.345	1.774	0.817
Feb	54.412	20.207	7.402	3.789	3.305	2.004	1.584	1.120	0.798	0.622	0.363
Mar	29.056	18.113	11.475	7.553	5.930	4.164	2.577	1.974	0.994	0.669	0.322
Apr	156.116	54.623	17.888	12.789	8.702	6.847	4.638	2.265	1.341	0.814	0.165
May	182.647	90.278	43.509	30.722	20.150	12.171	7.745	4.384	2.079	0.227	0.000
Jun	213.267	129.916	68.560	48.999	36.251	23.244	15.811	12.965	9.085	3.938	0.226
Jul	253.084	129.256	86.674	69.586	53.553	43.720	34.699	24.414	16.850	11.823	5.483
Aug	480.461	177.290	101.751	75.337	67.301	48.359	38.477	31.453	27.166	17.289	10.367
Sep	132.406	105.926	64.102	53.221	40.005	31.893	29.146	22.485	20.408	14.379	10.995

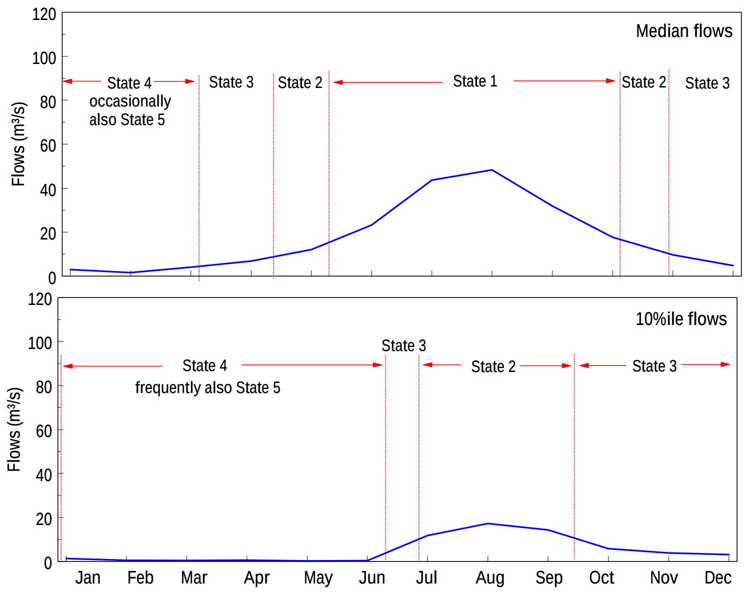
TABLE 3 : MONTHLY RUNOFF DATA (in m³/s) FOR LIMITED DEVELOPMENT SCENARIO, SIMULATED OVER A 64-YEAR PERIOD

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	0.00	7.73	2.84	1.12	0.49	13.20	3.46	0.00	44.70	7.43	17.04	23.26	10.11
1928	4.63	48.60	17.34	2.55	0.94	5.13	6.83	4.39	11.26	72.28	66.80	17.90	21.56
1929	6.48	4.01	7.73	4.56	31.14	18.52	4.15	2.67	2.05	4.13	31.88	51.83	14.10
1930	18.38	7.37	3.88	3.44	1.53	5.29	69.58	36.04	7.19	56.35	99.37	40.39	29.07
1931	59.40	17.57	34.57	11.72	32.25	4.30	0.87	7.74	17.32	28.55	17.87	137.10	30.77
1932	46.12	7.70	4.36	1.91	1.08	1.11	0.65	0.19	48.64	94.50	63.67	22.06	24.33
1933	6.49	9.70	4.32	5.07	3.69	3.97	1.12	0.00	2.43	16.18	37.42	37.91	10.69
1934	84.32	40.79	6.83	2.50	1.98	1.28	6.94	21.42	21.16	35.09	35.88	24.08	23.52
1935	6.89	11.53	4.88	2.62	0.99	0.48	0.16	0.80	2.36	16.13	37.88	38.48	10.27
1936	12.59	100.96	41.86	6.06	1.61	9.95	4.80	3.18	48.89	89.17	26.08	16.00	30.10
1937	5.83	7.11	9.31	6.54	0.96	6.73	14.18	24.22	9.13	16.83	24.99	27.47	12.77
1938	11.25	12.12	5.93	2.39	20.25	21.02	7.62	11.91	3.53	10.08	89.85	37.93	19.49
1939	5.50	3.84	2.81	0.61	26.00	12.05	14.18	4.06	20.34	16.87	10.43	12.51	10.77
1940	3.54	25.88	6.31	2.99	0.69	0.23	37.87	85.99	139.19	69.74	67.84	129.65	47.49
1941	47.70	14.74	4.83	6.31	1.79	0.84	0.54	36.64	186.10	31.76	42.26	12.05	32.13
1942	13.74	6.15	14.83	45.18	15.22	5.80	6.21	4.30	13.48	44.30	71.16	67.44	25.65
1943	19.90	47.67	12.77	3.09	0.68	2.39	1.99	36.31	108.28	34.60	75.08	70.60	34.45
1944	26.80	8.63	3.71	2.04	0.46	0.38	1.05	92.12	154.01	211.66	150.79	29.56	56.77
1945	87.66	30.17	4.27	2.63	0.75	32.71	13.36	2.53	3.30	6.21	14.80	55.29	21.14
1946	15.04	3.58	2.33	0.75	0.50	26.81	10.22	4.67	4.98	69.90	30.81	20.94	15.88
1947	13.23	8.32	4.04	2.39	0.79	8.47	6.29	10.97	9.59	42.23	14.13	62.78	15.27
1948	131.02	40.10	3.67	2.38	0.59	0.41	7.74	1.40	6.17	18.89	30.26	24.94	22.30
1949	19.51	138.73	35.72	2.78	1.13	0.41	18.18	0.32	0.29	69.57	15.16	34.68	28.04
1950	17.91	46.42	11.21	32.66	10.03	2.50	13.03	1.29	72.67	53.45	29.13	41.92	27.68
1951	16.89	10.68	3.19	2.00	1.04	0.63	0.64	20.72	12.02	39.79	127.29	107.82	28.56
1952	27.04	90.35	19.21	3.73	1.43	0.49	70.25	46.29	12.39	88.44	47.47	20.61	35.64
1953	21.36	18.00	5.64	2.45	0.56	0.97	12.76	132.24	74.44	221.04	222.71	65.40	64.80
1954	14.43	5.82	4.46	5.24	82.11	21.91	1.64	0.00	23.30	90.02	252.65	44.09	45.47
1955	39.69	12.00	3.82	2.80	0.76	3.97	2.04	16.43	52.61	56.32	68.50	17.47	23.03
1956	17.49	6.02	6.35	3.30	18.69	5.97	2.24	96.11	232.99	234.56	188.65	62.85	72.93
1957	93.33	18.60	4.34	2.75	1.92	6.61	3.87	117.34	54.13	10.34	52.32	20.11	32.14
1958	11.67	5.43	3.32	4.30	5.57	4.65	66.27	159.49	23.40	61.84	93.25	30.92	39.18
1959	55.46	13.74	3.96	3.16	0.91	2.17	1.92	12.26	44.16	13.28	10.26	9.57	14.24
1960	5.19	4.37	6.56	7.05	2.70	1.33	2.27	7.70	12.92	17.72	44.92	63.24	14.66
1961	18.33	6.05	3.18	2.56	2.45	9.96	9.35	0.51	156.82	59.17	428.20	119.45	68.00
1962	118.29	57.33	11.56	4.52	1.49	17.14	9.20	17.85	15.44	31.49	107.15	22.53	34.50
1963	12.29	9.75	5.69	5.45	6.32	15.78	6.87	0.08	73.92	43.14	77.62	28.10	23.75
1964	17.97	28.70	7.85	3.83	2.29	7.53	8.34	20.94	12.97	20.78	29.47	13.29	14.50
1965	39.42	28.73	8.34	5.12	1.57	1.30	1.32	1.28	13.86	50.81	94.17	48.70	24.55
1966	8.54	3.07	2.94	1.27	1.77	4.52	150.46	75.94	100.33	31.86	29.23	21.97	35.99
1967	22.87	9.38	4.32	2.92	0.54	0.63	4.33	39.75	54.38	71.53	67.43	17.30	24.61
1968	53.56	14.11	4.60	3.82	1.28	0.92	8.73	4.38	14.43	13.60	16.00	22.06	13.12
1969	27.92	3.98	2.35	1.60	3.68	1.21	0.00	0.00	32.85	36.00	72.98	31.29	17.82
1970	10.99	4.09	3.37	1.15	4.44	5.97	20.62	14.01	9.10	98.18	113.92	30.36	26.35
1971	5.85	17.98	6.42	2.51	3.64	2.24	5.41	11.86	14.95	12.05	31.52	21.99	11.37
1972	5.39	4.30	2.81	0.86	0.19	0.26	0.70	0.00	0.03	63.98	24.96	13.27	9.73
1973	8.34	3.78	5.04	2.41	19.99	7.77	0.81	20.99	39.82	17.21	569.44	105.95	66.80
1974	31.08	9.68	3.81	3.76	0.81	0.77	4.82	43.58	21.42	48.32	62.82	31.14	21.83
1975	14.82	5.96	3.62	1.84	1.89	5.95	9.34	5.86	158.22	85.50	33.95	18.43	28.78
1976	28.78	79.38	19.34	6.69	17.63	7.22	43.09	222.07	201.68	284.62	343.61	49.85	108.66
1977	16.88	11.93	7.50	4.24	0.96	0.82	9.99	7.53	4.89	10.64	42.66	32.22	12.52
1978	17.27	5.49	6.48	3.29	33.77	11.09	0.58	10.85	37.10	21.74	40.88	31.57	18.34
1979	33.79	5.94	3.59	5.14	1.55	0.61	4.60	5.84	13.16	11.73	18.05	13.69	9.81
1980	10.58	60.06	16.96	156.44	37.52	13.12	49.06	20.91	8.54	51.75	103.50	95.98	52.04
1981	18.55	6.99	6.73	4.87	1.13	5.43	165.75	61.16	23.15	24.71	26.61	34.74	31.65
1982	16.05	5.15	4.62	1.19	2.07	1.01	0.26	40.11	85.07	139.39	49.25	58.96	33.59
1983	22.66	8.10	4.58	2.16	1.49	20.02	3.84	122.48	24.27	70.53	27.54	114.55	35.19
1984	57.84	15.24	7.53	12.43	8.97	19.36	17.59	12.61	62.95	141.70	130.57	29.04	42.98
1985	48.19	39.05	9.23	4.71	1.79	2.98	8.58	9.56	19.45	53.58	297.63	105.87	50.05
1986	19.95	8.62	3.87	3.53	0.50	0.52	32.50	52.70	46.56	38.90	100.59	52.99	30.10
1987	13.39	3.04	4.95	1.59	0.52	1.71	16.30	15.58	32.37	24.88	35.61	60.21	17.51
1988	9.77	3.45	3.63	1.46	0.71	12.60	57.01	30.13	27.41	44.65	72.29	127.37	32.54
1989	67.93	38.63	5.55	3.15	3.40	2.04	80.01	43.46	65.82	105.60	46.32	13.38	39.61
1990	8.07	3.54	4.17	2.93	1.70	0.79	0.65	3.39	50.01	216.53	55.34	82.86	35.83

< 0.5	1	0	0	0	3	7	3	8	2	0	0	0
0.5 – 3.0	0	0	6	32	41	23	17	7	3	0	0	0
3.0 –10.0	14	34	47	27	8	20	23	13	10	3	0	1
10.0 - 20.0	25	13	8	2	5	9	9	10	13	14	9	11
> 20.0	24	17	3	3	7	5	12	26	36	47	55	52

b. *Predicted changes in occurrence and variability of Abiotic States under the Limited Development Scenario, are as follows:*

To estimate the occurrence and duration of the different Abiotic States during the Limited Future Development Scenario, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively:



- Under the Limited Development Scenario, the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)	
Months	Duration
Nov – Apr	6 months

DROUGHTS (10%ile)	
Months	Duration
Oct - Jun	9 months

- The average, as well as the maximum distances (in km), at which certain salinities penetrate during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)		
SALINITY (ppt)	DISTANCE FROM MOUTH (km)	
	Average	Maximum
30	9	12
20	16	26
10	28	37

DROUGHTS (10%ile)		
SALINITY (ppt)	DISTANCE FROM MOUTH (km)	
	Average	Maximum
30	12	23
20	27	43
10	41	None

- The average and maximum salinities at the head of the estuary (about 52 km from the mouth) during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Salinities (ppt) at head of estuary	
Average	Maximum
<1	~3

DROUGHTS (10%ile) Salinities (ppt) at head of estuary	
Average	Maximum
~2.5	~14

- The average and maximum salinities at 12 km from the mouth during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
20	4 - 5
30	Few tidal cycles

DROUGHTS (10%Ile) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
20	7 - 8
30	4

Predicted Effects of Limited Development Scenario on Biotic Components

a. Microalgae

Based on the predicted changes in the occurrence and variability in Abiotic States, microalgae under the Limited Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Very little change. Under limited development. **Motivation:** Similar conditions as described for Present State would apply. **Confidence:** 60 %
Biomass distribution: Small change within the estuary and out at sea under limited development. **Motivation:** Similar conditions as described for Present State would apply. **Confidence:** 60 %
Seasonal variability and Community composition: Very little change under limited development. **Motivation:** Similar conditions as described for Present State would apply. **Confidence:** 60 %

b. Macrophytes

Based on the predicted changes in the occurrence and variability in Abiotic states, macrophytes under the Limited Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: No change **Motivation:** Similar conditions as those described for the Present State would apply. **Confidence:** 80%
Biomass distribution: No change **Motivation:** Similar conditions as those described for the Present State would apply. **Confidence:** 80%
Seasonal variability and Community composition: No change **Motivation:** Similar conditions as those described for the Present State would apply. **Confidence:** 80 %

c. Invertebrates

Based on the predicted changes in the occurrence and variability in Abiotic States, invertebrates under the Limited Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Not likely to change significantly. **Motivation**: Salinity changes are small – macrophyte distribution (providing specialized habitat for some species) is not likely to change significantly. **Confidence:** 80%
Biomass distribution: Not likely to change significantly. **Motivation:** Salinity changes are small – macrophyte distribution (providing habitat for some species) not likely to change significantly. **Confidence**: 80%
Seasonal variability and Community composition: Not likely to change significantly. **Motivation**: Salinity changes are small – macrophyte distribution (providing habitat for some species) not likely to change significantly. **Confidence:** 80%

d. Fish

Based on the predicted changes in the occurrence and variability in Abiotic states, fish under the Limited Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Possibly slightly lower due to decrease of species that prefer low or zero salinities. **Motivation:** System less river dominated **Confidence:** 60 %
Biomass distribution: Overall abundance 8 % greater than reference conditions, 1-2 % greater than present day **Motivation**: Based on salinity preferences and densities of fish in various salinity ranges under present day conditions. The higher salinity zones are greater in area than present. **Confidence**: 60 %
Seasonal variability and Community composition: Estuarine breeders and catadromous species 20-37 % less abundant than under reference conditions. 5-19 % increase in abundance of selective feeders that prefer less turbid conditions **Motivation:** Preferred salinities of the REI zone are more extensive under reference and present day conditions. Lower turbidity in the lower reaches **Confidence:** 60 %

e. Birds

Based on the predicted changes in the occurrence and variability in Abiotic states, birds under the Limited Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: No change **Motivation:** Little or no predicted change in macrophytes, invertebrates or fish **Confidence:** 60%
Biomass: Minor change **Motivation:** Little or no predicted change in macrophytes, invertebrates or fish **Confidence:** 60%
Seasonal variability and Community composition: Minor change **Motivation:** Little or no predicted change in macrophytes, invertebrates or fish **Confidence:** 60%

Effect of predicted changes in Abiotic and Biotic components under the Limited Development Scenario on the Present Status Category of the Breede River Estuary, using the EHI:

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. Reduction in MAR (%)	46.6	For some permanently open estuary, such as the Breede River Estuary, critical low flow cut off are not easily definable. Changes in MAR, as a reflection in the reduction in flows, were therefore considered a more suitable indicator of change	60%
b. Decrease in mean annual frequency (%) of floods	25.8	Using average monthly flows of greater than 300 m3/s	40%
Hydrology score	**62**		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of mouth closure, e.g. over a 5 or 10 year period	100	Not applicable to the Breede River Estuary	80%
Hydrodynamic score	**100**		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	71	Use the increase in marine dominance as an indicator. Breede River Estuary use to be a freshwater dominated system where significant marine influence was limited to 3 months of the year (i.e. State 3). Under Present Conditions, significant, and far stronger marine influence in the estuary occurs for 6.5 months of the year.	60%
2a. Nitrate and phosphate concentration in the estuary	80	Nitrate concentrations in river inflows may have increased owing to agricultural activities in the catchment. No Reference Condition data on river inflows are available to confirm this.	40%
2b. Suspended solids in present in inflowing freshwater	80	Although agricultural activities in the catchment probably led to higher suspended solid concentrations in river inflows, vegetation along the banks acts as a sediment trap.	40%
2c. Dissolved oxygen in inflowing freshwater	100	There are no available data, or any other evidence, that indicate reduction in DO levels in the freshwater inflows.	80%
2d. Levels of toxins	90	Pesticides and herbicides associated with agricultural activities could be an issue, but no data or any other evidence are available to confirm this.	40%
Water quality score	**76**		

Physical habitat alteration

VARIABLE	SCORE	MOTIVATION	
1a. Change in the inter- tidal exposed area (%)	100	No marked changes observed	80%
1b. Change in the sand fraction relative to total sand and mud (%)	75	Due to reduction river inflows, particularly floods, an increase in marine sediments (i.e. sands) is expected in the lower reaches. Due to stronger seawater intrusion, flocculation of muds may now occur over larger area.	40%
2. Change in subtidal area of the estuary: e.g. bed or channel modification, canalisation	100	No marked changes	80%
3. Migration barriers, bridges, weirs, bulkheads, training walls, jetties, marinas	90	There are a number of small jetties along the entire estuary, particularly in the lower reaches and near Malgas	80%
Physical Habitat score	**92**		

Human disturbance of habitats and biota

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. Degree of human non-consumptive activity on the estuary, e.g. walking, water-skiing, and associated damage to habitats (e.g. trampling, boating activity).	30	The estuary is used extensively during the summer season for recreational activities.	60%
b. Degree of human consumptive activity (fishing and bait collecting) on the estuary, and associated levels of exploitation and damage to habitats (e.g. digging by bait collectors).	10	Recreational angling removes 40 t and illegal netting 5 t of fish from the estuary each year. There appears to be a strong negative correlation between boat traffic and fish abundance and/or catchability within the estuary.	60%
Human Disturbance score	**18**		

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	Similar conditions as described for Present State would apply.	60%
2a. Abundance	90	Similar conditions as described for Present State would apply.	60%
2b. Community composition	90	Similar conditions as described for Present State would apply.	60%
Microalgae score	**90**		

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	No change compared with Reference Condition	80%
2a. Abundance	80	A predicted decrease in the abundance of *Phragmites australis* (common reed) and *Potamogeton pectinatus* (pondweed) as a result of an increase in salinity.	80%
2b. Community composition	100	No change compared with Reference Condition.	80%
Macrophyte score	**80**		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	Not likely to change significantly from the Present State	80%
2a. Abundance	90	Not likely to change significantly from the Present State	60%
2b. Community composition	80	Not likely to change significantly from the Present State	60%
Invertebrate score	**80**		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	99	Possible loss of one or two species that prefer lower salinities.	60%
2a. Abundance	80	19-37 % decrease in estuarine breeders & catadromous species from Reference Conditions. Overall 8 % increase in abundance	60%
2b. Community composition	80	15-25 % decrease in estuarine breeders & catadromous species. 12-25 % increase and decrease in abundance of the four dominant piscivores and benthic feeders	60%
Fish score	**80**		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	No change compared with Present State	60%
2a. Abundance	90	Minor change compared with Present State	60%
2b. Community composition	85	Minor change compared with Present State	60%
Bird score	**85**		

The individual variable scores obtained for the Limited Development Scenario are incorporated into a Habitat health score and Biological health score and, finally into the Estuarine Health Score, as follows:

VARIABLE	EHI SCORE				
	Present State	**Limited Development**	**Moderate Development**	**Bromberg Development**	**Le Chasseur Development**
Hydrology	66	62			
Hydrodynamics and mouth condition	100	100			
Water quality	78	76			
Physical habitat	92	92			
Human disturbance	18	18			
HABITAT HEALTH SCORE	**73**	**72**			
Microalgae	90	90			
Macrophytes	80	80			
Invertebrates	80	80			
Fish	80	80			
Birds	85	85			
BIOLOGICAL HEALTH SCORE	**83**	**83**			
ESTUARINE HEALTH INDEX (EHI) SCORE	**78**	**77**			
CATEGORY	**B**	**B**			

MODERATE DEVELOPMENT SCENARIO

Effect of Moderate Development Scenario on Abiotic Components:

a. River inflow characteristics

Floods

In table below, the 13 highest monthly flows for the reference conditions obtained from the datasets of simulated monthly flows are listed and these are compared with the flows in the same months for the other scenarios. It is likely that during a month with such a high average flow a major flood with a much higher peak flow would have occurred. Therefore this analysis only gives an indication of the occurrence of major floods under the different scenarios.

YEAR/MONTH	SIMULATED RUNOFF SCENARIOS					
	Reference (Natural)	Present	Limited Development	Moderate Development	Bromberg	Le Chasseur
June 1942	321	194	186	174	162	115
July 1954	344	240	221	213	195	217
August 1954	303	260	222	220	216	224
August 1955	344	271	252	241	239	245
June 1957	337	244	232	210	195	188
August 1962	565	436	428	420	370	424
August 1974	744	577	569	562	525	435
May 1977	313	230	222	211	198	169
June 1977	310	211	201	194	190	197
July 1977	352	328	284	273	274	278
August 1977	367	352	343	312	312	315
August 1986	338	310	297	283	259	285
July 1991	314	227	216	208	183	148
Average	**381**	**99**	**283**	**271**	**255**	**249**
% of Reference	**100**	**78.4**	**74.2**	**71.3**	**66.9**	**65.4**

The relatively small further reduction of floods from the Present Condition, will probably have only minor additional effect on further reduction in flushing of sediments during floods.

Monthly flow distributions

Monthly-simulated runoff data for the Moderate Development Scenario, over a 64-year period (1927 to 1990) are provided in Table 4. The MAR for this scenario is 863 x 10^6 m^3 (48.3% of the natural MAR). A summary of flow distribution (mean monthly flows in m^3/s) for the Moderate Development Scenario, derived from the 64-year simulated data set, is provided below:

MONTH	1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	115.052	53.295	37.178	22.913	16.791	14.542	10.730	9.343	7.154	3.744	1.015
Nov	112.741	46.678	31.884	16.185	10.212	7.896	6.197	5.241	3.968	3.017	2.341
Dec	33.221	13.960	7.893	6.051	5.208	3.998	3.617	3.422	3.189	2.616	1.819
Jan	83.637	5.666	4.457	3.828	2.988	2.392	2.106	1.897	1.506	1.064	0.581
Feb	52.871	18.248	6.915	3.313	1.863	1.536	1.220	0.967	0.764	0.535	0.356
Mar	26.334	15.487	10.414	5.906	5.184	2.849	2.079	1.069	0.798	0.492	0.245
Apr	148.383	50.459	12.881	8.631	6.141	4.361	3.116	1.701	0.697	0.438	0.019
May	168.928	80.376	35.443	23.593	10.919	5.166	2.224	0.738	0.169	0.000	0.000
Jun	202.472	124.636	62.615	37.606	28.374	18.739	11.944	6.795	3.524	1.056	0.016
Jul	235.570	126.708	84.460	61.202	51.500	40.271	31.808	22.068	13.371	7.826	2.012
Aug	472.804	154.873	97.823	73.746	65.141	47.626	35.678	29.425	25.631	16.551	8.922
Sep	129.568	103.083	62.737	49.143	38.919	30.831	27.215	21.322	19.211	12.973	9.670

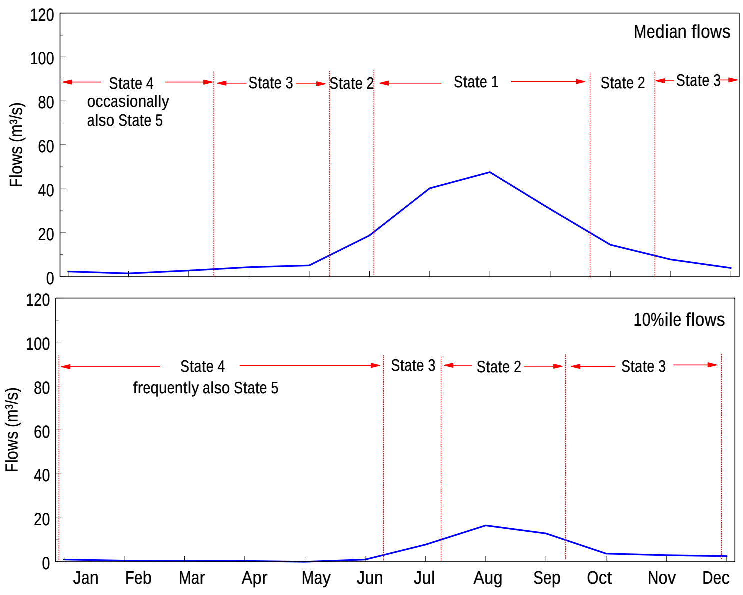
TABLE 4 : MONTHLY RUNOFF DATA (in m^3/s) FOR MODERATE DEVELOPMENT SCENARIO, SIMULATED OVER A 64-YEAR PERIOD

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	0.00	3.33	1.92	0.87	0.49	13.14	3.46	0.00	31.81	5.96	16.31	22.15	8.29
1928	3.00	47.79	15.35	2.08	0.83	3.95	2.74	0.18	1.12	69.42	65.72	16.72	19.07
1929	5.49	3.40	7.14	3.24	26.95	15.07	3.52	2.19	2.05	2.22	23.25	42.56	11.42
1930	14.70	6.04	3.26	3.25	1.53	5.29	65.08	29.55	3.07	53.37	95.20	39.31	26.64
1931	53.96	16.11	32.92	10.63	18.51	2.07	0.45	0.00	12.65	27.80	17.12	135.98	27.35
1932	44.20	6.14	3.61	1.37	1.08	1.08	0.43	0.13	32.02	92.38	62.75	20.88	22.17
1933	3.13	8.68	3.96	4.78	3.94	3.74	0.90	0.00	0.00	6.98	33.32	35.40	8.73
1934	79.56	37.76	5.29	1.92	1.87	1.13	3.38	13.88	18.26	29.84	35.18	22.98	20.92
1935	5.22	8.45	4.19	1.49	0.99	0.48	0.03	0.75	0.46	7.87	29.70	37.37	8.08
1936	9.69	99.54	33.73	5.04	1.44	5.48	1.89	0.00	37.04	87.56	25.30	14.80	26.79
1937	4.77	6.44	8.95	4.39	0.83	6.42	9.70	10.67	3.70	15.83	24.24	26.36	10.19
1938	7.16	9.72	5.15	1.99	15.30	19.14	6.20	2.35	0.83	6.11	85.42	36.80	16.35
1939	3.52	2.61	2.06	0.44	25.96	12.05	10.52	3.46	11.03	15.57	9.65	11.38	9.02
1940	1.61	17.73	6.04	2.81	0.69	0.23	32.38	76.76	134.07	68.08	66.66	120.69	43.98
1941	42.67	12.29	4.48	5.85	1.83	0.84	0.58	26.39	174.36	31.15	41.17	10.85	29.37
1942	12.25	5.60	14.48	44.31	15.41	5.37	5.90	2.62	6.90	36.56	69.40	66.35	23.76
1943	16.46	44.09	12.30	2.68	0.63	2.37	0.94	25.14	102.63	34.03	73.47	69.48	32.02
1944	22.71	5.78	3.09	1.47	0.45	0.38	0.21	81.93	143.36	203.55	137.14	28.35	52.37
1945	85.97	29.14	3.91	2.26	0.84	32.94	11.92	0.88	1.03	1.66	8.01	53.14	19.31
1946	9.62	2.60	1.94	0.66	0.50	22.46	8.56	1.81	2.42	55.34	30.08	19.75	12.98
1947	10.32	7.46	3.77	2.27	0.79	3.20	3.95	0.44	5.81	37.54	13.37	60.62	12.46
1948	125.30	38.16	3.29	1.86	0.58	0.41	5.84	1.40	0.25	7.81	28.86	23.83	19.80
1949	15.23	135.22	29.72	2.30	1.11	0.41	12.67	0.32	0.03	61.54	14.33	32.80	25.47
1950	14.80	42.64	10.53	31.84	10.00	2.50	7.01	0.17	67.60	52.43	28.39	40.80	25.73
1951	13.55	7.76	2.77	1.59	1.00	0.63	0.25	9.81	8.85	38.15	124.97	105.61	26.25
1952	23.52	86.87	18.52	3.45	1.48	0.49	57.36	44.55	11.83	86.85	46.79	19.40	33.42
1953	20.06	15.54	5.22	1.90	0.55	0.81	6.85	118.33	72.78	213.03	220.94	64.27	61.69
1954	10.79	4.53	3.45	4.56	78.87	22.00	1.11	0.00	13.14	85.39	241.52	42.92	42.36
1955	33.52	9.31	3.31	2.22	0.91	4.17	1.93	10.98	43.36	54.77	62.84	16.29	20.30
1956	14.64	5.61	5.93	3.00	12.38	5.44	1.77	85.82	216.61	194.40	162.48	61.72	64.15
1957	84.14	16.86	3.94	2.24	0.73	6.71	3.80	108.71	49.65	9.33	50.81	18.93	29.65
1958	8.10	4.22	3.01	4.14	5.82	4.75	59.62	143.87	22.79	61.17	91.96	29.75	36.60
1959	50.55	12.64	3.64	2.93	0.91	2.11	0.84	1.25	37.04	12.63	9.46	7.66	11.80
1960	1.81	3.59	5.88	6.87	2.67	1.32	2.27	7.25	4.56	13.87	43.28	61.06	12.87
1961	14.94	5.23	2.59	1.89	2.10	9.96	7.85	0.51	136.24	58.35	420.15	118.28	64.84
1962	109.04	53.60	11.06	4.21	1.76	17.42	9.25	16.79	11.45	22.19	103.11	21.37	31.77
1963	10.70	7.52	4.83	5.24	3.33	15.67	5.84	0.08	61.52	42.35	76.27	26.93	21.69
1964	14.44	25.21	6.98	2.46	1.78	2.12	3.26	13.99	12.40	20.18	28.71	12.12	11.97
1965	31.87	24.92	7.26	4.93	1.48	0.70	0.70	1.28	4.33	49.26	93.16	47.49	22.28
1966	7.88	2.79	2.54	1.04	1.71	4.52	142.57	68.11	92.78	31.25	28.05	20.82	33.67
1967	18.90	7.00	3.37	1.52	0.53	0.63	0.61	27.47	52.77	69.95	66.24	15.97	22.08
1968	45.29	13.14	4.03	2.05	1.26	0.92	4.94	0.00	5.08	6.93	15.29	20.69	9.97
1969	21.36	1.90	1.65	1.41	3.68	1.21	0.00	0.00	19.22	34.33	71.21	30.15	15.51
1970	7.71	2.91	2.67	0.92	4.36	5.86	19.51	10.68	5.02	86.71	111.33	28.93	23.88
1971	4.77	17.33	6.15	2.33	3.60	2.24	4.78	4.89	9.87	8.84	29.49	20.69	9.58
1972	2.47	4.30	2.74	0.85	0.19	0.26	0.70	0.00	0.03	49.76	24.23	12.16	8.14
1973	4.27	3.34	3.45	1.97	19.97	7.77	0.81	18.89	28.62	15.77	562.46	104.83	64.34
1974	25.38	8.04	3.43	3.17	0.97	0.90	3.01	31.14	19.45	46.66	61.44	29.49	19.42
1975	9.48	4.84	3.31	1.73	1.95	5.87	8.33	3.59	136.04	83.84	33.17	16.57	25.73
1976	26.93	75.32	14.74	4.58	17.63	7.33	34.78	211.60	194.17	273.95	312.29	48.70	101.83
1977	13.20	10.33	6.36	3.81	1.16	0.89	7.84	0.60	2.13	9.89	37.68	31.11	10.42
1978	13.81	4.73	5.95	3.11	33.77	11.09	0.58	5.45	29.21	20.99	40.10	30.55	16.61
1979	25.36	5.24	3.30	4.30	1.54	0.61	0.56	0.00	3.26	10.97	17.37	12.18	7.06
1980	7.41	52.28	12.76	150.61	37.60	13.12	48.13	20.22	7.40	48.29	101.75	93.88	49.45
1981	16.88	5.49	6.32	3.96	1.21	5.56	158.29	56.07	16.04	23.03	25.85	33.54	29.35
1982	10.40	3.44	2.48	0.85	1.96	1.01	0.26	29.89	81.49	136.50	48.46	55.41	31.01
1983	22.85	7.60	3.97	1.85	1.48	18.73	3.08	101.83	23.60	69.41	26.79	104.13	32.11
1984	51.74	14.17	4.82	10.44	8.56	14.87	13.20	8.42	60.48	136.99	119.62	25.54	39.07
1985	49.06	36.62	8.84	4.39	1.99	2.43	4.78	0.17	16.01	51.93	283.60	100.65	46.71
1986	19.91	8.08	3.59	1.93	0.50	0.50	30.35	42.11	42.73	38.19	93.33	47.11	27.36
1987	10.72	2.67	3.54	1.25	0.51	1.63	11.41	3.22	27.41	24.30	33.80	59.10	14.96
1988	7.40	2.72	2.98	1.11	0.71	6.25	51.46	23.42	22.63	43.04	70.98	125.80	29.88
1989	63.72	36.01	5.23	2.75	3.31	2.04	64.13	41.90	64.26	103.85	45.55	12.19	37.08
1990	7.14	3.26	3.47	2.50	1.68	0.79	0.28	0.00	36.28	208.64	54.57	70.03	32.39

< 0.5	1	0	0	1	3	7	8	17	5	0	0	0
0.5 - 3.0	4	7	11	37	41	25	16	11	6	2	0	0
3.0 -10.0	17	31	42	21	9	19	23	8	12	9	3	1
10.0 - 20.0	19	10	8	2	6	10	6	7	11	6	6	14
> 20.0	23	16	3	3	5	3	11	21	30	47	55	49

b. ***Predicted changes in occurrence and variability of Abiotic States Moderate Development Scenario, are as follows***

To estimate the occurrence and duration of the different Abiotic States during the Moderate Future Development Scenario, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively:



- Under the Moderate Development Scenario, the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)	
Months	Duration
Nov – May	7 months

DROUGHTS (10%ile)	
Months	Duration
Oct – Jul	10 months

- The average, as well as the maximum distances (in km), at which certain salinities penetrate during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)		
SALINITY (ppt)	**DISTANCE FROM MOUTH (km)**	
	Average	**Maximum**
30	9	13
20	17	28
10	30	40

DROUGHTS (10%ile)		
SALINITY (ppt)	**DISTANCE FROM MOUTH (km)**	
	Average	**Maximum**
30	13	27
20	28	46
10	45	None

- The average and maximum salinities at the head of the estuary (about 52 km from the mouth) during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Salinities (ppt) at head of estuary	
Average	Maximum
<1	~4

DROUGHTS (10%ile) Salinities (ppt) at head of estuary	
Average	Maximum
~3	~17

- The average and maximum salinities at 12 km from the mouth during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
20	5
30	Few tidal cycles

DROUGHTS (10%Ile) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
20	8
30	5 - 6

Predicted Effects of Moderate Development Scenario on Biotic Components

a. Microalgae

Based on the predicted changes in the occurrence and variability in Abiotic States, microalgae under the Moderate Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Very little change under Moderate Development Scenario compared with Present State **Motivation:** Similar conditions as described for Present State would apply as far as microalgae are concerned. **Confidence:** 40 %
Biomass distribution: Biomass in the estuary would probably increase, but there will be a decrease in biomass at sea compared with the Present State. **Motivation:** Lower flow to sea would provide a longer residence time within the estuary. As the flow decreases, the biomass in the estuary increases. **Confidence:** 40 %
Seasonal variability and Community composition: The community composition in the estuary decreases compared with the present. **Motivation:** The change reflects the greater sensitivity of community composition in the estuary to the higher salinity. However, change in community composition is not to be equated directly with estuarine condition, but also with near shore condition. **Confidence:** 40 %

b. Macrophytes

Based on the predicted changes in the occurrence and variability in Abiotic States, macrophytes under the Moderate Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Loss of pondweed habitat. **Motivation:** A further 3 km of pondweed habitat would be lost due to an increase in saline penetration upstream. The seagrass, *Zostera capensis* would colonise the middle reaches of the estuary and displace brackish species. **Confidence:** 60%
Biomass distribution: Decrease in pondweed and reed biomass. **Motivation:** There will be a loss of reeds as a result of the increase in salinity. Reeds would now be exposed to salinity of 20 ppt for 5 months during the low flow summer season. Regrowth could occur during the high flow months, but this is mainly during winter which is not the growing season for the plants. **Confidence:** 60%
Seasonal variability and Community composition: Change in species composition of the brackish salt marshes. **Motivation:** Brackish species such as *Juncus kraussii* and *Cotula cornopifolia* would be replaced by more salt tolerant species as a result of the increase in the duration of saline conditions in the lower and middle reaches of the estuary. **Confidence:** 60%

c. Invertebrates

Based on the predicted changes in the occurrence and variability in Abiotic States, invertebrates under the Moderate Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Not likely to change significantly. **Motivation**: Although marine dominance will extend further upstream, the same abiotic driving forces will influence the estuary and invertebrates inhabiting specific areas (although persistence and magnitude of species occurrence may change). **Confidence:** 80%
Biomass distribution: Biomass of some species will change. Intertidal areas inhabited by mudprawns *(Upogebia africana)* will probably extend further upstream. The biomass of river prawns will decrease (loss of habitat) as well as detritus derived from the reeds (probably an important food source for estuarine organisms). **Motivation:** Marine influence (particularly salinity) will extend further upstream, on average, but particularly during dry years. **Confidence:** 60%
Seasonal variability and Community composition: Seasonal variability will possibly increase, particularly during dry years. Greater variability in salinity further upstream is likely to affect composition of communities, particularly brackish water species. **Motivation**: Marine influence (particularly salinity) will extend further upstream, on average, but particularly during dry years **Confidence:** 60%

d. Fish

Based on the predicted changes in the occurrence and variability in Abiotic States, fish under the Moderate Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Possibly slightly lower due to near loss of species that prefer low or zero salinities. **Motivation:** System less river dominated, loss of variability in flow due to flow control from 2 rainfall zones **Confidence:** 40%
Biomass distribution: Overall abundance 9-15 % greater than reference conditions, 3-9 % greater than present day **Motivation**: Based on salinity preferences and densities of fish in various salinity ranges under present day conditions. The higher salinity zones are greater in area than present. Increase in abundance of marine and partially estuarine dependent species **Confidence**: 60%
Seasonal variability and Community composition: Estuarine breeders and catadromous species 22-37 % less abundant than under reference conditions. 22 % increase in abundance of selective feeders that prefer less turbid conditions. 30 % reduction in the larger piscivorous predators that prefer the REI zone **Motivation:** Preferred salinities of the REI zone are more extensive under present day conditions. Lower turbidity in the lower reaches **Confidence:** 60%

e. Birds

Based on the predicted changes in the occurrence and variability in Abiotic States, birds under the Moderate Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: No change **Motivation:** Little or no change in diversity of other components **Confidence:** 80%
Biomass: A slight increase, particularly in lower estuary **Motivation:** Increased productivity of estuary, increase in inverts and fish in lower estuary **Confidence:** 60%
Seasonal variability and Community composition: More piscivores, fewer herbivores, more invertebrate feeders **Motivation**: Increase in inverts and fish, decrease in macrophytes **Confidence:** 40%

Effect of Predicted Changes in Abiotic and Biotic Components under the Moderate Development Scenario on the Present Status Category of the Breede River Estuary, using the EHI:

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. Reduction in MAR (%)	51.7	For some permanently open estuaries, such as the Breede River Estuary, critical low flow cut off are not easily definable. Changes in MAR, as a reflection in the reduction in flows, were therefore considered a more suitable indicator of change	60%
b. Decrease in mean annual frequency (%) of floods	28.7	Using average monthly flows of greater than 300 m^3/s as the indicator.	40%
Hydrology score	**58**		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of mouth closure, e.g. over a 5 or 10 year period	100	Not applicable to the Breede River Estuary	80%
Hydrodynamic score	**100**		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	58	The increase in marine dominance was used as an indicator. Breede River Estuary use to be a freshwater dominated system where significant marine influence was limited to 3 months of the year (i.e. State 3). Under Present Conditions, significant, and far stronger marine influence in the estuary occurs for 8 months of the year.	60%
2a. Nitrate and phosphate concentration in the estuary	90	Because river inflows decrease, high nutrient-river water will have less of an effect on nitrate concentrations in the estuary. Therefore, nitrate concentrations in the estuary will decrease slightly compared with the present.	40%
2b. Suspended solids in present in inflowing freshwater	80	Although agricultural activities in the catchment probably led to higher suspended solid concentrations in river inflows, vegetation along the banks acts as a sediment trap.	40%
2c. Dissolved oxygen in inflowing freshwater	90	Reduced river flows, particularly during State 5, may lead to near stagnant conditions, resulting in slightly reduced DO levels in inflows to the estuary compared to the present.	40%
2d. Levels of toxins	90	Pesticides and herbicides associated with agricultural activities may still be an issue, but no data or any other evidence are available to confirm this.	40%
Water quality score	**71**		

Physical habitat alteration

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1a. Change in the inter- tidal exposed area (%)	100	No marked changes observed	80%
1b. Change in the sand fraction relative to total sand and mud (%)	75	Due to reductions in river inflows, particularly floods, an increase in marine sediments (i.e. sands) is expected in the lower reaches. Due to stronger seawater intrusion, flocculation of muds may now occur over larger areas.	40%
2. Change in subtidal area of the estuary: e.g. bed or channel modification, canalisation	100	No marked changes	80%
3. Migration barriers, bridges, weirs, bulkheads, training walls, jetties, marinas	90	There are a number of small jetties along the entire estuary, particularly in the lower reaches and near Malgas	80%
Physical Habitat score	**92**		

Human disturbance of habitats and biota

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. Degree of human non-consumptive activity on the estuary, e.g. walking, water-skiing, and associated damage to habitats (e.g. trampling, boating activity).	30	The estuary is used extensively during the summer season for recreational activities.	60%
b. Degree of human consumptive activity (fishing and bait collecting) on the estuary, and associated levels of exploitation and damage to habitats (e.g. digging by bait collectors).	10	Recreational angling removes 40 t and illegal netting 5 t of fish from the estuary each year. There appears to be a strong negative correlation between boat traffic and fish abundance and/or catchability within the estuary.	60%
Human Disturbance score	**18**		

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	Similar conditions as described for Present State would apply.	40%
2a. Abundance	80	Score reflects increase in biomass from Present State	40%
2b. Community composition	70	Reflects greater sensitivity to higher salinities in estuary	40%
Microalgae score	**70**		

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	Loss of pondweed, increase in seagrass.	60%
2a. Abundance	77	A predicted decrease in the abundance of *Phragmites australis* (common reed) and *Potamogeton pectinatus* (pondweed) as a result of an increase in salinity.	60%
2b. Community composition	85	Change in the community composition of the brackish salt marshes. Replacement of brackish species by salt tolerant species.	60%
Macrophyte score	**77**		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	Not likely to change significantly from the Present State.	80%
2a. Abundance	60	Biomass of some species will change. Intertidal areas inhabited by mudprawns (*Upogebia africana*) will probably extend further upstream because marine influence (particularly salinity) will extend further upstream, on average, but particularly during dry years.	60%
2b. Community composition	60	Seasonal variability will possibly increase, particularly during dry years. Greater variability in salinity further upstream is likely to affect composition of communities, particularly brackish water species. Marine influence (particularly salinity) will extend further upstream, on average, but particularly during dry years.	60%
Invertebrate score	**60**		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	60	Possible loss of one or two (maybe more) species that prefer lower salinities.	40%
2a. Abundance	60	22-37 % decrease in estuarine breeders and catadromous species from reference conditions. Overall 9-15 % increase in abundance	60%
2b. Community composition	70	22-37 % decrease in estuarine breeders & catadromous species. 12-30 % increase and decrease in abundance of the four dominant piscivores and benthic feeders	60%
Fish score	**60**		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	No change, as there would be little or no change in diversity of other biotic components	80%
2a. Abundance	80	A slight increase, particularly in lower estuary due to increased productivity of estuary and increase in invertebrates and fish in the lower parts.	60%
2b. Community composition	75	More piscivores, fewer herbivores, more invertebrate feeders associated with the predicted increase in invertebrates and fish, and decrease in macrophytes.	40%
Bird score	**75**		

The individual variable scores obtained for the Moderate Development Scenario are incorporated into a Habitat health score and Biological health score and, finally into the Estuarine Health Score, as follows:

VARIABLE	EHI SCORE				
	Present State	Limited Development	Moderate Development	Bromberg Development	Le Chasseur Development
Hydrology	66	62	58		
Hydrodynamics and mouth condition	100	100	100		
Water quality	78	76	71		
Physical habitat	92	92	92		
Human disturbance	18	18	18		
HABITAT HEALTH SCORE	**73**	**72**	**70**		
Microalgae	90	90	70		
Macrophytes	80	80	77		
Invertebrates	80	80	60		
Fish	80	80	60		
Birds	85	85	75		
BIOLOGICAL HEALTH SCORE	**83**	**83**	**67**		
ESTUARINE HEALTH INDEX (EHI) SCORE	**78**	**77**	**68**		
CATEGORY	**B**	**B**	**C**		

BROMBERG DEVELOPMENT SCENARIO

Effect of Bromberg Development Scenario on Abiotic Components:

a. River inflow characteristics

Floods

In the table below, the 13 highest monthly flows for the reference conditions obtained from the datasets of simulated monthly flows are listed and these are compared with the flows in the same months for the other scenarios. It is likely that during a month with such a high average flow a major flood with a much higher peak flow would have occurred. Therefore this analysis only gives an indication on the occurrence of major floods under the different scenarios.

YEAR/MONTH	SIMULATED RUNOFF SCENARIOS					
	Reference (Natural)	Present	Limited Development	Moderate Development	Bromberg	Le Chasseur
June 1942	321	194	186	174	162	115
July 1954	344	240	221	213	195	217
August 1954	303	260	222	220	216	224
August 1955	344	271	252	241	239	245
June 1957	337	244	232	210	195	188
August 1962	565	436	428	420	370	424
August 1974	744	577	569	562	525	435
May 1977	313	230	222	211	198	169
June 1977	310	211	201	194	190	197
July 1977	352	328	284	273	274	278
August 1977	367	352	343	312	312	315
August 1986	338	310	297	283	259	285
July 1991	314	227	216	208	183	148
Average	**381**	**99**	**283**	**271**	**255**	**249**
% of Reference	**100**	**78.4**	**74.2**	**71.3**	**66.9**	**65.4**

Significant further reduction in flushing of sediments during floods can be expected for the high development scenarios, including the Bromberg. More detailed investigations on the effects of these dams on the sediment dynamics of the estuary will be required if any of these schemes will be considered for implementation.

Monthly flow distributions

Monthly-simulated runoff data for the Bromberg Development Scenario, over a 64-year period (1927 to 1990), are provided in Table 5. The MAR for this scenario is 772 x 10^6 m^3 (43.3% of the natural MAR). A summary of flow distribution (mean monthly flows in m^3/s) for the Bromberg Development Scenario, derived from the 64-year simulated data set, is provided below:

MONTH	1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	102.293	47.210	32.074	18.475	14.253	10.108	8.903	6.679	4.519	3.231	1.499
Nov	90.588	43.887	26.106	11.666	8.090	6.408	4.989	3.882	2.914	2.358	1.699
Dec	27.879	11.347	5.736	4.428	3.510	2.641	2.135	2.007	1.703	1.500	1.499
Jan	70.150	4.087	3.005	1.847	1.566	1.500	1.499	1.499	1.499	1.499	1.237
Feb	40.059	16.701	5.673	2.504	1.501	1.501	1.501	1.501	1.501	1.500	0.800
Mar	22.285	13.731	8.734	4.938	4.008	2.251	1.500	1.499	1.499	1.499	0.204
Apr	129.213	40.545	12.153	7.811	5.487	3.540	2.743	1.501	1.500	1.500	0.578
May	158.722	71.840	33.986	19.693	9.848	3.788	1.499	1.498	1.498	1.420	0.103
Jun	192.337	115.850	61.285	37.949	28.829	16.066	12.463	5.377	4.132	1.501	0.389
Jul	224.685	111.904	75.272	55.501	48.481	38.047	28.914	22.746	11.887	7.390	2.454
Aug	427.624	154.892	91.832	67.624	57.498	41.463	29.523	25.454	22.081	16.017	7.308
Sep	118.347	89.249	58.356	47.185	32.431	27.386	22.551	19.051	16.469	11.124	6.684

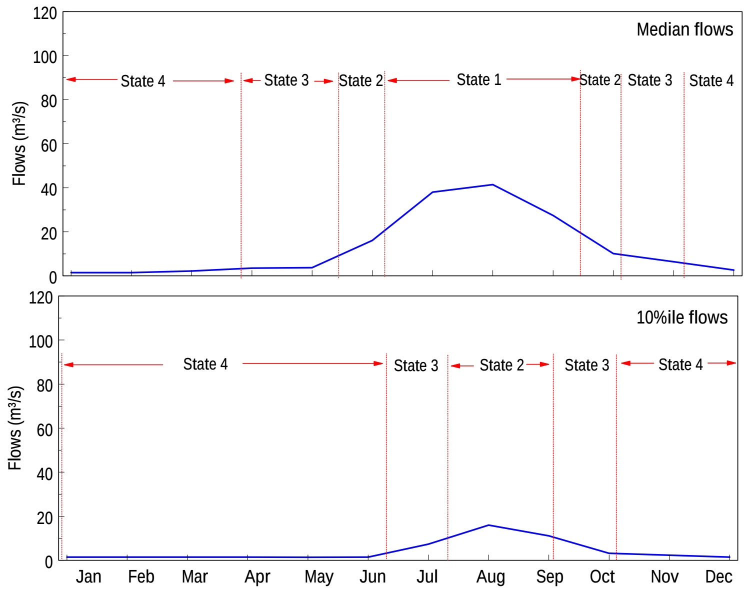
TABLE 5 : MONTHLY RUNOFF DATA (in m^3/s) FOR BROMBERG DEVELOPMENT SCENARIO, SIMULATED OVER A 64-YEAR PERIOD

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	1.50	2.64	1.50	1.50	1.50	12.57	3.32	0.12	31.63	5.95	15.46	19.91	8.13
1928	2.58	47.00	14.17	1.50	0.87	3.39	2.45	0.66	0.83	69.33	62.02	13.57	18.20
1929	4.69	2.56	5.45	1.84	26.24	13.84	3.05	2.00	2.01	2.21	18.83	33.69	9.70
1930	9.31	4.31	1.57	1.80	1.50	4.72	50.26	23.68	2.11	40.11	85.89	34.44	21.64
1931	39.75	10.78	28.97	8.33	16.82	1.50	1.50	1.50	12.83	28.79	16.65	121.41	24.07
1932	39.02	4.85	2.01	1.50	1.50	1.50	1.50	1.50	31.40	86.66	56.35	16.39	20.35
1933	1.94	7.66	2.66	3.63	3.26	3.16	1.50	1.50	1.50	7.68	29.20	30.34	7.83
1934	75.07	35.39	3.54	1.50	1.50	1.16	2.44	10.57	15.69	26.69	32.34	20.70	18.88
1935	4.03	7.36	2.81	1.50	1.10	0.46	0.07	0.93	0.62	5.89	25.57	32.53	6.91
1936	7.32	82.64	27.24	2.93	1.50	4.92	1.83	1.50	37.56	84.73	21.74	12.35	23.85
1937	3.99	5.56	7.42	3.10	0.94	4.05	8.26	8.99	4.32	14.09	20.07	20.41	8.43
1938	3.25	8.25	3.59	1.50	12.43	17.39	5.55	1.39	0.85	6.04	77.08	31.31	14.05
1939	3.22	1.87	1.50	1.35	24.51	11.22	7.79	1.50	11.62	12.08	7.32	9.54	7.79
1940	1.50	13.25	4.05	1.50	0.68	0.19	27.53	74.47	127.76	61.18	58.63	111.25	40.17
1941	34.52	9.23	2.74	4.21	1.50	1.50	1.50	22.87	162.00	25.06	25.12	6.92	24.76
1942	8.04	4.12	12.21	36.41	12.90	4.31	5.24	1.50	7.41	37.43	65.76	62.15	21.46
1943	14.31	36.63	9.39	1.50	1.50	1.93	1.50	24.78	98.45	29.43	56.87	56.49	27.73
1944	19.48	4.56	1.65	1.50	1.50	1.50	1.50	71.86	130.29	193.36	137.05	26.66	49.24
1945	83.50	23.84	2.29	1.50	1.50	29.55	10.54	1.50	1.50	2.60	9.36	54.04	18.48
1946	9.49	1.82	1.50	1.50	1.50	17.83	7.09	1.50	2.56	52.85	25.83	16.70	11.68
1947	8.84	6.42	2.27	1.50	0.87	2.50	3.61	0.84	5.41	37.55	12.49	57.02	11.61
1948	99.95	29.51	1.81	1.50	1.50	1.50	4.56	1.50	1.50	8.53	28.72	22.24	16.90
1949	14.05	104.12	20.71	1.50	1.50	1.50	12.05	1.50	1.50	60.66	11.39	30.70	21.76
1950	12.25	33.22	7.15	25.00	7.84	1.91	6.62	1.50	63.86	46.91	25.13	28.43	21.65
1951	7.90	6.40	1.50	1.50	1.50	1.50	1.50	9.01	9.17	38.15	115.44	92.27	23.82
1952	17.16	63.36	11.90	1.73	1.50	1.50	52.80	43.27	12.39	83.87	42.90	16.53	29.07
1953	18.81	13.49	3.67	1.50	1.50	1.50	6.20	101.99	61.65	195.61	216.19	62.57	57.06
1954	7.42	3.49	2.03	3.31	61.37	16.02	1.50	1.50	13.49	78.61	239.51	41.30	39.13
1955	30.44	7.63	1.79	1.50	1.50	3.51	1.70	8.97	41.47	48.87	57.16	11.52	18.00
1956	12.51	4.60	4.42	1.54	11.71	4.27	1.50	71.80	195.22	194.57	162.54	60.37	60.42
1957	81.49	11.50	2.12	1.50	1.50	5.32	3.10	89.61	45.81	8.96	50.91	17.20	26.59
1958	6.69	3.19	1.67	2.99	5.06	4.02	51.18	135.53	17.28	54.93	92.06	28.11	33.56
1959	47.58	10.69	2.06	1.56	1.50	1.63	1.50	1.50	37.54	11.59	7.29	6.29	10.89
1960	1.75	2.89	4.67	5.47	1.87	1.50	1.87	5.75	5.06	12.82	40.03	53.81	11.46
1961	10.35	3.91	1.50	1.50	1.50	8.92	6.71	1.50	131.73	53.64	370.18	116.55	59.00
1962	106.29	49.09	6.17	2.38	1.50	16.83	8.94	16.32	12.02	23.07	100.72	19.17	30.21
1963	9.27	6.22	3.15	3.79	2.65	11.68	4.22	1.50	56.79	36.99	70.41	21.65	19.03
1964	12.07	21.90	5.00	1.50	1.50	1.50	2.73	12.84	13.03	16.45	24.23	8.79	10.13
1965	24.59	20.00	5.08	3.02	1.50	1.50	1.50	1.50	4.67	50.26	67.55	34.83	18.00
1966	5.19	2.07	1.50	1.50	1.50	3.95	122.42	56.24	86.06	25.94	25.37	19.33	29.25
1967	15.68	5.67	1.77	1.50	1.50	1.50	1.50	26.08	44.32	65.95	58.08	11.01	19.55
1968	42.58	8.15	2.63	1.50	1.50	1.50	3.47	1.50	4.75	5.16	15.75	17.80	8.86
1969	18.44	1.50	1.50	1.50	2.58	1.50	1.49	0.08	19.17	34.33	65.77	26.03	14.49
1970	5.15	2.25	1.50	1.04	3.79	5.34	18.84	10.06	5.03	73.88	94.12	23.78	20.40
1971	5.20	13.14	4.56	1.50	3.05	2.00	4.64	4.39	8.54	7.27	22.31	17.97	7.88
1972	2.29	3.02	1.50	1.50	1.50	0.21	0.88	0.12	0.00	49.60	24.23	12.13	8.08
1973	4.18	2.85	2.40	1.50	19.26	7.23	1.06	17.93	29.05	15.75	525.43	90.65	59.77
1974	21.33	5.80	2.06	1.74	1.50	1.50	2.79	31.18	19.68	42.49	57.58	17.98	17.14
1975	9.87	3.63	1.95	1.50	1.51	4.72	7.97	1.94	123.31	77.35	20.79	11.40	22.16
1976	14.69	69.92	11.93	2.89	16.42	6.41	29.55	198.22	190.64	274.19	312.23	47.09	97.85
1977	9.79	7.86	4.53	1.94	1.50	1.50	6.12	1.50	2.56	9.29	30.83	23.83	8.44
1978	6.55	2.93	4.36	1.57	27.54	8.61	1.50	3.19	29.80	21.71	32.96	25.76	13.87
1979	21.88	3.27	1.88	3.03	1.50	1.50	1.50	1.50	3.85	9.13	18.30	8.36	6.31
1980	5.19	50.92	10.07	127.61	27.36	10.34	43.32	17.37	4.76	45.31	91.68	81.53	42.95
1981	13.63	4.63	4.18	1.82	1.50	5.08	140.79	49.93	12.76	22.86	25.55	32.03	26.23
1982	9.15	2.76	1.50	1.50	1.55	1.50	1.50	28.50	81.99	121.85	39.79	48.00	28.30
1983	16.80	6.17	2.61	1.50	1.50	18.02	2.79	99.48	20.54	68.70	25.46	85.98	29.13
1984	41.98	10.41	3.04	8.25	6.60	13.48	12.31	6.98	61.04	117.95	119.29	23.84	35.43
1985	46.35	31.54	6.88	2.67	1.50	1.75	4.00	1.50	16.44	52.93	259.51	99.09	43.68
1986	16.78	6.43	2.12	1.50	1.50	1.50	26.98	40.53	43.23	39.07	81.15	34.27	24.59
1987	7.17	2.11	2.21	1.50	1.50	1.50	8.27	1.99	27.94	23.88	29.12	55.70	13.57
1988	4.17	2.27	1.73	1.50	1.50	3.84	34.08	19.34	14.28	37.94	68.29	109.10	24.84
1989	60.91	30.91	3.38	1.50	2.50	1.50	60.44	38.20	63.92	97.80	36.22	10.51	33.98
1990	4.26	2.80	2.08	1.63	1.50	1.50	1.50	1.50	35.58	183.36	47.18	68.44	29.28

< 0.5	0	0	0	0	0	3	1	3	1	0	0	0
0.5 - 3.0	6	14	35	51	47	30	27	28	11	2	0	0
3.0 -10.0	26	27	21	10	6	19	21	7	11	10	3	5
10.0 - 20.0	15	8	5	0	6	11	4	7	13	6	7	17
> 20.0	17	15	3	3	5	1	11	19	28	46	54	42

b. ***Predicted changes in occurrence and variability of Abiotic States Bromberg Development Scenario, compared with the Present State and Reference Condition is as follows***

To estimate the occurrence and duration of the different Abiotic States during the Bromberg Future Development Scenario, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively:



- Under the Bromberg Development Scenario, the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)	
Months	Duration
Nov – May	7 months

DROUGHTS (10%ile)	
Months	Duration
Oct – Jul	10 months

- The average, as well as the maximum distances (in km), at which certain salinities penetrate during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)		
SALINITY (ppt)	**DISTANCE FROM MOUTH (km)**	
	Average	**Maximum**
30	11	14
20	20	31
10	34	44

DROUGHTS (10%ile)		
SALINITY (ppt)	**DISTANCE FROM MOUTH (km)**	
	Average	**Maximum**
30	12	17
20	27	34
10	40	47

- The average and maximum salinities at the head of the estuary (about 52 km from the mouth) during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Salinities (ppt) at head of estuary	
Average	Maximum
<1	~5

DROUGHTS (10%ile) Salinities (ppt) at head of estuary	
Average	Maximum
~1.5	~7

- The average and maximum salinities at 12 km from the mouth during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
20	5 - 6
30	2

DROUGHTS (10%Ile) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
20	9
30	6

Predicted Effects of Bromberg Development Scenario on Biotic Components

a. Microalgae

Based on the predicted changes in the occurrence and variability in Abiotic States, microalgae under the Bromberg Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Very little change under Bromberg development. **Motivation:** Similar conditions as described for Present State would apply as far as microalgae are concerned. **Confidence:** 40 %
Biomass distribution: Biomass in the estuary would probably increase, but there will be a decrease in biomass at sea compared with the Present State. **Motivation:** Lower flow to sea would provide a longer residence time within the estuary. As the flow decreases, the biomass in the estuary increases. **Confidence:** 40 %
Seasonal variability and Community composition: The community composition in the estuary decreases compared with the present. **Motivation:** The change reflects the greater sensitivity of community composition in the estuary to the higher salinity. However, change in community composition is not to be equated directly with estuarine condition, but also with near shore condition. **Confidence:** 40 %

b. Macrophytes

Based on the predicted changes in the occurrence and variability in Abiotic States, macrophytes under the Bromberg Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Loss of pondweed habitat. **Motivation:** Pondweed habitat (area less than 10 ppt) would be lost due to an increase in saline penetration upstream. The seagrass, *Zostera capensis* would colonize the middle reaches of the estuary and displace brackish species. **Confidence:** 60%
Biomass distribution: Decrease in pondweed and reed biomass. **Motivation:** There will be a loss of reeds as a result of the increase in salinity. Reeds would now be exposed to salinity of 20 ppt for 5-6 months and 30 ppt for 2 months. This would allow little time for regrowth during optimal salinity conditions (< 20 ppt). **Confidence**: 60%
Seasonal variability and Community composition: Change in species composition of the brackish salt marshes. **Motivation:** Brackish species such as *Juncus kraussii* and *Cotula cornopifolia* would be replaced by more salt tolerant species as a result of the increase in the duration of saline conditions in the lower and middle reaches of the estuary. **Confidence:** 60%

c. Invertebrates

Based on the predicted changes in the occurrence and variability in Abiotic States, invertebrates under the Bromberg Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Over time (years), diversity, richness likely to be similar to the Moderate Development scenario. However, during dry periods, changes likely to be significant. **Motivation**: Marine influence (particularly salinity) will extend further upstream, on average, but particularly during dry years **Confidence:** 80%
Biomass distribution: If considerable reed dieback occurs during dry years, recovery rate of reedbeds may be too slow to recover to pre-drought conditions and before the next dry period. Consequently, biomass of some species likely to decrease, particularly brackish water species. **Motivation:** Marine influence (particularly salinity) will extend further upstream, particularly during dry years **Confidence:** 40%
Seasonal variability and Community composition: As in Moderate Development Scenario **Motivation**: As in Moderate Development Scenario **Confidence:** 40%

d. Fish

Based on the predicted changes in the occurrence and variability in Abiotic States, fish under the Bromberg Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Possibly slightly lower due to near loss of species that prefer low or zero salinities. Quite drastic decrease in abundance of large predators. System becoming marine dominated with species that prefer higher salinities. **Motivation:** Reduction in REI zone, preferred low salinities and decrease in turbidity in the lower reaches **Confidence:** 40%
Biomass distribution: Overall abundance 12 % greater than Reference Conditions, 6 % greater than present day **Motivation**: Based on salinity preferences and densities of fish in various salinity ranges under present day conditions. The higher salinity zones are greater in area than present. Increase in abundance of marine and partially estuarine dependent species. **Confidence**: 60%
Seasonal variability and Community composition: Estuarine breeders and catadromous species 29-49 % less abundant than under reference conditions. 30 % increase in abundance of selective feeders that prefer less turbid conditions. 39 % reduction in the larger piscivorous predators that prefer the REI zone **Motivation:** Preferred salinities of the REI zone are more extensive under present day conditions. Lower turbidity in the lower reaches **Confidence:** 60%

e. Birds

Based on the predicted changes in the occurrence and variability in Abiotic States, birds under the Bromberg Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Little change **Motivation:** Little change in other components **Confidence:** 80%
Biomass distribution: Increase relative to Present State and Limited Development Scenario, but not as much as in Moderate Development Scenario. **Motivation:** Estuary productivity, invertebrates, fish follow same trend. **Confidence:** 60%
Seasonal variability and Community composition: Same as for Moderate Development Scenario, but less pronounced **Motivation:** Estuary productivity, invertebrates, fish follow same trend. **Confidence:** 60%

Effect of Predicted Changes in Abiotic and Biotic Components under the Bromberg Development Scenario on the Present Status Category of the Breede River Estuary, using the EHI:

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. Reduction in MAR (%)	56.7	For some permanently open estuaries, such as the Breede River Estuary, critical low flow cut off are not easily definable. Changes in MAR, as a reflection of the reduction in flows, were therefore considered a more suitable indicator of change	60%
b. Decrease in mean annual frequency (%) of floods	33.1	Using average monthly flows of greater than 300 m^3/s as indicator.	40%
Hydrology score	**53**		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of mouth closure, e.g. over a 5 or 10 year period	100	Not applicable	80%
Hydrodynamic score	**100**		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	58	Use the increase in marine dominance as an indicator. Breede River Estuary use to be a freshwater dominated system where significant marine influence was limited to 3 months of the year (i.e. State 3). Under present conditions, significant, and far stronger marine influence in the estuary occurs for 8 months of the year.	80%
2a. Nitrate and phosphate concentration in the estuary	90	Because river inflows decrease, high nutrient-river water will have less of an effect on nitrate concentrations in the estuary. Therefore, nitrate concentrations in the estuary will decrease slightly compared with the present.	40%
2b. Suspended solids in present in inflowing freshwater	80	Although agricultural activities in the catchment probably led to higher suspended solid concentrations in river inflows, vegetation along the banks act as a sediment trap.	40%
2c. Dissolved oxygen in inflowing freshwater	100	There are no available data, or any other evidence, that indicate reduction in DO levels in the freshwater inflows.	40%
2d. Levels of toxins	90	Pesticides and herbicides associated with agricultural activities may still be an issue, but no data or any other evidence are available to confirm this.	40%
Water quality score	**71**		

Physical habitat alteration

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1a. Change in the inter- tidal exposed area (%)	100	No marked changes observed	80%
1b. Change in the sand fraction relative to total sand and mud (%)	70	Due to reduction in river inflows, particularly floods, an increase in marine sediments (i.e. sands) is expected in the lower reaches. Due to stronger seawater intrusion, flocculation of muds may now occur over larger areas.	40%
2. Change in subtidal area of the estuary: e.g. bed or channel modification, canalisation	100	No marked changes	80%
3. Migration barriers, bridges, weirs, bulkheads, training walls, jetties, marinas	90	There are a number of small jetties along the entire estuary, particularly in the lower reaches and near Malgas	80%
Physical Habitat score	**91**		

Human disturbance of habitats and biota

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. Degree of human non-consumptive activity on the estuary, e.g. walking, water-skiing, and associated damage to habitats (e.g. trampling, boating activity).	30	The estuary is used extensively during the summer season for recreational activities.	60%
b. Degree of human consumptive activity (fishing and bait collecting) on the estuary, and associated levels of exploitation and damage to habitats (e.g. digging by bait collectors).	10	Recreational angling removes 40 t and illegal netting 5 t of fish from the estuary each year. There appears to be a strong negative correlation between boat traffic and fish abundance and/or catchability within the estuary.	60%
Human Disturbance score	**18**		

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	Similar to Present State	40%
2a. Abundance	80	Score reflects increase in biomass from Present State	40%
2b. Community composition	70	Reflects greater sensitivity to higher salinities in estuary	40%
Microalgae score	**70**		

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	Loss of pondweed, increase in seagrass.	60%
2a. Abundance	75	A predicted decrease in the abundance of *Phragmites australis* (common reed) and *Potamogeton pectinatus* (pondweed) as a result of an increase in salinity.	60%
2b. Community composition	85	Change in the community composition of the brackish marshes. Loss of brackish species and replacement by saline species.	60%
Macrophyte score	**75**		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	Over time (years), diversity, richness likely to be similar to the Moderate development scenario. However, during dry periods, changes likely to be significant.	80%
2a. Abundance	60	If considerable reed dieback occurs during dry years, recovery rate of reed beds may be too slow to recover to pre-drought conditions and before the next dry period. Consequently, biomass of some species likely to decrease, particularly brackish water species.	40%
2b. Community composition	60	As in Moderate Development Scenario	40%
Invertebrate score	**60**		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	70	Possible loss of one or two (maybe more) species that prefer lower salinities. Increase in species that prefer higher salinities	40%
2a. Abundance	60	29-49 % decrease in estuarine breeders & catadromous species from reference conditions. Overall 12 % increase in abundance	40%
2b. Community composition	70	29-49 % decrease in estuarine breeders & catadromous species. 16-40 % increase and decrease in abundance of the four dominant piscivores and benthic feeders	60%
Fish score	**60**		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	Little change, due to little change in other biotic components.	80%
2a. Abundance	85	Increase relative to Present State and Limited Development Scenario, but not as much as in Moderate Development Scenario.	60%
2b. Community composition	80	Same as for Moderate Development Scenario, but less pronounced.	60%
Bird score	**80**		

The individual variable scores obtained for the Bromberg Development Scenario are incorporated into a Habitat health score and Biological health score and, finally into the Estuarine Health Score, as follows:

VARIABLE	EHI SCORE				
	Present State	**Limited Development**	**Moderate Development**	**Bromberg Development**	**Le Chasseur Development**
Hydrology	66	62	58	53	
Hydrodynamics and mouth condition	100	100	100	100	
Water quality	78	76	71	71	
Physical habitat	92	92	92	91	
Human disturbance	18	18	18	18	
HABITAT HEALTH SCORE	**73**	**72**	**70**	**68**	
Microalgae	90	90	70	70	
Macrophytes	80	80	77	75	
Invertebrates	80	80	60	60	
Fish	80	80	60	60	
Birds	85	85	75	80	
BIOLOGICAL HEALTH SCORE	**83**	**83**	**67**	**69**	
ESTUARINE HEALTH INDEX (EHI) SCORE	**78**	**77**	**68**	**69**	
CATEGORY	**B**	**B**	**C**	**C**	

LE CHASSEUR DEVELOPMENT SCENARIO

Effect of Le Chasseur Development Scenario on Abiotic Components:

a. River inflow characteristics

Floods

In the table below, the 13 highest monthly flows for the reference conditions obtained from the datasets of simulated monthly flows are listed and these are compared with the flows in the same months for the other scenarios. It is likely that during a month with such a high average flow a major flood with a much higher peak flow would have occurred. Therefore this analysis only gives an indication of the occurrence of major floods under the different scenarios.

YEAR/MONTH	SIMULATED RUNOFF SCENARIOS					
	Reference (Natural)	Present	Limited Development	Moderate Development	Bromberg	Le Chasseur
June 1942	321	194	186	174	162	115
July 1954	344	240	221	213	195	217
August 1954	303	260	222	220	216	224
August 1955	344	271	252	241	239	245
June 1957	337	244	232	210	195	188
August 1962	565	436	428	420	370	424
August 1974	744	577	569	562	525	435
May 1977	313	230	222	211	198	169
June 1977	310	211	201	194	190	197
July 1977	352	328	284	273	274	278
August 1977	367	352	343	312	312	315
August 1986	338	310	297	283	259	285
July 1991	314	227	216	208	183	148
Average	**381**	**99**	**283**	**271**	**255**	**249**
% of Reference	**100**	**78.4**	**74.2**	**71.3**	**66.9**	**65.4**

Significant further reduction in flushing of sediments during floods can be expected for the high development scenarios, including the Le Chasseur Scenario. More detailed investigations on the effects of these dams on the sediment dynamics of the estuary will be required if any of these schemes will be considered for implementation.

Monthly flow distribution

Monthly-simulated runoff data for the Le Chasseur Development Scenario, over a 64-year period (1927 to 1990), are provided in Table 6. The MAR for this scenario is 649 x 10^6 m^3 (36.4% of the natural MAR). A summary of flow distribution (mean monthly flows in m^3/s) for the Le Chasseur Development Scenario, derived from the 64-year simulated data set, is provided below:

MONTH	1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	107.077	46.512	36.775	19.987	12.632	10.649	8.705	7.346	4.778	3.150	1.684
Nov	102.291	37.660	25.349	13.448	8.687	5.974	4.821	4.276	3.449	2.266	1.941
Dec	32.768	10.935	6.693	5.451	4.683	3.552	3.305	2.888	2.734	2.395	1.635
Jan	58.896	5.091	3.784	3.016	2.443	2.161	1.818	1.536	1.500	1.500	1.500
Feb	46.229	15.996	4.584	2.750	1.750	1.501	1.501	1.501	1.500	1.500	1.438
Mar	27.117	14.405	7.182	5.513	4.524	2.641	2.026	1.501	1.500	1.500	1.225
Apr	139.029	38.437	9.470	7.890	5.025	3.428	1.804	1.501	1.501	1.500	1.488
May	125.996	40.883	20.607	13.303	4.883	2.130	1.500	1.500	1.500	1.500	0.750
Jun	192.149	45.082	24.602	13.745	8.198	6.006	3.479	1.501	1.501	1.500	1.500
Jul	239.611	107.311	66.744	25.980	17.917	13.504	10.009	9.103	6.350	3.305	1.500
Aug	428.612	158.345	78.877	56.925	45.049	30.547	23.536	15.902	12.079	7.372	5.690
Sep	124.754	104.523	63.754	42.412	27.653	21.850	18.252	14.858	12.240	9.590	4.725

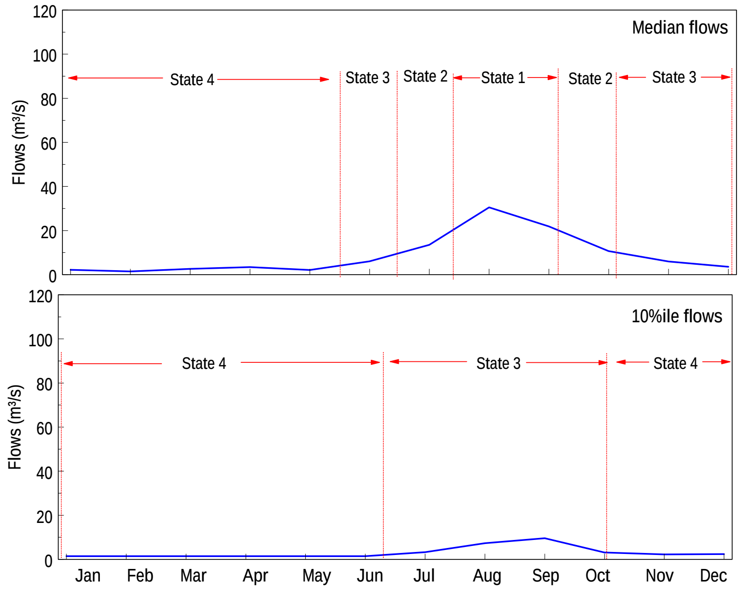
TABLE 6 : MONTHLY RUNOFF DATA (in m^3/s) FOR LE CHASSEUR DEVELOPMENT SCENARIO, SIMULATED OVER A 64-YEAR PERIOD

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	1.50	2.12	1.78	1.50	1.50	13.12	3.46	0.13	1.50	3.09	7.03	12.00	4.06
1928	3.10	44.80	15.35	2.08	1.50	4.53	1.59	1.46	1.50	28.71	28.21	14.18	12.25
1929	4.86	2.43	6.31	3.00	25.51	14.75	3.52	2.30	2.05	2.22	23.41	22.00	9.36
1930	14.12	5.34	3.23	3.12	1.53	5.29	54.52	21.77	4.72	44.67	28.61	13.94	16.74
1931	40.63	13.06	32.35	10.60	3.61	2.02	1.50	1.50	1.50	6.41	7.84	123.33	20.36
1932	41.75	6.30	3.63	1.50	1.50	1.50	1.50	1.50	1.50	12.49	31.38	21.70	10.52
1933	2.88	7.92	3.48	4.10	3.66	3.56	1.50	1.50	1.50	8.71	24.23	16.49	6.63
1934	55.55	29.83	5.45	1.94	1.87	1.50	3.35	13.13	15.22	11.56	10.87	11.05	13.44
1935	4.95	8.72	4.23	1.51	1.50	1.50	1.50	1.11	1.50	7.01	12.42	18.46	5.37
1936	7.83	92.88	33.48	5.03	1.50	5.48	1.89	1.50	1.50	9.80	10.81	12.03	15.31
1937	3.57	5.36	8.05	3.49	1.50	6.59	7.89	2.50	3.74	9.90	12.92	14.11	6.63
1938	8.57	9.98	5.23	1.99	14.88	19.17	6.20	1.50	1.50	6.26	56.86	26.11	13.19
1939	3.27	2.63	2.06	1.50	25.96	12.05	7.90	3.08	2.43	9.73	8.11	9.97	7.39
1940	2.41	17.96	6.10	2.95	1.50	1.03	19.26	16.10	41.90	71.68	69.87	121.97	31.06
1941	37.57	9.22	3.73	5.12	1.70	1.50	1.50	10.85	115.42	34.31	44.30	11.68	23.07
1942	11.55	4.88	12.61	40.45	14.57	3.35	3.40	1.50	1.50	4.17	43.00	67.79	17.40
1943	11.06	38.59	11.36	2.40	1.50	2.36	1.50	18.81	26.04	37.17	76.96	70.59	24.86
1944	19.96	4.52	2.66	1.50	1.50	1.50	1.50	48.54	84.93	207.72	140.65	29.28	45.35
1945	81.46	25.11	3.22	1.68	1.50	32.11	11.37	1.50	1.50	3.82	4.66	4.45	14.36
1946	2.09	1.95	1.61	1.50	1.50	24.18	9.27	2.57	2.43	22.29	15.92	18.88	8.68
1947	10.62	6.88	3.49	2.12	1.50	3.20	3.95	1.50	1.50	4.54	7.17	10.49	4.75
1948	111.65	35.49	2.79	1.78	1.50	1.50	5.92	1.50	1.50	3.03	6.41	6.34	14.95
1949	3.60	118.32	31.02	2.30	1.50	1.50	1.60	1.50	1.50	11.24	12.26	7.76	16.17
1950	10.68	30.79	9.25	28.53	10.22	2.58	1.78	1.50	8.20	21.13	14.56	28.91	14.01
1951	12.00	3.09	2.38	1.50	1.50	1.50	1.50	1.50	1.50	2.43	85.33	106.85	18.42
1952	20.72	70.54	15.26	2.90	1.50	1.50	8.73	26.35	15.15	90.54	49.79	20.21	26.93
1953	19.29	13.40	4.69	1.78	1.50	1.50	3.47	54.20	46.44	217.03	224.45	65.20	54.41
1954	7.78	3.76	2.76	3.78	61.19	19.09	1.50	1.50	2.87	38.03	245.27	43.76	35.94
1955	28.25	4.76	2.70	1.50	1.50	3.81	1.70	10.79	13.59	17.55	66.04	17.13	14.11
1956	14.88	4.96	5.16	2.24	5.01	4.77	1.50	43.04	188.80	198.14	165.93	62.79	58.10
1957	78.79	13.88	3.30	1.65	1.50	6.44	3.48	100.56	48.68	10.45	39.32	18.73	27.23
1958	6.80	3.62	2.62	3.80	5.53	4.65	42.49	33.55	25.94	64.56	95.22	30.54	26.61
1959	45.84	11.08	3.15	2.40	1.50	2.11	1.50	1.50	3.51	9.26	9.70	8.92	8.37
1960	2.76	3.62	5.95	6.88	2.67	1.74	2.59	7.83	5.66	9.03	20.66	22.09	7.62
1961	11.76	4.39	2.56	1.74	2.10	9.96	7.71	1.50	10.13	21.77	424.48	119.03	51.43
1962	104.39	46.93	9.71	3.43	1.50	17.14	8.90	17.10	10.88	11.96	51.55	22.15	25.47
1963	9.48	5.63	3.99	4.67	2.73	15.67	5.84	1.50	32.10	21.30	45.24	27.93	14.67
1964	9.23	17.99	5.42	2.28	1.76	2.12	1.96	9.22	6.55	15.58	14.72	9.43	8.02
1965	36.24	25.71	7.26	5.03	1.50	1.50	1.50	1.50	1.50	3.88	81.75	42.26	17.47
1966	7.46	2.20	2.21	1.50	1.71	4.50	137.25	68.27	22.93	17.85	18.54	18.47	25.24
1967	12.19	5.65	3.37	1.50	1.50	1.50	1.50	1.74	23.71	14.51	33.75	16.83	9.81
1968	40.24	10.20	3.47	1.54	1.50	1.50	4.96	1.50	7.96	9.34	6.57	8.78	8.13
1969	5.33	1.92	1.65	1.50	3.68	1.50	1.50	1.50	1.50	2.35	23.68	13.56	4.97
1970	5.74	2.05	2.05	1.50	4.30	5.86	19.81	11.34	6.11	70.03	74.21	24.87	18.99
1971	3.95	16.39	5.77	2.16	3.60	2.24	5.04	4.37	6.88	9.11	23.50	14.93	8.16
1972	3.67	4.37	2.82	1.50	1.33	1.34	1.47	1.18	1.50	1.50	6.30	4.89	2.65
1973	1.79	2.54	2.85	1.80	20.04	7.79	1.50	20.35	12.29	4.74	435.65	105.73	51.42
1974	20.27	4.30	2.42	1.91	1.50	1.50	1.50	1.50	7.06	23.16	64.70	30.27	13.34
1975	4.65	3.99	2.86	1.50	1.82	5.87	8.48	3.98	52.26	87.27	36.19	17.44	18.86
1976	26.26	56.90	5.50	2.60	16.47	6.77	23.45	169.31	197.85	278.06	315.92	49.54	95.72
1977	10.36	8.54	5.08	2.67	1.50	1.50	5.81	1.50	1.50	9.45	22.86	18.20	7.41
1978	12.74	4.10	5.42	2.72	33.75	11.09	1.50	5.01	4.89	10.89	22.24	16.99	10.94
1979	9.47	4.40	2.91	3.81	1.54	1.50	1.50	1.50	1.50	6.71	6.49	12.38	4.48
1980	7.47	22.69	9.95	90.31	37.44	13.61	48.32	21.00	8.19	17.93	52.86	78.54	34.03
1981	14.06	3.30	5.70	3.14	1.50	5.43	142.05	51.11	13.41	16.64	11.81	34.15	25.19
1982	9.88	3.55	2.51	1.50	1.99	1.50	1.50	1.50	9.42	106.70	51.39	56.51	20.66
1983	21.72	6.75	3.46	1.50	1.50	4.92	2.00	35.85	26.90	72.84	29.71	105.77	26.08
1984	46.80	4.81	3.61	8.33	7.58	2.70	9.77	1.50	20.06	140.94	122.96	26.55	32.97
1985	45.56	33.76	7.68	3.66	1.50	1.87	1.50	1.50	1.50	1.50	285.36	101.70	40.59
1986	18.53	7.02	3.11	1.50	1.50	1.50	28.99	14.85	5.91	25.68	96.92	48.09	21.13
1987	8.28	2.01	2.79	1.50	1.50	1.63	8.94	1.96	3.47	7.45	15.72	46.51	8.48
1988	6.57	2.09	2.89	1.50	1.50	6.24	47.39	15.88	16.00	15.67	25.31	127.18	22.35
1989	58.58	32.07	4.67	2.16	2.93	2.04	43.01	24.00	29.62	107.57	48.44	12.94	30.67
1990	7.41	2.85	3.34	2.45	1.68	1.50	1.50	1.50	1.50	148.47	57.51	71.33	25.09

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
< 0.5	0	0	0	0	0	0	0	1	0	0	0	0
0.5 - 3.0	6	11	21	44	46	33	30	34	25	5	0	0
3.0 -10.0	24	30	36	16	8	20	22	6	15	21	10	8
10.0 - 20.0	15	8	4	1	4	9	3	9	8	13	11	22
> 20.0	19	15	3	3	6	2	9	14	16	25	43	34

b. Predicted changes in occurrence and variability of Abiotic States Le Chasseur Scenario are as follows

To estimate the occurrence and duration of the different Abiotic States during the Le Chasseur Future Development Scenario, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively:



- Under the Le Chasseur Development Scenario, the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN)	
Months	Duration
Nov - Jun	8 months

DROUGHTS (10%ile)	
Months	Duration
Oct – Sep	12 months

- The average, as well as the maximum distances (in km), at which certain salinities penetrate during the low flow period (< 10 m3/s) is estimated at:

NORMAL FLOWS (MEDIAN)		
SALINITY (ppt)	**DISTANCE FROM MOUTH (km)**	
	Average	**Maximum**
30	10	14
20	20	30
10	32	42

DROUGHTS (10%ile)		
SALINITY (ppt)	**DISTANCE FROM MOUTH (km)**	
	Average	**Maximum**
30	11	17
20	22	34
10	35	47

- The average and maximum salinities at the head of the estuary (about 52 km from the mouth) during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Salinities (ppt) at head of estuary	
Average	Maximum
<1	~5

DROUGHTS (10%ile) Salinities (ppt) at head of estuary	
Average	Maximum
~1	~6

- The average and maximum salinities at 12 km from the mouth during the low flow period (< 10 m^3/s) is estimated at:

NORMAL FLOWS (MEDIAN) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
30	7
20	3

DROUGHTS (10%Ile) Duration of specific saline conditions at a point 12 km from the mouth	
Salinity (ppt)	Months
30	10
20	7

Predicted Effects of Le Chasseur Development Scenario on Biotic Components

a. Microalgae

Based on the predicted changes in the occurrence and variability in Abiotic States, microalgae under the Le Chasseur Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Very little change under Le Chasseur development. **Motivation:** Similar conditions as described for Present State would apply as far as microalgae are concerned. **Confidence:** 40%
Biomass distribution: Biomass in the estuary would probably increase, but there will be a decrease in biomass at sea compared with the Present State. **Motivation:** Lower flow to sea would provide a longer residence time within the estuary. As the flow decreases, the biomass in the estuary increases. **Confidence:** 40 %
Seasonal variability and Community composition: The community composition in the estuary decreases compared with the present. **Motivation:** The change reflects the greater sensitivity of community composition in the estuary to the higher salinity. However, change in community composition is not to be equated directly with estuarine condition, but also with near shore condition. **Confidence:** 40 %

b. Macrophytes

Based on the predicted changes in the occurrence and variability in Abiotic States, macrophytes under the Le Chasseur Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Loss of pondweed habitat. **Motivation:** Pondweed habitat (area less than 10 ppt) would now occur from 42 km upstream compared to 37 km upstream for the present condition. The seagrass, *Zostera capensis* would colonize the middle reaches of the estuary and displace brackish species **Confidence:** 60%
Biomass distribution: Decrease in reed biomass. **Motivation**: There will be a loss of reeds as a result of the increase in salinity. Reeds would now be exposed to salinity of 20 ppt for 7 months and 30 ppt for 3 months. This would allow little time for regrowth during optimal salinity conditions (< 20 ppt). Reeds could potentially be lost for a 16 km stretch along the estuary where they presently occur i.e. from 14-30 km upstream. **Confidence:** 60 %
Seasonal variability and Community composition: Change in species composition of the brackish salt marshes. **Motivation:** Brackish species such as *Juncus kraussii* and *Cotula cornopifolia* would be replaced by more salt tolerant species as a result of the increase in the duration of saline conditions in the lower and middle reaches of the estuary. **Confidence:** 60%

c. Invertebrates

Based on the predicted changes in the occurrence and variability in Abiotic States, invertebrates under the Le Chasseur Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Over time (years), diversity, richness likely to be similar to the Moderate Development Scenario. However, during dry period changes likely to be significant. **Motivation**: Marine influence (particularly salinity) will extend further upstream, on average, but particularly during dry years. Marine influence likely to persist for longer each year as the first rains will be trapped by the dam in most cases. There also exists the possibility that species diversity will change because of the barrier presented by the dam as invertebrates attempt to migrate between river environments and the estuary (brackish water habitat required during the breeding season). **Confidence:** 80%
Biomass distribution: Biomass distribution: If considerable dieback of reeds occurs during dry years, recovery rate of reedbeds may be too slow to recover to pre-drought conditions. Consequently, biomass of some species likely to decrease significantly. Other species such as mudprawn likely to increase in biomass as they colonize mudbanks further upstream. **Motivation:** Marine influence (particularly salinity) will extend further upstream, particularly during dry years. **Confidence:** 60%
Seasonal variability and Community composition: Existing patterns of seasonal distribution and abundance of species likely to change and become more variable within years. For species such as mudprawn (*Upogebia africana*), colonization of some intertidal mudbanks upstream may be temporary within years. **Motivation**: Dams will fill after the first rains of the season, leading to more persistent high salinity conditions in the estuary for longer. The interannual range in salinity likely to be more variable along specific reaches of the estuary. **Confidence:** 40%

d. Fish

Based on the predicted changes in the occurrence and variability in Abiotic States, fish under the Le Chasseur Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Possibly slightly lower due to near loss of species that prefer low or zero salinities. Quite drastic decrease in abundance of large predators but not lost from the system. System becoming marine dominated with species that prefer higher salinities. **Motivation:** Reduction in REI zone, preferred low salinities and decrease in turbidity in the lower reaches **Confidence:** 40%
Biomass distribution: Overall abundance 15 % greater than reference conditions, 8 % greater than present day **Motivation**: Based on salinity preferences and densities of fish in various salinity ranges under present day conditions. The higher salinity zones are greater in area than present. Increase in abundance of marine and partially estuarine dependent species. **Confidence**: 60%
Seasonal variability and Community composition: Estuarine breeders and catadromous species 37-62 % less abundant than under reference conditions. 37 % increase in abundance of selective feeders that prefer less turbid conditions. 49 % reduction in the larger piscivorous predators that prefer the REI zone **Motivation:** Preferred salinities of the REI zone are more extensive under present day conditions. Lower turbidity in the lower reaches **Confidence:** 60%

e. Birds

Based on the predicted changes in the occurrence and variability in Abiotic States, birds under the Le Chasseur Development Scenario will differ from the Present State as follows:

Species diversity, richness and rarity: Little change **Motivation:** Little change in other components **Confidence:** 80%
Biomass distribution: Intermediate between Moderate Development and Bromberg Development Scenarios **Motivation:** As for other components **Confidence:** 60%
Seasonal variability and Community composition: Intermediate between Moderate Development and Bromberg Development Scenarios **Motivation:** As for other components **Confidence:** 60%

Effect of Predicted Changes in Abiotic and Biotic Components under the Le Chasseur Development Scenario on the Present Status Category of the Breede River Estuary, using the EHI

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. Reduction in MAR (%)	63.6	For some permanently open estuaries, such as the Breede River Estuary, critical low flow cut off are not easily definable. Changes in MAR, as a reflection in the reduction in flows, were therefore considered a more suitable indicator of change	60%
b. Decrease in mean annual frequency (%) of floods	34.6	Using average monthly flows of greater than 300 m3/s as indicator.	40%
Hydrology score	**48**		

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of mouth closure, e.g. over a 5 or 10 year period	100	Not applicable to the Breede River Estuary	80%
Hydrodynamic score	**100**		

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification	50	Use the increase in marine dominance as an indicator. Breede River Estuary use to be a freshwater dominated system where significant marine influence was limited to 3 months of the year (i.e. State 3). Under present conditions, significant, and far stronger marine influence in the estuary occurs for 9 months of the year.	60%
2a. Nitrate and phosphate concentration in the estuary	90	Because river inflows decrease, high nutrient-river water will have less of an effect on nitrate concentrations in the estuary. Therefore, nitrate concentrations in the estuary will decrease slightly compared with the present.	40%
2b. Suspended solids in present in inflowing freshwater	80	Although agricultural activities in the catchment probably led to higher suspended solid concentrations in river inflows, vegetation along the banks acts as a sediment trap.	40%
2c. Dissolved oxygen in inflowing freshwater	100	There are no available data, or any other evidence, that indicate reduction in DO levels in the freshwater inflows.	40%
2d. Levels of toxins	90	Pesticides and herbicides associated with agricultural activities may still be an issue, but no data or any other evidence are available to confirm this.	40%
Water quality score	**68**		

Physical habitat alteration

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1a. Change in the inter- tidal exposed area (%)	100	No marked changes observed	80%
1b. Change in the sand fraction relative to total sand and mud (%)	70	Due to reduction river inflows, particularly floods, an increase in marine sediments (i.e. sands) is expected in the lower reaches. Due to stronger seawater intrusion, flocculation of muds may now occur over larger area.	40%
2. Change in subtidal area of the estuary: e.g. bed or channel modification, canalisation	100	No marked changes	80%
3. Migration barriers, bridges, weirs, bulkheads, training walls, jetties, marinas	90	There are a number of small jetties along the entire estuary, particularly in the lower reaches and near Malgas	60%
Physical Habitat score	**89**		

Human disturbance of habitats and biota

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. Degree of human non-consumptive activity on the estuary, e.g. walking, water-skiing, and associated damage to habitats (e.g. trampling, boating activity).	30	The estuary is used extensively during the summer season for recreational activities.	60%
b. Degree of human consumptive activity (fishing and bait collecting) on the estuary, and associated levels of exploitation and damage to habitats (e.g. digging by bait collectors).	10	Recreational angling removes 40 t and illegal netting 5 t of fish from the estuary each year. There appears to be a strong negative correlation between boat traffic and fish abundance and/or catchability within the estuary.	60%
Human Disturbance score	**18**		

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	Similar to Present State	40%
2a. Abundance	80	Score reflects increase in biomass from Present State	40%
2b. Community composition	70	Reflects greater sensitivity to higher salinities in estuary	40%
Microalgae score	**70**		

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	Loss of pondweed, increase in seagrass.	60%
2a. Abundance	72	A predicted decrease in the abundance of *Phragmites australis* (common reed) and *Potamogeton pectinatus* (pondweed) as a result of an increase in salinity.	60%
2b. Community composition	85	Change in the community composition of the brackish marshes. Loss of brackish species and replacement by saline species.	60%
Macrophyte score	**72**		

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	100	Over time (years), diversity, richness likely to be similar to the Moderate Development Scenario. However, during dry period changes likely to be significant.	80%
2a. Abundance	80	If considerable dieback of reeds occurs during dry years, recovery rate of reed beds may be too slow to recover to pre-drought conditions. Consequently, biomass of some species likely to decrease significantly. Other species such as mud prawn likely to increase in biomass as they colonise mud banks further upstream.	60%
2b. Community composition	45	Existing patterns of seasonal distribution and abundance of species likely to change and become more variable within years. For species such as mud prawn (*Upogebia africana*), colonisation of some inter-tidal mud banks upstream may be temporary within years.	40%
Invertebrate score	**45**		

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	60	Possible loss of one or two (maybe more) species that prefer lower salinities. Increase in species that prefer higher salinities. Decrease and maybe loss of species that prefer higher turbidities	40%
2a. Abundance	40	37-62 % decrease in estuarine breeders & catadromous species from reference conditions. Overall 15 % increase in abundance	60%
2b. Community composition	40	37-62 % decrease in estuarine breeders & catadromous species. 25-49 % increase and decrease in abundance of the four dominant piscivores and benthic feeders. 50 % reduction in abundance of most completely estuarine dependent species.	60%
Fish score	**40**		

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness	90	Little change, due to little change in other components	80%
2a. Abundance	85	Intermediate between Moderate Development and Bromberg Development Scenarios	60%
2b. Community composition	80	Intermediate between Moderate Development and Bromberg Development Scenarios	60%
Bird score	**80**		

The individual variable scores obtained for the Le Chasseur Development Scenario are incorporated into a Habitat health score and Biological health score and, finally into the Estuarine Health Score, as follows:

VARIABLE	EHI SCORE				
	Present State	**Limited Development**	**Moderate Development**	**Bromberg Development**	**Le Chasseur Development**
Hydrology	66	62	58	53	48
Hydrodynamics and mouth condition	100	100	100	100	100
Water quality	78	76	71	71	68
Physical habitat	92	92	92	91	89
Human disturbance	18	18	18	18	18
HABITAT HEALTH SCORE	**73**	**72**	**70**	**68**	**66**
Microalgae	90	90	70	70	70
Macrophytes	80	80	77	75	72
Invertebrates	80	80	60	60	45
Fish	80	80	60	60	40
Birds	85	85	75	80	80
BIOLOGICAL HEALTH SCORE	**83**	**83**	**67**	**69**	**61**
ESTUARINE HEALTH INDEX (EHI) SCORE	**78**	**77**	**68**	**69**	**64**
CATEGORY	**B**	**B**	**C**	**C**	**C**

SETTING THE RESERVE FOR WATER QUANTITY

Reserve for ERC of B (recommended ERC for the Breede River Estuary):

According to the RDM Methodologies, the 'acceptable scenario' is defined as the future runoff scenario, or a slight modification thereof, that represents the highest reduction in river inflow that will still maintain the aquatic ecosystem in the desired ERC. This evaluation must be done by a group of experts, e.g. at a workshop. The acceptable scenario then needs to be translated into the format required for the water quantity component of the Reserve.

Based on the above evaluations, the *Limited Development Scenario* meets the flow requirements for the recommended ERC of B allocated to the Breede River Estuary. Therefore, the Reserve for Water Quantity for an ERC of **B** is estimated at **954 x 10^6 m^3** (53.4% of natural MAR). A summary of the flow distribution (mean monthly flows in m^3/s) for the water quantity reserve is provided below **(confidence = 60%):**

MONTH	1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	123.003	58.931	42.203	27.128	19.824	17.703	14.860	12.231	8.338	5.608	1.952
Nov	115.104	48.469	33.666	18.117	12.362	9.791	7.949	6.321	5.509	4.064	3.277
Dec	38.100	16.345	8.981	6.879	6.283	5.010	4.464	4.100	3.775	3.252	2.496
Jan	86.420	7.510	5.394	4.641	3.861	3.307	2.919	2.568	2.345	1.774	0.817
Feb	54.412	20.207	7.402	3.789	3.305	2.004	1.584	1.120	0.798	0.622	0.363
Mar	29.056	18.113	11.475	7.553	5.930	4.164	2.577	1.974	0.994	0.669	0.322
Apr	156.116	54.623	17.888	12.789	8.702	6.847	4.638	2.265	1.341	0.814	0.165
May	182.647	90.278	43.509	30.722	20.150	12.171	7.745	4.384	2.079	0.227	0.000
Jun	213.267	129.916	68.560	48.999	36.251	23.244	15.811	12.965	9.085	3.938	0.226
Jul	253.084	129.256	86.674	69.586	53.553	43.720	34.699	24.414	16.850	11.823	5.483
Aug	480.461	177.290	101.751	75.337	67.301	48.359	38.477	31.453	27.166	17.289	10.367
Sep	132.406	105.926	64.102	53.221	40.005	31.893	29.146	22.485	20.408	14.379	10.995

Floods: It has been assumed that Reserves set as part of an Intermediate RDM will NOT be used to issue water abstraction licenses that will affect the magnitudes of larger floods (e.g. 1:5 year and above). The Intermediate RDM methodology for estuaries, therefore, does not require extensive evaluation of changes in, for example, the magnitude and occurrence of floods.

Although this study provides a preliminary assessment of potential changes in floods from one scenario to another, these were based on very limited data sets and are, by no means, sufficient to quantify specific specifications in terms of, for example the magnitude and occurrence of floods. Specific specifications in terms of the occurrence and magnitude of different flood regimes, therefore, can only be provided once more detailed analysis of floods under the Reference Condition, Present State and Future Development Scenario have been conducted.

Reserve for ERC of A:

At the workshop, the specialist team concluded that the largest factor that contributed to the change in the state of the Breede River Estuary from the Reference Condition to its Present State (putting it in a Category B) was the large reduction in river inflow. Therefore, to improve the Breede River Estuary's ERC from a Category B to a Category A, a large amount of water, already abstracted in the catchment by dams, will have to be re-allocated to the estuary. It was assumed unlikely that large volumes of water could be re-allocated to the estuary such that would elevate the ERC to a Category A.

Reserve for ERC of C (confidence = 40%):

NOTE: Determination of the Reserve for Water Quantity for an ERC lower than the recommended ERC was not part of the Terms of Reference for this project and has therefore not been reviewed by the entire specialist team, as required by the Protocol.

According to the RDM Methodologies, an 'acceptable scenario' is defined as the runoff scenario, or a slight modification thereof, that represents the highest reduction in river inflow that will still maintain the aquatic ecosystem in the desired ERC, in this case a Category C. Following this rule, the flows represented by the Le Chasseur Development Scenario meets the requirements for the Reserve for Water Quantity for a ERC of C. Therefore, the Reserve for Water Quantity for an ERC of C for the Breede River Estuary is estimated at **649 x 10^6 m^3** (36.4% of natural MAR). A summary of the flow distribution (mean monthly flows in m^3/s) for the water quantity reserve is provided below:

MONTH	1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	107.077	46.512	36.775	19.987	12.632	10.649	8.705	7.346	4.778	3.150	1.684
Nov	102.291	37.660	25.349	13.448	8.687	5.974	4.821	4.276	3.449	2.266	1.941
Dec	32.768	10.935	6.693	5.451	4.683	3.552	3.305	2.888	2.734	2.395	1.635
Jan	58.896	5.091	3.784	3.016	2.443	2.161	1.818	1.536	1.500	1.500	1.500
Feb	46.229	15.996	4.584	2.750	1.750	1.501	1.501	1.501	1.500	1.500	1.438
Mar	27.117	14.405	7.182	5.513	4.524	2.641	2.026	1.501	1.500	1.500	1.225
Apr	139.029	38.437	9.470	7.890	5.025	3.428	1.804	1.501	1.501	1.500	1.488
May	125.996	40.883	20.607	13.303	4.883	2.130	1.500	1.500	1.500	1.500	0.750
Jun	192.149	45.082	24.602	13.745	8.198	6.006	3.479	1.501	1.501	1.500	1.500
Jul	239.611	107.311	66.744	25.980	17.917	13.504	10.009	9.103	6.350	3.305	1.500
Aug	428.612	158.345	78.877	56.925	45.049	30.547	23.536	15.902	12.079	7.372	5.690
Sep	124.754	104.523	63.754	42.412	27.653	21.850	18.252	14.858	12.240	9.590	4.725

Floods: It has been assumed that Reserves set as part of an Intermediate RDM will NOT be used to issue water abstraction licenses that will affect the magnitudes of larger floods (e.g. 1:5 year and above). The Intermediate RDM methodology for estuaries, therefore, does not require extensive evaluation of changes in, for example, the magnitude and occurrence of floods.

Although this study provides a preliminary assessment of potential changes in floods from one scenario to another, these were based on very limited data sets and are, by no means, sufficient to quantify specific specifications in terms of, for example the magnitude and occurrence of floods. Specific specifications in terms of the occurrence and magnitude of different flood regimes, therefore, can only be provided once more detailed analysis of floods under the Reference Condition, Present State and Future Development Scenario have been conducted.

STEP 6b : DETERMINATION OF THE RESERVE FOR WATER QUALITY

The procedures to determine the Reserve for Water quality in estuaries is laid out in the *Resource Directed Measures for Protection of Water Resources: Estuarine Ecosystem Component* (http://www-dwaf.pwv.gov.za/idwaf/Documents) as follows:

a. **Obtain the water quality component of the Reserve specified for the riverine resource unit just upstream of the estuary** (this would specify the water quality at the end of that resource unit, and would therefore be representative of the river water entering the estuary).

b. Compare water quality concentrations and/or loads with those of the Present State and Reference Condition. **Evaluate the effect that any changes in river water quality may have on the water quality in the estuary.** Describe these in terms of the different water quality components, i.e.:

c. **Predict the implications of these changes on the different biotic components**

d. **Use Estuarine health index to assess the implication of the above on the Status category/ERC of the estuary**.

e. **If the EHI score indicates that the estuary will remain in the allocated ERC, accept the Reserve for Water Quality of the riverine resource as that for the estuary.**

At the time of the Intermediate Determination of the RDM for the Breede River Estuary, the Reserve for Water Quality for the river section just upstream of the estuary was not yet available.

In the absence of a water quality monitoring station closer to the head of the Breede River Estuary, (about 52 km upstream of the mouth), Present State data were obtained from the Swellendam Monitoring Station - H7H006Q01 (about 102 km from upstream of the mouth). Data for the period 1994 to 1999, i.e. last five years, were used.

Reference Condition data for this point on the Breede River could not be derived from existing water quality monitoring stations of the DWAF.

At the workshop, it was concluded that the Present State of the quality of water entering at the head of the Breede River Estuary is unlikely to deteriorate the ERC of the estuary beyond a Category B. Using the precautionary approach, the Reserve for Water Quality at the head of the estuary (i.e. 20° 30' 40" E; 34° 15' 00" S), is estimated as the median water quality concentrations measured at the Swellendam Monitoring Station (H7H006Q01) over the past 5 years [1994 – 1999]. The Reserve for Water Quality for an ERC of B is presented below (confidence = 40%):

WATER QUALITY VARIABLE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
System variables:												
Salinity (Conductivity)	~ 0 ppt											
Temperature	Should not be altered from average seasonal variation (No data available to establish seasonal variation)											
pH	Should not be altered from average seasonal variation (No data available to establish seasonal variation)											
Dissolved oxygen	Should not be altered from average seasonal variation (No data available to establish seasonal variation)											
Suspended solids	Should not be altered from average seasonal variation (No data available to establish seasonal variation)											
Inorganic nutrients (in mg/L):												
Dissolved nitrate/nitrite-N	0.078	0.015	0.053	0.020	0.395	0.337	0.517	0.471	0.278	0.205	0.182	0.126
Dissolved total Ammonia-N	0.011	0.024	0.014	0.021	0.038	0.006	0.017	0.017	0.051	0.017	0.019	0.025
Dissolved reactive Phosphate-P	0.017	0.015	0.009	0.019	0.016	0.023	0.017	0.020	0.021	0.016	0.021	0.014
Dissolved reactive Silicate-Si	1.205	0.970	0.765	1.460	1.945	1.920	1.665	1.500	1.140	0.925	1.005	1.620
Toxic substances:												
Pesticides and Herbicides	No data available, refer to Reserve for Water Quality for IFR site just upstream of the estuary											

STEP 6c : DETERMINATION OF THE RESOURCE QUALITY OBJECTIVES

RDM Methodologies for the determination of Resource Quality Objectives (RQO) for Estuaries have not been developed. Based on the generic RDM methodology, RQO may need to be set for Water quantity, Water quality, Biota and Habitat.

STEP 7

RESOURCE MONITORING PROGRAMME

STEP 7 : RESOURCE MONITORING PROGRAMME

Future Monitoring Requirements can be sub-divided as follows:

- Additional monitoring surveys to improve the confidence to a level required by an Intermediate determination of RDM for estuaries (available data for this study is listed in Appendix A).

- Additional monitoring surveys to meet the requirements of a Comprehensive determination of RDM

- Long-term monitoring programmes to verify the validity of predictions made during the allocation of the Reserve and RQO (this will occur once the Reserve and RQO are being implemented).

To improve the confidence of this Intermediate determination of RDM of the Breede River Estuary, in particular, the following monitoring surveys are recommended:

Abiotic Components

1. Atypical rain patterns during the study period, prevented specialists from measuring the extreme extent of saline intrusion typically encountered during low flow periods in the Breede River Estuary. To improve confidence, particularly for the low flow period, salinity distribution patterns, as well as water quality conditions at such times still need to be monitored.

2. The levels of water quality variables, such as suspended solids and toxic substances (e.g. pesticides and herbicides) in inflowing river water need to be established for the Present State.

3. Reference Conditions for water quality variables need to be established for inflowing river water needs to be established.

Biotic Components

4. To improve confidence of the predictions that need to be made in RDM determinations requires more data on the relationships between different biotic and abiotic variables. This requires in-depth research – a cross-sectional analysis across different states or systems to determine these relationships. Some of these issues are being addressed in a Water Research Commission Project aimed at improving information requirements and understanding in terms of determination of Resource Directed Measures.

5. The utilisation of microphytobenthos needs to be better established, i.e. "Who eats what" is not well understood.

6. Plant habitat monitoring: Area of intertidal flats should distinguish *Zostera* beds, and area of unvegetated sandflat versus mudflat.

7. The extent to which macrophytes in the Breede River Estuary rely on groundwater must be established.

8. Phytomicrobenthos species and biomass assays need to be conducted to determine the extent of species change with seasons.

9. Monitoring the distribution of fringing macrophytes along the banks of the estuary, particularly *Phragmites australis.* If average salinity increases in an upstream direction, dieback of macrophytes may occur as a consequence. Sampling should be done during the wet and dry seasons.

10. Monitor distribution and abundance (hole counts) of intertidal macrobenthos, particularly large burrowing forms. If average salinity increases in an upstream direction, more suitable conditions provided by higher salinity values may allow colonisation of new intertidal banks by some species. At the same time, sub-surface sediment samples should be collected at high, mid and low tide levels for particle size analysis.

11. For fish, four sampling exercises at 25 sites from the mouth to 40 km upstream during spring, summer, autumn and winter need to be undertaken. At least one sampling exercise must be done over a complete weather cycle or 7 days to get some idea of the short-term responses of fish to changes in flow.

12. To improve confidence and to evaluate performance in the long term, the following would be required for birds: all water birds need to be counted in the different estuarine sections described in this report during late summer (Feb-Mar) (essential), midwinter (Jun-Jul) (important), and spring (Sep) (could be important) at spring low tides. Also, birds in the lower estuary should be counted in one low tide period, the upper estuary in one day (the following day at low tide), with the count being done on days of low human disturbance.

Appendix A

Inventory of data available for the Intermediate determination of RDM for the Breede River Estuary

TABLE A-1. Data requirements on hydrodynamics and water quality for an Intermediate determination of RDM and the availability of such data for this study on the Breede River Estuary

PROPOSED DATA REQUIREMENTS	AVAILABILITY	COMMENT
Simulated monthly runoff data (at the head of the estuary) for Present State, Reference Condition, as well as selected future runoff scenarios over a 50 to 70 year period	Yes	Simulated runoff data were provided by Ninham Shand Consulting Engineers for a 64-year period.
Aerial photographs of estuary (earliest available year as well as most recent)	Yes	Only lower reaches available. Aerial photographs for 1942 and 1989. Orthophoto maps for 1981.
Measured river inflow data (gauging stations) at the head of the estuary over a 5-year period	Yes	Daily inflow data were available for the Swellendam (H7H006Q01) and Eenzaamheid Buffeljags Dam, (H7H013-A01) gauging stations
Continuous water level recordings near mouth of the estuary	Yes	A new water level recorder has been installed by DWAF at the mouth of the estuary. There are no long term records available at present
Longitudinal salinity and temperature profiles (*in situ*) taken on a spring high and low tide at (river flow data must be collected during these periods as well): • 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)	Some	Atypical rain patterns during the study period, prevented specialists from measuring the extreme extent of saline intrusion typically encountered during low flow periods in the Breede River Estuary.
Water quality measurements (i.e. system variables and nutrients) taken along the length of the estuary (surface and bottom samples) on a spring high tide at: • end of low flow season • peak of high flow season	Some	Atypical rain patterns during the study period, prevented specialists from measuring the extreme extent of saline intrusion typically encountered during low flow periods in the Breede River Estuary.
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary	No	Not considered to be a major issue in the Breede River Estuary, as the catchment near the estuary does not support major urban or industrialized areas
Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary	Some	Only nutrient data were available. Data were from the monitoring station at Swellendam for the period 1994 to 1999, representative of the present state.
Water quality (e.g. system variables, nutrients and toxic substances) measurements of near shore seawater	No	Data listed in the *South African Water Quality Guidelines for Coastal Marine Waters* for the south coast was used.

TABLE A-2. Data requirements on sediment dynamics for a Comprehensive determination of RDM and the availability of such data for this study on the Breede River Estuary

DATA REQUIREMENTS	AVAILABILITY	COMMENT
Simulated flood hydrographs for present and Reference Conditions for: • 1:1, 1:2, 1:5 floods (influencing aspects such as flood plain inundation) • 1:20, 1:50, 1:100, 1:200 year floods (influencing sediment dynamics)	Some	Some simulated flood hydrographs for present and future conditions were provided by Ninham Shand Consulting Engineers, but there were no data on the Reference Condition.
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) [1].	No	Not a requirement for an Intermediate Reserve study, the data from a 1982 study done by the CSIR was use to give some indication of sediment distribution trough the estuary
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.	No	Cross section profile data were only available for 1996.
Set of cross section profiles and a set of sediment core samples for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations), need to be taken immediately after a major flood	No	Not a requirement for an Intermediate Reserve study.

TABLE A-3. Data requirements on microalgae for an Intermediate determination of RDM and the availability of such data for this study on the Breede Estuary

DATA REQUIREMENTS	AVAILABILITY	COMMENTS
Chlorophyll-a measurements taken at 5 stations (at least) at the surface, 0.5 m and 1 m depths thereafter. Cell counts of dominant phytoplankton groups i.e. flagellates, dinoflagellates, diatoms and blue-green algae. Measurements should be taken coinciding with typically high and low flow conditions.	Yes	Samples collected 19/03/2000 Samples collected 11/08/2000
Intertidal and subtidal benthic chlorophyll-a measurements taken at 5 stations. Epipelic diatoms need to be collected for identification. Measurements should 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).	Yes	Samples taken from 5 stations under high and medium fresh water flow on three occasions. Samples collected 19/03/2000 Samples collected 11/08/2000 Samples collected 3/04/2001 None previously available
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.	Yes	Not required for benthic samples because benthic samples integrate the environmental factors.

TABLE A-4. Data requirements on macrophytes for an Intermediate determination of RDM and the availability of such data for this study on the Breede River Estuary

DATA REQUIREMENTS	AVAILABILITY	COMMENTS
Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the Present State, as well as the Reference Condition. Orthophoto maps of the area	Yes	Only lower reaches available. Aerial photographs for 1942 and 1989. Orthophoto maps for 1981.
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.	Yes	Field surveys in March & August 2000.
Permanent transects (a fix monitoring station that can be used to measure change in vegetation in response to changes in salinity and inundation patterns) Measurements of percentage plant cover along an elevation gradient. Measurements of salinity, water level and sediment moisture content.	Yes	The distribution of salt marsh plants along 2 transects on Green Point marsh was documented in March 2000 and related to various substrate characteristics.

TABLE A-5. Data requirements on invertebrates for an Intermediate determination of RDM and the availability of such data for this study on the Breede River Estuary

DATA REQUIREMENTS	AVAILABILITY	COMMENTS
Derive preliminary sediment map of the estuary.	Yes – for the estuary channel	Sediment samples collected from channel areas and presented in table format in the report.
Obtain a preliminary determination of the extent and distribution of shallows and tidally exposed substrates.	Yes	These are included in the report – used to design sampling sites in the intertidal. Upeer estuarine interetidal areas not included as exposed mud or sandy areas are very limited in extent.
For six benthic sites, collect sediment samples for analysis of grain size and organic content	Yes	Information in the report
Determine the longitudinal distribution of salinity, as well as other system variables (e.g. temperature, pH and dissolved oxygen and turbidity) at each of the six benthic sampling sites	Yes	Information in the report
During a spring tide (preferably for both low flow and high flow conditions), 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.	Yes	Two series of benthic samples collected – unfortunately both coincide with periods of high flow (summer and winter). Benthic sites located along the estuary – the uppermost site a short distance before Malgas.
During a spring tide (preferably at both low and high water and for both low flow and high flow conditions), collect two sets of beam trawl samples (i.e. over 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. Samples should be collected every second week under low and high flow conditions for at least two months each (i.e. five sampling sessions under the two flow scenarios) Survey as much shoreline for signs of crabs and prawns and record observations.	Yes	Hyperbenthic sled samples collected during both sampling trips and at the same sites as benthic sites.
During spring tides (preferably at both low and high water and for both low flow and high flow conditions), collect three samples, at night, one each from the upper, middle and lower reaches of the estuary for zooplankton. Samples should be collected every second week under low and high flow conditions for at least two months each (i.e. five sampling sessions under the two flow scenarios)	No	Hyperbenthic sampler will provide an indication of the macrozooplankton. Available information (sampled by Grindley) suggests that zooplanlkton biomass is low.

TABLE A-6. Data requirements on fish for an Intermediate determination of RDM and the availability of such data for this study on the Breede River Estuary

DATA	AVAILABILITY	COMMENTS
Collect three sets of small and large seine and gill net samples, one each from the lower, middle and upper reaches of the estuary. Depending on the size and depth of the estuary, it may be necessary to also undertake cast netting, particularly in smaller systems.	Three years (1997-1999) of bimonthly seine and gillnet samples. One summer and one winter sampling trip each comprising 25 seine & gillnet samples from the mouth to 40 km upstream. Limited data available from previous work on the system and from angler records from 1997-2000	One summer and one winter sampling trip each comprising 25 seine & gillnet samples from the mouth to 40 km upstream. System extremely variable, needs intensive sampling to determine short term and long term responses of the fish fauna to different flow regimes
Information on fish gained during the macrocrustacean beam trawls should also be used.	No	Beam trawls not carried out in this study. Impractical in most SA systems

TABLE A-7. Data requirements on birds for an Intermediate determination of RDM and the availability of such data for this study on the Birds River Estuary

DATA	AVAILABILITY	COMMENTS
During a summer spring tide, 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.	Summer count available for ca. 1980; Fieldwork carried out for this study	Both a summer and a winter count were carried out in this study, and additional counts were carried out of the lower estuary in summer and spring..

Appendix B

Proposed changes to the RDM methodologies for estuaries

Intermediate RDM process:

a. Every effort must be made to do the field sampling for the different components at the same time.

b. Specialists should interact more before the workshop.

c. The detailed scoring guidelines for completion of the EHI must be supplied to the specialists together with the RDM Templates.

d. Video conferencing should be investigated as a means of reducing costs in future.

e. A method must be determined for providing the overall confidence of an RDM determination.

Data Requirements:

a. Details on the planned developments i.e. alternative dam scenarios and capacity of the dams should be included in the starter reports to the specialists. All details on the scenarios i.e. releases from the dams, agricultural return flows must be given.

b. For water quality, turbidity measurements need to be added to the list of system variables.

c. Where possible more photographs, pictures should be included in the specialist reports for illustrative purposes.

Step 3: Assessment of Present State and Reference Condition

a. In the description of the Abiotic State Templates, the following parameters should also be included:

- 'Turbidity' should be added to the list of System Variables
- Estimates on water retention times for different states
- Estimates of (maximum) tidal velocities along the estuary for different states.

b. To allow for easier comparison, reference to stations in the specialist reports need to be standardized to '*Distance from the mouth*' rather than each specialists using their own station name or number.

c. An assessment of the effect of tidal velocities on sediment movement need to be included in the Comprehensive Determination of RDM.

Step 4a: Determination of Present Status Category

a. Changes must be made to hydrological component of the EHI. Hydrology score mustn't be back to front i.e. subtracted from 100.

b. The EHI scoring related to salinities presently reflects changes in the duration of salinity distribution patterns from the reference condition. The scoring system, however, also need to include a measure of change in the intensity of extreme conditions, e.g. at the end of low flow periods.

c. Community composition in the Estuarine Health Index must be elaborated on to include trophic linkages

d. In the generic spreadsheet to be developed for calculating the EHI scores at workshops, it should be possible to flag individual scores with important notes or comments.

e. A component must be added to the EHI to include the functional importance of the estuary in terms of inputs to the marine environment.

f. Potential overlap (or double counting) related to the *Human disturbance of habitats and biota* sub-component in the EHI and other sub-components relating to habitat and biota must be addressed.

Step 4b: Determination of Estuarine Importance

a. The ratings allocated to the different Importance scores ranges need to be re-addressed. For example, rather uses categories such as 'Very high Importance', 'Medium Importance' and 'Low Importance' to describe these in RDM reports rather than quoting the specific percentage value.

b. Functional Importance:

SUB-COMPONENTS	SCORE	MOTIVATION
~~Stop-over function for migratory birds~~		It is proposed that this be taken out, as SA is not really a stopover destination for migrants

Step 5: Allocation of Ecological Reserve Category (ERC)

a. The term 'Ecological Management Class (EMC) ' has been changed to 'Ecological Reserve Category (ERC)'

b. Rules for including the Estuarine Importance Score into the ERC must be re-addressed (these rules were not strictly applied in the Breede River Estuary RDM).

Step 6a: Determination of Reserve for Water Quantity

a. Once the 'acceptable future scenario' has been identified in the specialist workshop, there should be the scope to refine the acceptable scenario to the optimal Reserve scenario, through an iterative process with the hydrological consultants.

Step 6c: Determination of RQO

a. Using the EHI as a means of setting RQO for the Biota and Habitat in estuaries should be investigated using, for example the sub-components in the EHI that relates to the habitat and biota, i.e. Physical habitat alteration, Human disturbance of habitat and biota and Microalgae, Macrophytes, Invertebrates, Fish and Birds. For example:

Physical habitat alteration

VARIABLE	ALLOWABLE SCORE	SPECIFIC, MEASUREABLE REQUIREMENTS
1a. Change in the inter- tidal exposed area (%)		
1b. Change in the sand fraction relative to total sand and mud (%)		
2. Change in subtidal area of the estuary: e.g. bed or channel modification, canalisation		
3. Migration barriers, bridges, weirs, bulkheads, training walls, jetties, marinas		

Human disturbance of habitats and biota

VARIABLE	ALLOWABLE SCORE	SPECIFIC, MEASUREABLE REQUIREMENTS
a. Degree of human non-consumptive activity on the estuary, e.g. walking, water-skiing, and associated damage to habitats (e.g. trampling, boating activity).		
b. Degree of human consumptive activity (fishing and bait collecting) on the estuary, and associated levels of exploitation and damage to habitats (e.g. digging by bait collectors).		

Microalgae, Macrophytes, Invertebrates, Fish and Birds (each separately):

VARIABLE	ALLOWABLE SCORE	SPECIFIC, MEASUREABLE REQUIREMENTS
1. Species richness		
2a. Abundance		
2b. Community composition		

Appendix C

Specialist Report:

Physical Dynamics and Water Quality

This report was compiled by:

S Taljaard, L van Niekerk and P Huizinga
CSIR, Environmentek
P O Box 320, Stellenbosch, 7599

February 2002

This report was compiled by:

Ms S Taljaard
Ms L van Niekerk
Mr P Huizinga

Published by:

CSIR, Evironmentek
P O Box 320
7599 STELLENBOSCH

Report No: CSIR Report ENV-S-C 2002-020/B

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SCOPE

Further developments of water resources from the Breede River system are being considered by the Department of Water Affairs and Forestry.

Detailed investigations on the viability of the developments are being undertaken by Ninham Shand Consulting Engineers and MBB Consulting Engineers as main consultants to the Department of Water Affairs and Forestry.

The investigations on the influence of river inflow on the environmental aspects on the Breede River Estuary are being co-ordinated by the CSIR as sub-consultant.

This report presents the results of the specialist study on the effects of the planned developments on the physical dynamics and water quality of the estuary, undertaken by the CSIR.

The results presented in this report are part of the investigations of the effects of further developments in the catchment on the estuary. These results address the effects on the physical dynamics of the estuary and are being used in other specialist studies on the ecological aspects of the estuary.

P Huizinga
COAST PROGRAMME

Stellenbosch, South Africa
February 2002

ACKNOWLEDGEMENTS

- The cross-sections of the Breede Estuary used for the set-up of the model were surveyed as part of a monitoring programme undertaken by the CSIR for the Department of Environment Affairs and Tourism.
- The hydrological simulation data used in this report were provided by Ninham Shand Consulting Engineers.

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LIST OF SYMBOLS

Q	=	discharge (m^3/s)
h	=	stage above datum (m)
C	=	Chezy coefficient ($m^{1/2}.s^{-1}$)
R	=	hydraulic radius (m)
α	=	momentum distribution coefficient
C	=	concentration (arbitrary units)
D	=	dispersion coefficients (m^2/s)
A	=	cross-sectional area (m^2)
x	=	space coordinate (m)
t	=	time coordinate (s)
v	=	the mean velocity in the cross-section (m/s)
MSL	=	mean sea level

1. BRIEF

Further developments of the water resources of the Breede River system are being considered by the Department of Water Affairs and Forestry, i.e. further abstraction of water from the Breede River and its main tributary the Riviersonderend. This includes additional schemes for irrigation of agricultural land and possibly also the transfer of water to the Cape Town metropolitan area. Detailed investigations on the viability of the developments are being undertaken by Ninham Shand Consulting Engineers, MBB Consulting Engineers and Jakoet & Associates as main consultants to the Department of Water Affairs and Forestry. The investigations on the influence of river inflow on the environmental aspects on the Breede River Estuary are being co-ordinated by the CSIR as sub-consultant.

This report presents the results of the specialist study on the effects of the planned developments on the physical dynamics and water quality of the estuary (i.e. abiotic components). In turn, these results will be used to assess the implication of these developments on the ecological or biotic components of the Breede River Estuary.

2. THE STUDY AREA

The Breede River has a length of about 257 km with a catchment area of about 12 625 km^2. Runoff from the catchment is strongly seasonal, with high flows and major floods during winter months (June to Augusts) and low flows during the summer (February to March).

There are three major dams on the Breede River: the Riviersonderend Dam built in 1980, which has a capacity of 433 x 10^6 m^3, the Brandvlei Dam built in 1926 with a capacity of 304 x 10^6 m^3 and the Kwaggaskloof Dam, built in 1975 with a capacity of 171x 10^6 m^3. Additionally, there are several smaller dams in the catchment and many farm dams. The mean annual run-off (MAR) of the river reaching the estuary has as a result been reduced by approximately 42 per cent from 1784 x 10^6 m^3 under reference (or natural) conditions to 1034 x 10^6 m^3 at present.

The Breede River Estuary stretches roughly from 10 km above Malgas to the town of Witsand some 220 km east of Cape Town (Figure 1). The estuary enters the sea through a permanently open mouth located at the southern end of an extensive sand spit. The channel of the estuary is incised in the coastal plain and depths of 3 to 6 m and even more are common over the first 28 km. Tidal influence extends beyond the pont at Malgas to approximately 50 km upstream. The mouth of the Breede River estuary is permanently open because of the length of the estuary and the still relatively high run-off of the system. It is considered highly unlikely that the mouth will close under present day conditions.

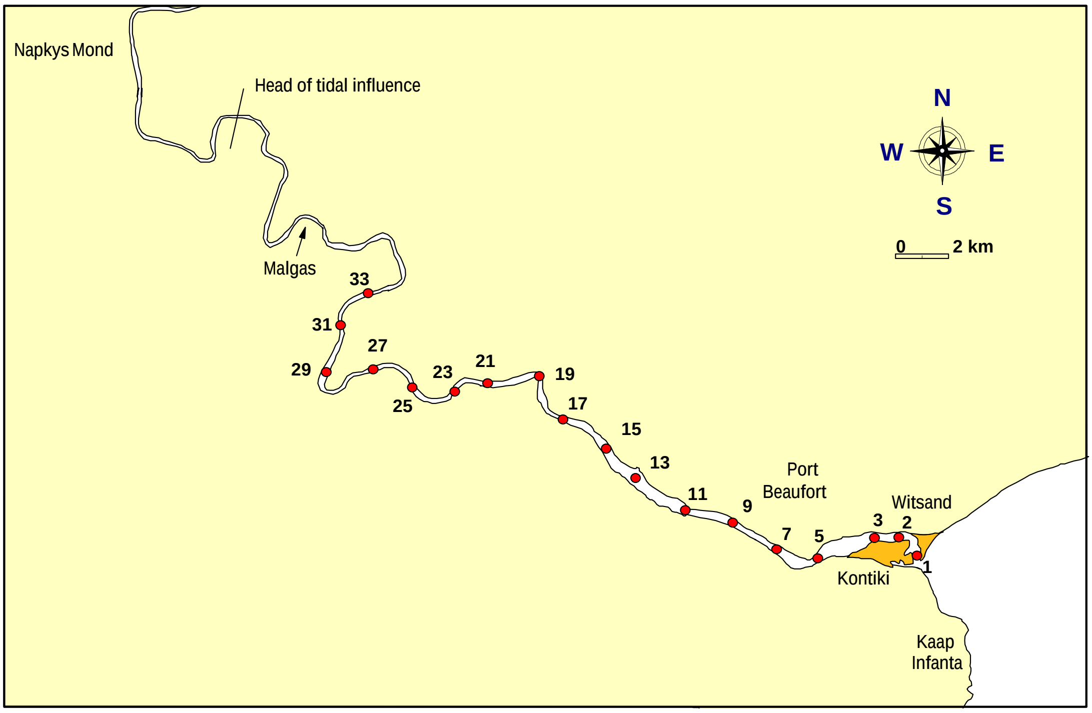


Figure 1. The Breede River Estuary, showing the water column sampling stations

For the purposes of the Intermediate Determination of Resource Directed Measures (RDM) for the Breede River Estuary, the geographical boundaries were defined as follows :

- Downstream boundary: The estuary mouth
- Upstream boundary: 52 km upstream of the mouth
- Lateral boundaries: 5 m contour above MSL along the banks.

3. AVAILABLE FIELD DATA

3.1 Topographical data

Bathymetric data used in this study was obtained from existing data sets collected by the CSIR in 1982 and 1996, as part of a monitoring programme of estuaries undertaken by the CSIR for the Department of Environment Affairs and Tourism and detailed data sets on bathymetry and cross-section profiles can be obtain from this report (CSIR, 2000).

The estuary is up to 1250 metres wide near the mouth and gradually becomes narrower further upstream with a width of 150 metres at Malgas, approximately 40 km upstream. The depths are mostly between 3 and 6 metres. A deep spot with a maximum depth of 17metres below MSL was in 1996 observed at 19 km from the mouth. In 1982, such a deep spot with a depth of 17,6 m was observed at Malgas. Cross-sections were surveyed at intervals of 1 km and such deep spots can occur between cross-sections in which case they sometimes are detected and sometimes not.

Accumulated area and accumulated volume for distance from the mouth for the Breede River Estuary is presented in Annexure C-1.

3.2 Sediment Data

Comprehensive sediment surveys were undertaken by the CSIR in 1982 (CSIR, 1983).

3.3 Measured River Inflow

Two gauging stations are present in the lower part of the Breede River catchment:

- The Swellendam Station, H7H006-A01 (catchment size 9840 km^2) on the main river, contributing the majority of the runoff.

- The Eenzaamheid Buffeljags Dam Station, H7H013-A01, (catchment size 602.00 km ^{2}) on the Buffeljags tributary contributes to the runoff mainly during freshets and flood events.

These gauging station are about 50 km above the top of the estuary and a delay of about a day can be expected before these measured flows could research the estuary. The measured average daily flows for two flow gauging stations were combined to estimate the total average daily inflow (m^3/s) into the estuary.

3.4 Water level data

Water level variations were measured by visual observations from gauging poles at four positions in the estuary at spring tide on 20 January 1996, as part of a CSIR research project (CSIR, unpublished report). Phase lags are interesting aspects of tidal movements in an estuary and those observed at high and low tide on 20 January 1996 are listed in Table 1.

TABLE 1. Tidal phase lags along the Breede River Estuary as measured on 20 January 1996 (spring tide)

POSITION	LOW TIDE AT..	PHASE LAG
Mossel Bay (predicted tide)	09:30	-
Station R1 (2 km from mouth)	10:00	30 minutes
Station R2 (16 km form mouth)	12:00	2 hours 30 minutes
Station R3 (26 km from mouth)	12:30	3 hours
Station R4 (39 km from mouth)	13:00	4 hours
POSITION	HIGH TIDE AT..	PHASE LAG
Mossel Bay (predicted tide)	15:43	-
Station R1 (2 km from mouth)	15:50	7 minutes
Station R2 (16 km form mouth)	16:40	57 minutes
Station R3 (26 km from mouth)	17:00	1 hour 17 minutes
Station R4 (39 km from mouth)	18:00	2 hours 17 minutes

Water level variations were also observed at Napkys Mond, 58 km upstream, but tidal variation was not observed at this location.

3.5 Evaporation Data

The net evaporation for the lower Breede River is as follows, based on data provided by Ninham Shand. The evaporation (in mm) together with surface areas was used to estimate evaporation rate in m^3/s (Table 2).

TABLE 2. Net evaporation rate for the lower Breede River (in m^3/s)

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
0.38	0.56	0.83	0.92	0.71	0.46	0.41	0.06	0.03	0.00	0.03	0.18

3.6 Salinity/Temperature and other Water Quality Data

Water quality data for river inflow was obtained from Ninham Shand (Dr N Rossouw, pers. comm.), using the monthly data sets collected by the DWAF at the Breede River Station at Swellendam (H7H006Q01). Data from 1995 to 1999 (i.e. TDS, nitrate/nitrite, total ammonia, reactive phosphate and reactive silicate) was considered representative of seasonal variations for present day conditions.

Water quality measurements were collected from the a selection of stations in the Breede River Estuary (Figure 1) on the following occasions:

- January 1996 (summer)
- February 2000 (summer)
- August 2000 (winter)

During the January 1996 survey, the following data were collected (CSIR, unpublished report):

- Salinity and temperature profiles on neap flood and ebb tides (14 January 1996)
- Salinity and temperature profiles, as well as dissolved oxygen and dissolved nutrient measurements on spring flood and ebb tides (20/21 January 1996).

During the February 2000 survey, the following data were collected (Annexure A-2):

- Salinity and temperature profiles on neap low and high tides (14 February 2000)
- Salinity and temperature profiles on spring high and low tides (21 February 2000).
- Dissolved oxygen and dissolved nutrient measurements on a spring high tide (21 February 2000).

During the August survey, the following data were collected (Annexure A-2):

- Salinity and temperature profiles on neap high and low tides (23/24 August 2000)
- Dissolved oxygen and dissolved nutrient measurements on a neap low tide (23 August 2000).

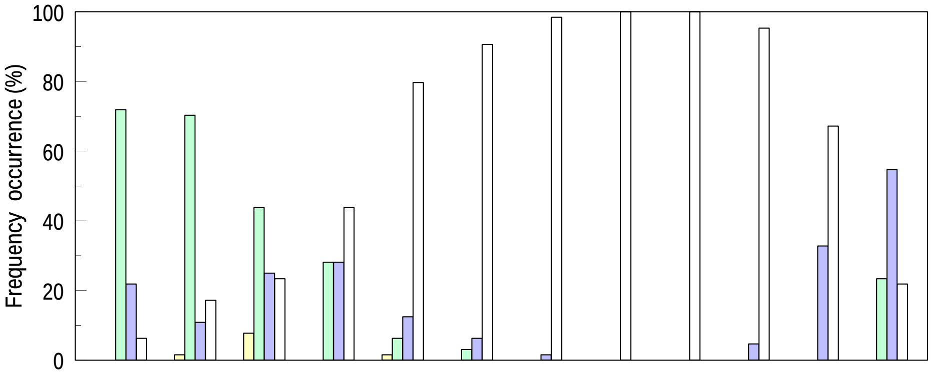
In situ measurements of salinity and temperature profiles were taken at selected hydrographic stations (Figure 1) along the length of the estuaries at approximately 0.5 m depth intervals, using a Valeport series 600 MK II CTDS Meter (accuracy 0,2 ppt, 0,2 ^{o}C, 0,1 m).

Dissolved oxygen and nutrients samples were collected in surface and bottom waters at each of the hydrographic stations. Dissolved oxygen measurements were done manually, using the Winkler titration method (CSIR,, 1997). Nutrients samples were frozen in the field. Samples were analysed at the CSIR marine chemistry laboratory (Stellenbosch), using a Technicon Auto-analyzer (CSIR, 1997).

4. SIMULATED RUNOFF SCENARIOS FOR THE BREEDE RIVER ESTUARY

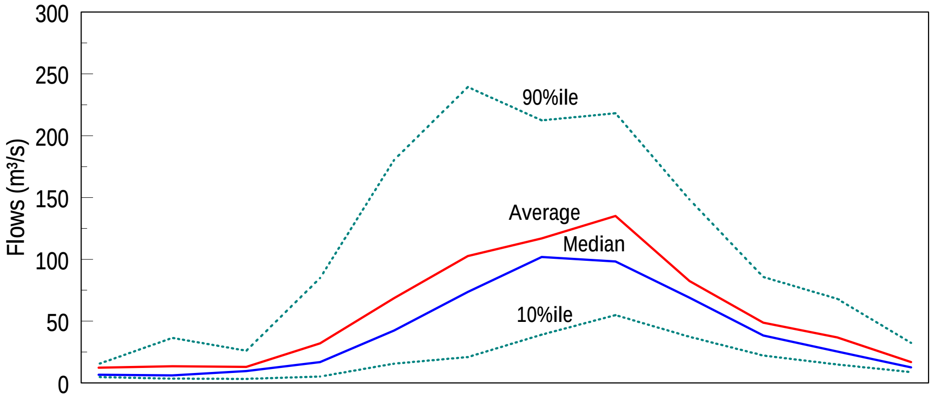
Simulated monthly runoff data sets (average flow in m³/s) were provided by Ninham Shand Consulting Engineers. For this study this included simulated runoff data, over a 64-year period (1927 to 1990) for a number of runoff scenarios. Detailed simulated monthly runoff data, provided by Ninham Shand, are listed in Annexure C-3. Colour coding has been used on these tables to highlight the occurrence and duration of low flows, significant for the salinity distributions in the estuary. Data from these tables are summarised below for each of the scenarios. This includes frequency distributions of flow ranges, as well as statistical analyses of each of the scenarios are provided below:

- <u>Reference (or natural) conditions</u>, MAR 1785 x10⁶ m³



Months	1	2	3	4	5	6	7	8	9	10	11	12
< 0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5 - 3.0	0.0	1.6	7.8	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.0 -10.0	71.9	70.3	43.8	28.1	6.3	3.1	0.0	0.0	0.0	0.0	0.0	23.4
10.0 - 20.0	21.9	10.9	25.0	28.1	12.5	6.3	1.6	0.0	0.0	4.7	32.8	54.7
> 20.0	6.3	17.2	23.4	43.8	79.7	90.6	98.4	100.0	100.0	95.3	67.2	21.9

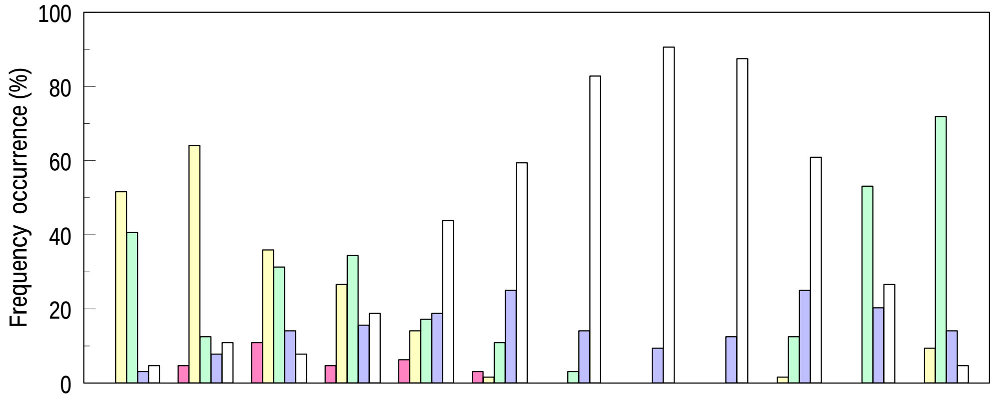
Figure 2a. Distribution frequency of flow ranges (in m³/s) for the Reference Condition, based on the 64-year simulated data



Months	1	2	3	4	5	6	7	8	9	10	11	12
Median	6.62	6.15	9.64	16.97	42.43	73.60	101.91	98.29	69.04	38.34	25.40	12.61
Average	12.33	13.52	12.96	32.10	68.58	102.62	117.00	135.10	82.48	48.79	36.78	16.87
10%ile	4.85	3.54	3.32	5.27	15.64	20.94	39.10	54.90	37.38	22.18	14.92	8.80
90%ile	15.37	36.43	26.11	84.96	180.41	239.36	212.41	218.22	148.40	85.75	68.13	32.41

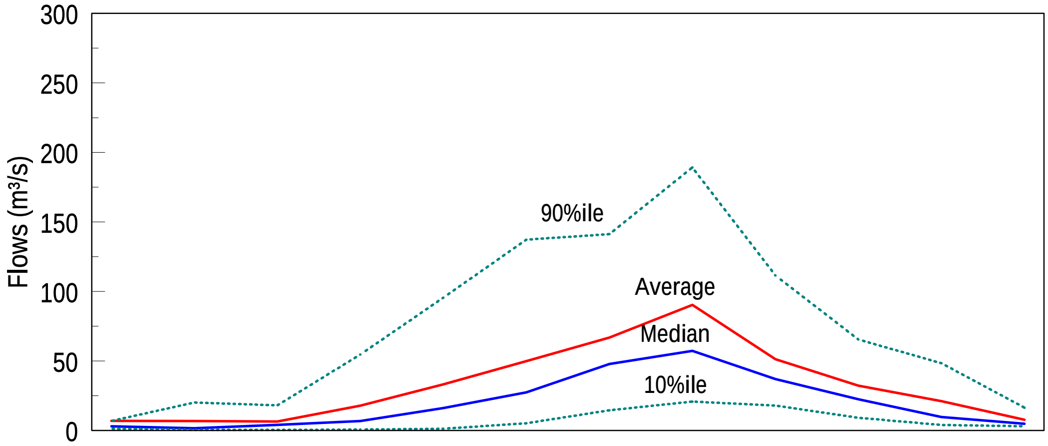
Figure 2b. Statistical analysis of the monthly, simulated runoff data for the Reference Condition, over a 64-year period (1927 to 1990)

- **Present State**, MAR 1034 x 10⁶ m³ (a reduction of 42.1 % from the reference condition)



Months	1	2	3	4	5	6	7	8	9	10	11	12
< 0.5	0.0	4.7	10.9	4.7	6.3	3.1	0.0	0.0	0.0	0.0	0.0	0.0
0.5 - 3.0	51.6	64.1	35.9	26.6	14.1	1.6	0.0	0.0	0.0	1.6	0.0	9.4
3.0 -10.0	40.6	12.5	31.3	34.4	17.2	10.9	3.1	0.0	0.0	12.5	53.1	71.9
10.0 - 20.0	3.1	7.8	14.1	15.6	18.8	25.0	14.1	9.4	12.5	25.0	20.3	14.1
> 20.0	4.7	10.9	7.8	18.8	43.8	59.4	82.8	90.6	87.5	60.9	26.6	4.7

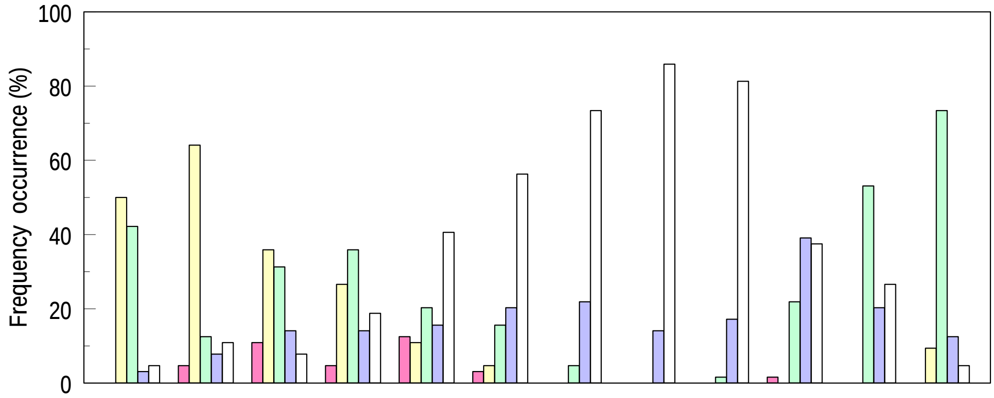
Figure 3a. Distribution frequency of flow ranges (in m³/s) for the Present State, based on the 64-year simulated data



Months	1	2	3	4	5	6	7	8	9	10	11	12
Median	2.99	1.59	4.12	6.91	16.10	27.50	47.82	57.28	37.05	22.56	9.72	4.84
Average	6.99	6.87	6.49	17.94	33.20	49.92	66.76	90.35	51.31	32.28	21.03	7.77
10%ile	1.26	0.54	0.49	0.66	1.31	5.27	14.54	20.83	17.94	9.18	4.03	3.13
90%ile	6.89	20.18	18.10	54.70	95.55	137.25	141.19	189.21	111.57	65.52	48.38	16.48

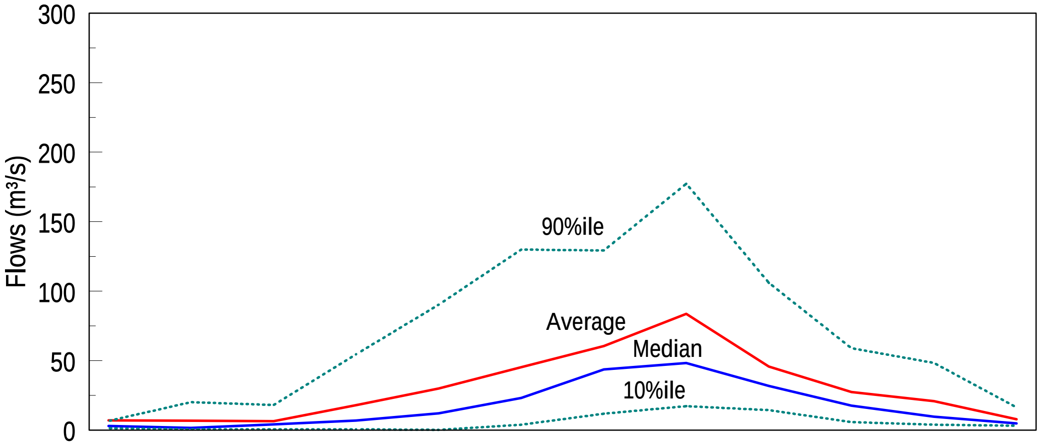
Figure 3b. Statistical analysis of the monthly, simulated runoff data for the Present State, over a 64 year period (1927 to 1990)

- Limited future development scenario, MAR 954 x 10^6 m^3 (a reduction of 46.6% from the reference condition)



Months	1	2	3	4	5	6	7	8	9	10	11	12
< 0.5	0.0	4.7	10.9	4.7	12.5	3.1	0.0	0.0	0.0	1.6	0.0	0.0
0.5 - 3.0	50.0	64.1	35.9	26.6	10.9	4.7	0.0	0.0	0.0	0.0	0.0	9.4
3.0 -10.0	42.2	12.5	31.3	35.9	20.3	15.6	4.7	0.0	1.6	21.9	53.1	73.4
10.0 - 20.0	3.1	7.8	14.1	14.1	15.6	20.3	21.9	14.1	17.2	39.1	20.3	12.5
> 20.0	4.7	10.9	7.8	18.8	40.6	56.3	73.4	85.9	81.3	37.5	26.6	4.7

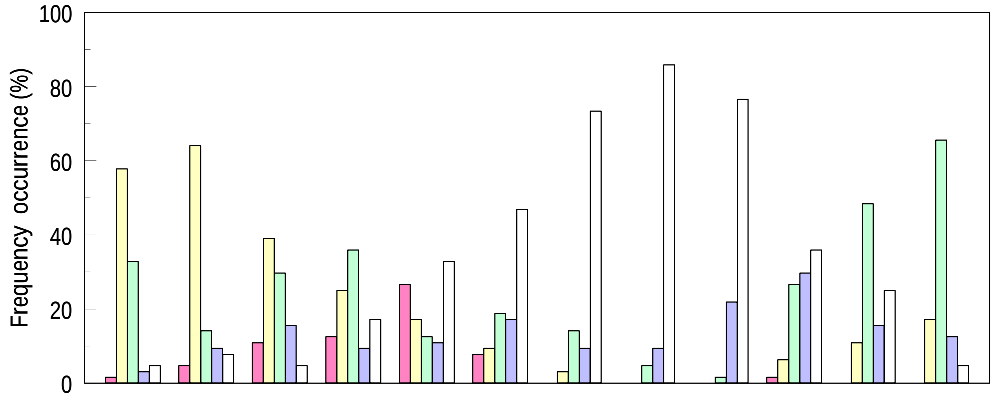
Figure 4a. Distribution frequency of flow ranges (in m^3/s) for the Limited future Development Scenario, based on the 64-year simulated data



Months	1	2	3	4	5	6	7	8	9	10	11	12
Median	3.04	1.59	4.13	6.85	12.08	23.22	43.72	48.36	31.89	17.70	9.69	4.86
Average	7.01	6.83	6.47	17.89	29.96	45.32	60.53	83.72	45.75	27.37	20.87	7.75
10%ile	1.33	0.55	0.50	0.65	0.23	3.94	11.82	17.29	14.38	5.84	3.89	3.18
90%ile	6.64	20.18	18.11	54.62	90.28	129.92	129.26	177.29	105.93	58.93	48.32	16.32

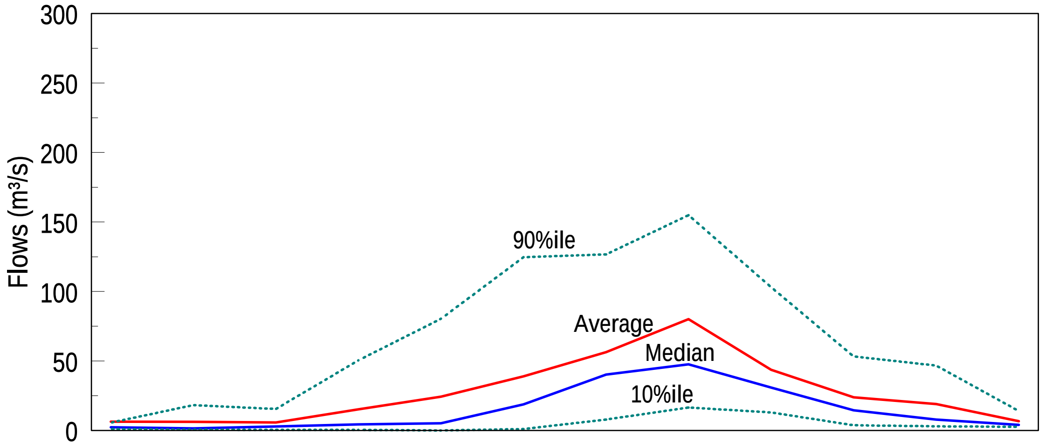
Figure 4b. Statistical analysis of the monthly simulated runoff data for the Limited Future Development Scenario, over a 64 year period (1927 to 1990)

- <u>Moderate Future Development Scenario</u>, MAR 863 x10^6 m^3 (a reduction of 51.7% from reference condition)



Months	1	2	3	4	5	6	7	8	9	10	11	12
< 0.5	1.6	4.7	10.9	12.5	26.6	7.8	0.0	0.0	0.0	1.6	0.0	0.0
0.5 - 3.0	57.8	64.1	39.1	25.0	17.2	9.4	3.1	0.0	0.0	6.3	10.9	17.2
3.0 -10.0	32.8	14.1	29.7	35.9	12.5	18.8	14.1	4.7	1.6	26.6	48.4	65.6
10.0 - 20.0	3.1	9.4	15.6	9.4	10.9	17.2	9.4	9.4	21.9	29.7	15.6	12.5
> 20.0	4.7	7.8	4.7	17.2	32.8	46.9	73.4	85.9	76.6	35.9	25.0	4.7

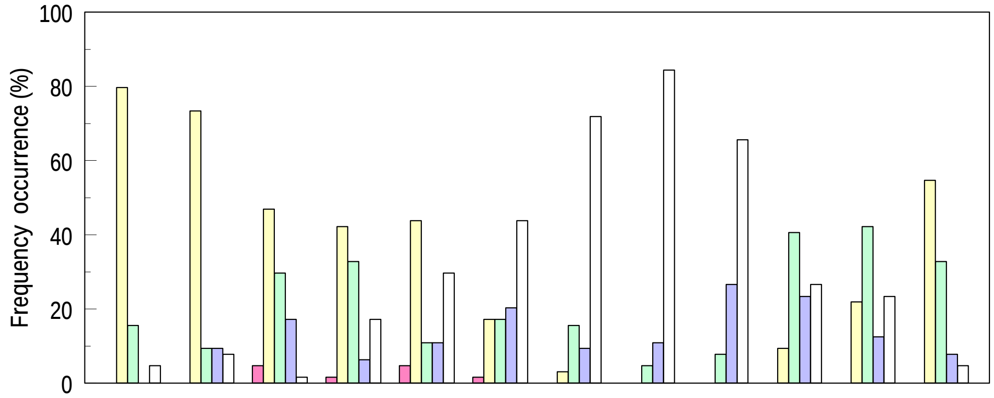
Figure 5a. Distribution frequency of flow ranges (in m^3/s) for the Moderate Future Development Scenario, based on the 64-year simulated data



Months	1	2	3	4	5	6	7	8	9	10	11	12
Median	2.39	1.54	2.85	4.36	5.17	18.74	40.27	47.63	30.83	14.54	7.90	4.00
Average	6.34	6.25	5.80	15.24	24.28	38.98	56.35	80.08	43.65	23.86	18.96	6.74
10%ile	1.06	0.53	0.49	0.44	0.00	1.06	7.83	16.55	12.97	3.74	3.02	2.62
90%ile	5.67	18.25	15.49	50.46	80.38	124.64	126.71	154.87	103.08	53.29	46.68	13.96

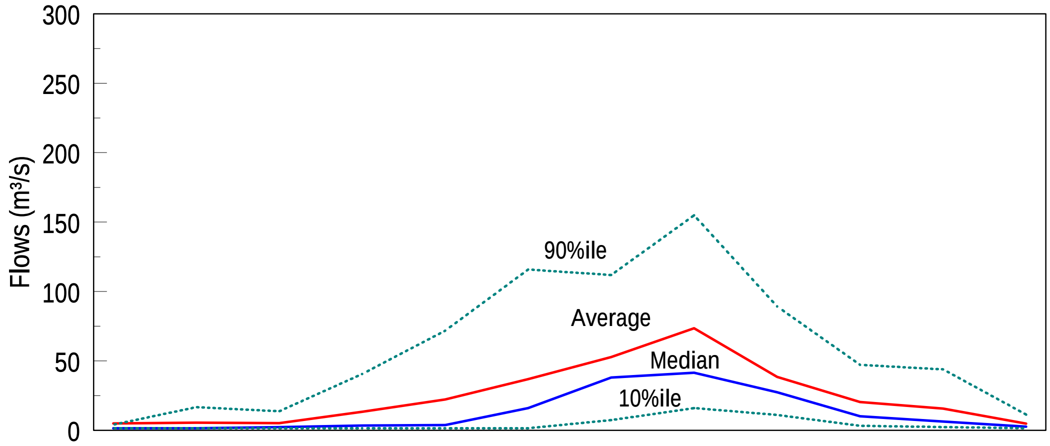
Figure 5b. Statistical analysis of the monthly, simulated runoff data for the Moderate Future Development Scenario, over a 64-year period (1927 to 1990).

- <u>Alternative major future development scenario including the Bromberg Dam development</u>, MAR 772 x10⁶ m³ (a reduction of 56,7% from reference condition)



Months	1	2	3	4	5	6	7	8	9	10	11	12
< 0.5	0.0	0.0	4.7	1.6	4.7	1.6	0.0	0.0	0.0	0.0	0.0	0.0
0.5 - 3.0	79.7	73.4	46.9	42.2	43.8	17.2	3.1	0.0	0.0	9.4	21.9	54.7
3.0 -10.0	15.6	9.4	29.7	32.8	10.9	17.2	15.6	4.7	7.8	40.6	42.2	32.8
10.0 - 20.0	0.0	9.4	17.2	6.3	10.9	20.3	9.4	10.9	26.6	23.4	12.5	7.8
> 20.0	4.7	7.8	1.6	17.2	29.7	43.8	71.9	84.4	65.6	26.6	23.4	4.7

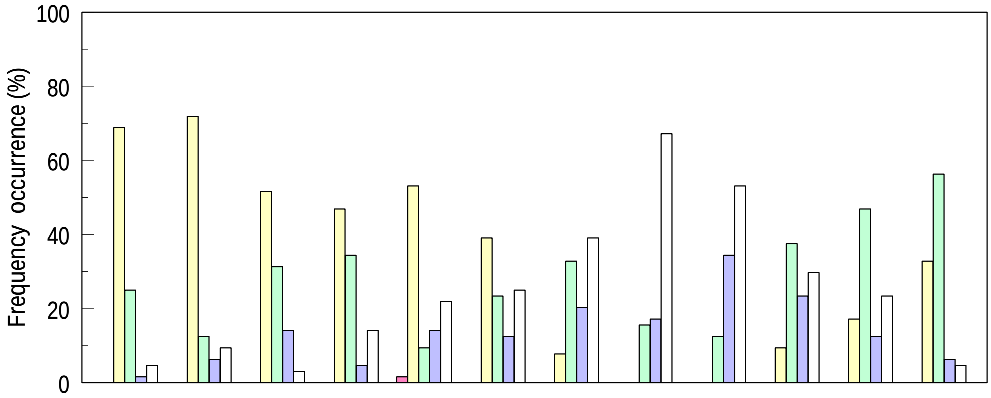
Figure 6a. Distribution frequency of flow ranges (in m³/s) for the Bromberg Future Development Scenario, based on the 64-year simulated data



Months	1	2	3	4	5	6	7	8	9	10	11	12
Median	1.50	1.50	2.25	3.54	3.79	16.07	38.05	41.46	27.39	10.11	6.41	2.64
Average	4.99	5.58	5.20	13.40	22.21	36.90	52.78	73.58	38.46	20.39	15.61	4.82
10%ile	1.50	1.50	1.50	1.50	1.42	1.50	7.39	16.02	11.12	3.23	2.36	1.50
90%ile	4.09	16.70	13.73	40.55	71.84	115.85	111.90	154.89	89.25	47.21	43.89	11.35

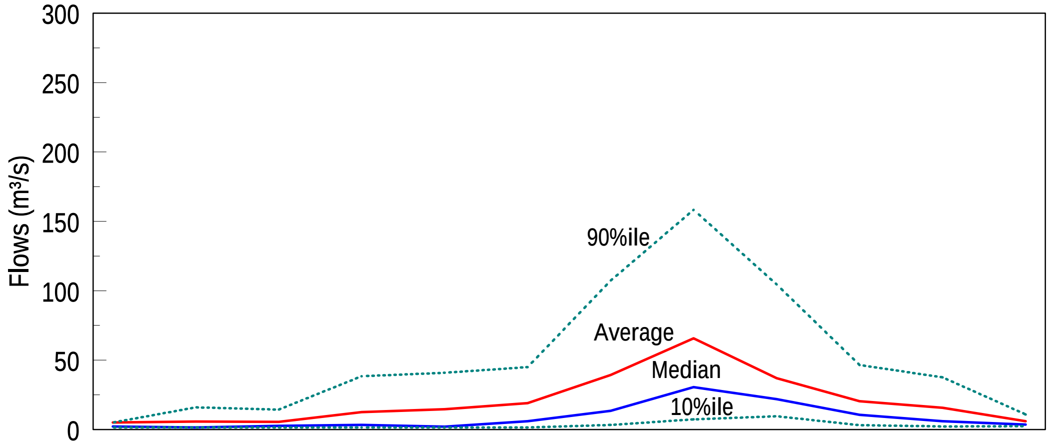
Figure 6b. Statistical analysis of the monthly, simulated runoff data for the Bromberg Future Development Scenario, over a 64-year period (1927 to 1990)

- <u>Major future development scenario including the Le Chasseur Dam development</u>,
  MAR 649x10^6 m^3 (a reduction of 63.6% from the reference condition)



Months	1	2	3	4	5	6	7	8	9	10	11	12
< 0.5	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5 - 3.0	68.8	71.9	51.6	46.9	53.1	39.1	7.8	0.0	0.0	9.4	17.2	32.8
3.0 -10.0	25.0	12.5	31.3	34.4	9.4	23.4	32.8	15.6	12.5	37.5	46.9	56.3
10.0 - 20.0	1.6	6.3	14.1	4.7	14.1	12.5	20.3	17.2	34.4	23.4	12.5	6.3
> 20.0	4.7	9.4	3.1	14.1	21.9	25.0	39.1	67.2	53.1	29.7	23.4	4.7

Figure 7a. Distribution frequency of flow ranges (in m^3/s) for the Le Chasseur Future Development Scenario, based on the 64-year simulated data



Months	1	2	3	4	5	6	7	8	9	10	11	12
Median	2.16	1.50	2.64	3.43	2.13	6.01	13.50	30.55	21.85	10.65	5.97	3.55
Average	5.05	5.82	5.57	12.53	14.60	19.12	39.37	65.73	37.07	20.51	15.73	6.05
10%ile	1.50	1.50	1.50	1.50	1.50	1.50	3.30	7.37	9.59	3.15	2.27	2.40
90%ile	5.09	16.00	14.40	38.44	40.88	45.08	107.31	158.35	104.52	46.51	37.66	10.93

Figure 7b. Statistical analysis of the monthly simulated runoff data for the Le Chasseur Future Development Scenario, over a 64-year period (1927 to 1990)

5. Relationship Between Salinity Distributions and River Inflow

5.1 Measured Data

5.1.1 Measured inflow data

The measured average daily flows from the Swellendam Station (H7H006-A01) and Eenzaamheid Buffeljags Dam Station (H7H013-A01) were combined to estimate the total average daily inflow (m³/s) into the estuary. Two hydrological years are included in the assessment, i.e. October 1995 to September 1996 (Table 3a) and October 2000 to September 2000 (Table 3b). The periods during which salinity data were collected from the estuary, i.e. in January 1996, February 2000, March 2000 and August 2000 are highlighted in the tables.

TABLE 3a. Measured river flows in m³/s (combination of Stations H7H006-A01 and H7H013-A01) for the period October 1995 to September 1996

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	10.86	41.14	57.00	29.00	6.06	2.66	4.78	3.66	3.60	26.10	55.82	86.10
2	17.59	36.12	48.10	23.85	4.87	5.05	5.58	2.97	5.07	24.04	51.01	74.00
3	14.76	30.30	35.78	22.28	4.11	54.86	5.47	2.75	25.50	80.15	47.48	64.30
4	11.76	29.18	27.05	19.92	3.88	17.08	5.19	2.49	39.80	115.03	79.09	58.80
5	10.32	28.57	31.43	15.87	4.11	14.76	5.28	2.31	26.60	156.05	119.46	58.80
6	9.28	28.75	32.75	13.78	4.27	11.42	4.60	2.29	17.99	370.67	87.57	53.70
7	9.02	26.47	122.90	12.50	3.89	7.48	4.20	3.08	13.74	502.61	64.24	52.40
8	9.67	22.60	90.60	9.94	3.39	5.67	4.36	4.38	11.20	296.07	55.95	141.00
9	11.07	18.58	61.70	7.99	#	4.77	5.17	4.53	10.50	188.90	53.53	125.00
10	13.85	15.63	52.40	7.78	#	3.94	5.03	4.26	60.70	159.92	51.90	110.00
11	11.03	13.11	45.50	7.26	#	3.32	4.76	4.23	79.06	135.84	50.10	134.01
12	8.96	11.30	32.61	6.56	#	8.69	4.66	4.09	43.61	118.03	66.38	117.01
13	7.82	9.90	24.38	5.62	#	5.90	4.79	4.46	28.66	109.98	88.52	85.48
14	12.57	8.52	17.38	4.83	#	4.11	4.80	4.48	37.31	106.74	75.52	87.36
15	98.65	6.59	52.50	4.39	#	3.74	4.91	4.48	96.60	106.34	190.47	216.69
16	79.63	5.18	58.50	4.23	10.11	3.27	5.39	4.50	149.01	87.95	243.06	192.28
17	45.31	4.17	32.00	4.45	9.11	2.94	5.06	13.00	1023.00	88.07	188.74	146.83
18	32.09	3.37	29.88	5.67	8.00	2.59	4.58	10.50	1107.00	79.59	160.99	120.81
19	26.07	2.78	26.73	9.51	6.85	2.38	4.32	7.29	537.11	57.65	145.35	138.78
20	22.65	2.36	34.59	5.68	5.75	2.12	4.04	5.70	329.30	46.82	122.67	275.72
21	20.63	2.17	34.09	4.36	4.89	1.68	3.95	4.66	213.45	41.05	97.39	243.04
22	19.61	3.37	58.50	4.36	3.96	1.73	7.59	3.95	132.78	37.43	79.03	176.51
23	17.79	35.79	53.00	4.12	2.91	1.81	12.66	4.89	94.10	35.34	67.43	140.40
24	16.08	37.11	44.90	4.56	2.44	2.25	8.48	5.25	71.40	33.60	57.28	121.92
25	15.66	13.58	42.51	7.08	2.35	2.42	5.82	5.16	52.70	32.36	47.53	101.55
26	15.64	13.74	59.40	30.97	3.17	2.41	4.11	5.26	44.80	31.32	39.18	91.77
27	164.7	9.58	77.10	32.87	3.16	2.59	3.27	4.71	40.22	33.19	34.84	303.46
28	186.7	7.27	78.90	16.85	2.93	4.30	2.97	4.85	36.00	40.62	50.04	386.27
29	94.09	81.59	61.84	14.30	2.82	3.89	3.14	3.84	31.30	44.57	214.02	265.19
30	57.17	85.70	46.88	10.84		4.31	3.96	3.06	28.50	58.13	182.01	197.09
31	45.75		36.87	7.95		4.18		3.06		67.09	113.00	

TABLE 3b. Measured river flows in m³/s (combination of Stations H7H006-A01 and H7H013-A01) for the period October 2000 to September 2001

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
	1.07	0.54	0.00	0.00	0.51	4.46	5.66	1.00	3.32	0.17	0.44	2.11
1	64.96	4.94	4.95	8.76	5.86	53.78	22.29	9.27	51.40	9.89	22.37	9.45
2	48.99	6.34	4.36	12.24	5.50	94.68	23.19	9.06	214.23	8.41	19.42	11.51
3	36.24	9.94	3.85	6.78	4.45	65.10	50.90	8.56	140.63	7.79	17.33	41.56
4	26.67	14.41	3.14	12.90	3.43	44.40	23.17	8.39	50.63	7.12	16.32	53.18
5	27.96	7.12	2.55	13.88	3.45	87.80	18.98	7.68	48.27	6.07	77.64	232.93
6	42.37	4.93	2.05	11.05	3.66	86.70	19.63	6.95	48.42	5.23	107.15	246.22
7	38.50	5.69	1.80	7.75	2.82	43.60	17.57	6.19	29.97	3.98	78.91	106.01
8	33.97	5.24	1.93	5.36	2.06	42.58	15.27	6.29	21.25	3.81	50.48	58.45
9	30.17	4.35	1.76	4.46	1.59	49.30	12.12	6.32	16.42	3.29	35.28	70.04
10	27.95	4.93	1.38	4.46	1.54	34.82	10.54	5.62	13.66	3.31	28.00	56.04
11	29.32	3.80	1.18	33.25	12.00	25.93	9.96	5.57	12.28	3.22	24.07	37.56
12	24.57	2.90	1.18	26.34	24.58	21.32	10.53	5.07	11.04	3.08	21.39	37.58
13	21.55	2.31	1.18	9.89	6.41	18.58	10.13	3.83	9.94	3.05	19.34	63.57
14	19.21	2.36	1.13	14.93	4.27	25.20	10.00	3.89	53.31	2.61	18.27	45.68
15	17.34	2.65	2.87	15.49	3.30	19.18	8.98	3.75	39.99	2.99	16.82	55.37
16	14.82	3.03	3.75	12.06	4.26	23.80	8.07	3.53	24.64	4.08	15.02	81.08
17	45.20	4.26	2.99	8.02	4.26	24.19	7.76	3.41	18.58	41.85	14.81	59.81
18	42.70	4.48	2.46	5.90	3.74	23.66	7.23	3.27	18.29	97.54	13.44	42.74
19	24.26	4.55	1.94	4.45	8.41	19.76	6.75	2.85	16.72	70.78	13.08	34.73
20	32.80	3.80	1.67	3.39	15.59	16.23	6.62	2.78	14.75	54.61	13.78	29.61
21	23.98	3.13	2.75	2.63	7.07	13.51	6.17	2.73	13.38	218.41	12.96	25.87
22	20.66	2.67	3.09	2.14	6.03	11.30	5.77	4.98	12.36	252.37	12.27	22.04
23	24.70	6.18	2.85	1.62	8.81	9.47	5.90	5.06	11.52	168.26	11.72	18.71
24	22.25	6.08	4.94	1.27	6.80	72.78	5.85	3.58	10.34	88.65	11.63	16.95
25	14.06	4.53	5.62	1.00	5.71	49.89	7.14	6.93	25.31	60.01	17.16	15.87
26	13.78	3.48	9.71	1.06	11.76	31.10	8.87	7.03	28.65	49.78	14.63	13.85
27	12.38	2.82	8.20	5.68	7.63	68.60	8.30	5.58	20.75	40.19	12.18	12.48
28	9.96	2.59	5.77	7.20	5.25	43.90	8.11	5.23	16.02	32.61	11.34	14.65
29	8.00	2.50	4.22	6.55	2.93	35.66	7.92	4.71	13.57	28.02	10.43	17.22
30	6.84	3.40	3.23	6.19		31.35	6.40	6.32	11.60	25.39	9.71	14.40
31	5.10		2.78	5.04		19.40		5.32		23.60	8.76	

5.1.2 Variation in Total Dissolved Solids (TDS) in river inflow

The seasonal variation of TDS in the Breede River, as represented by the monthly data collected from 1995 to 1999 at the station at Swellendam (H7H006Q01), are listed in Table 4. Total dissolved solids, although different to salinity, also provides an indication of the variation in dissolved salt content, similar to salinity measurements.

TABLE 4. Monthly variation in the TDS (g/L) of the Breede River estuary at Swellendam, based on monthly data sets collected from 1995 to 1999.

MONTH	TDS (g/L)		
	MINIMUM	MEDIAN	MAXIMUM
January	0.310	0.457	0.595
February	0.551	0.663	0.860
March	0.401	0.552	0.630
April	0.212	0.542	0.780
May	0.350	0.516	0.855
June	0.060	0.242	0.321
July	0.134	0.158	0.336
August	0.163	0.188	0.229
September	0.069	0.141	0.417
October	0.148	0.342	0.639
November	0.083	0.323	0.623
December	0.176	0.255	0.669

The data show that there is a tendency for the salt content of the river inflow to increase during the drier summer months compare to winter.

5.1.3 Salinity distribution in estuary - January 1996 (Summer survey)

Longitudinal salinity profiles taken during the summer surveys of January 1996 are illustrated in Figure 8. The neap tide measurements were taken on 14 January 1996 while the spring tide measurements were taken the following week on 20 and 21 January 1996.

The flow for December 1995 varied between 17 m³/s and 123 m³/s and, on average was high enough to flush and reset the system (Table 3a). The flows only started to decrease below 20 m³/s by 4 January 1996 and below 10 m³/s by 5 January 1996. Therefore, the measured salinity of 14 January 1996 is the response on average of about 10 days of lower flows. This trend continued for another 6 days till the spring tide of 20 January 1996 and contributed to the general increase in the observed salinities.

During the neap tide, the middle reaches, i.e. between 4 km and 16 km from the mouth, showed some stratification, particularly during the ebb tide. During the flood tide, intrusion of new seawater resulted in salinities at the mouth increasing to 34 ppt, with the 5 ppt contour line 17 km upstream from the mouth.. During the ebb tide, the longitudinal salinity gradient ranged from 30 ppt in the mouth decreasing to 5 ppt between 16 km (surface waters) and 18 km (bottom waters) from the mouth. Salinities of 1 ppt were measured 23 km and 19 km upstream, during the flood and ebb tides, respectively.

On the following spring tide the entire water column was vertically well mixed during both the flood and ebb tides. During the flood tide, the intrusion of new seawater (32 ppt) was evident at the mouth with the 5 ppt contour at about 18 km from the mouth. On the ebb tide, the 5 ppt contour line moved downstream to about 17 km from the mouth. Salinities of 1 ppt were measured 24 km and 20 km upstream, during the flood and ebb tides, respectively.

5.1.4 Salinity distribution in estuary - February 2000 (summer survey)

Longitudinal salinity profiles taken during the summer surveys of February 2000 are illustrated in Figure 9. The neap tide measurements were taken on 14 February 2000 while the spring tide measurements were taken the following week on 21 and 22 February 2000.

The high flows (> 20 m³/s) recorded in the beginning of October 1999 (Table 3b), would have resulted in the flushing and resetting of the system completely. November 1999 to January 2000 were low inflow months, with recorded baseflows on average below 5 m³/s, except for 11 and 16 January 2000 with measured inflows greater than 10 m³/s. These low flows would have resulted in a steady increase in salinity penetration until 10 February 2000. Unfortunately, a pulse event of 25 m³/s on average recorded on the 12 February 2000 probably depressed the extent of the measured salinity penetration taken on the 14 Feb 2000 to some extent.

The results for 21 and 22 February 2000 illustrate the difference in salinity penetration between high tide and low tide for a spring tide. However, this difference was also, to some extent, enhanced by the increase in river flow as recorded at the gauging station on 20 February 2000.

At neap low tide, the water column showed some stratification up to about 20 km from the mouth. Salinities ranged from 25 ppt at the mouth with the 5 ppt contour line at 18 km (surface waters) and 21 km (bottom waters) from the mouth. At neap high tide, vertical stratification was less pronounced. Intrusion of new seawater resulted in salinities at the mouth increasing to 34 ppt, with the 5 ppt contour line moving upstream to about 23 km from the mouth. Salinities of 1 ppt were measured 25 km and 28 km from the mouth during the low and high tides, respectively.

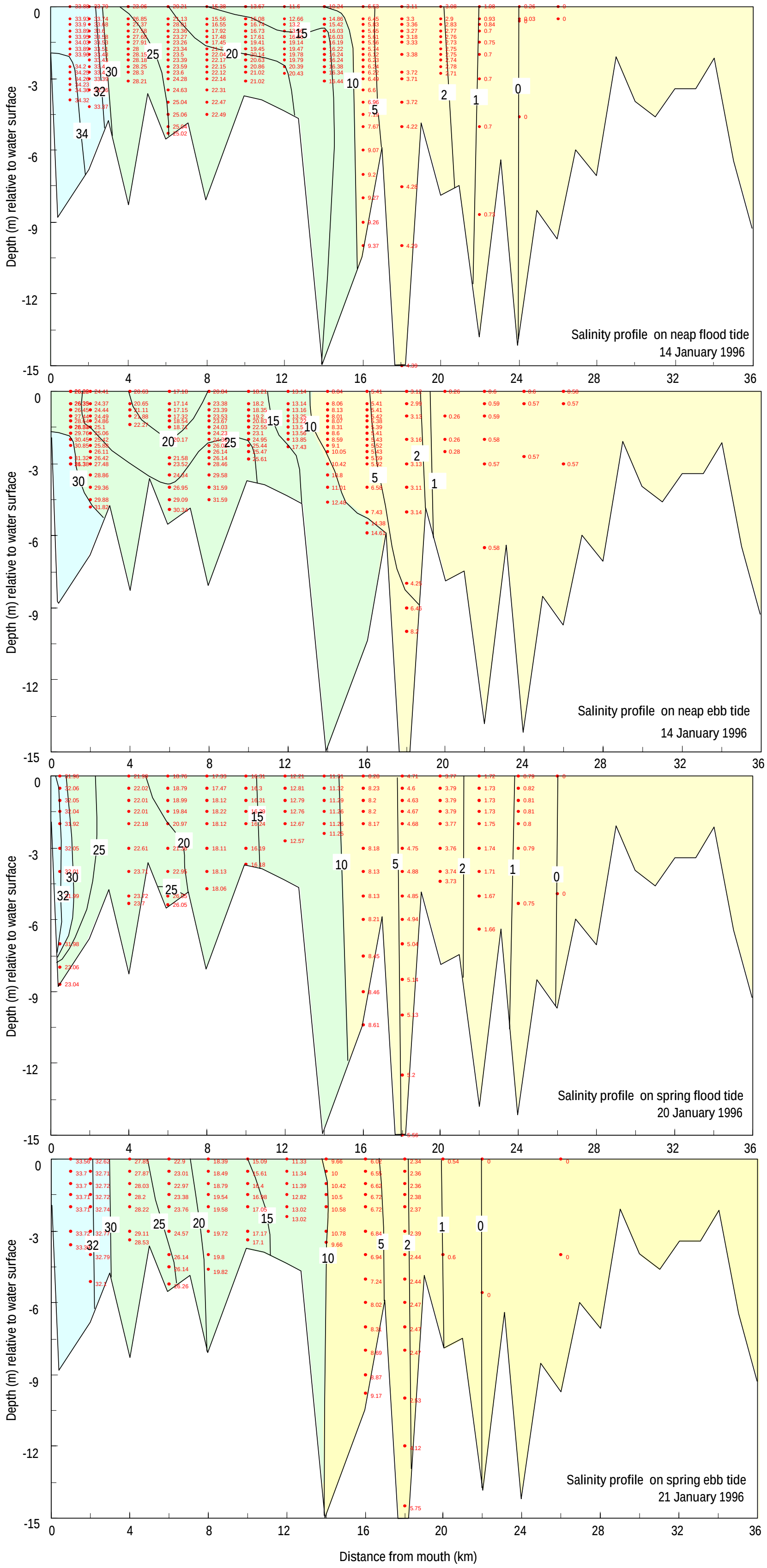


Figure 8. Salinity profiles (in ppt) taken during the summer survey in January 1996

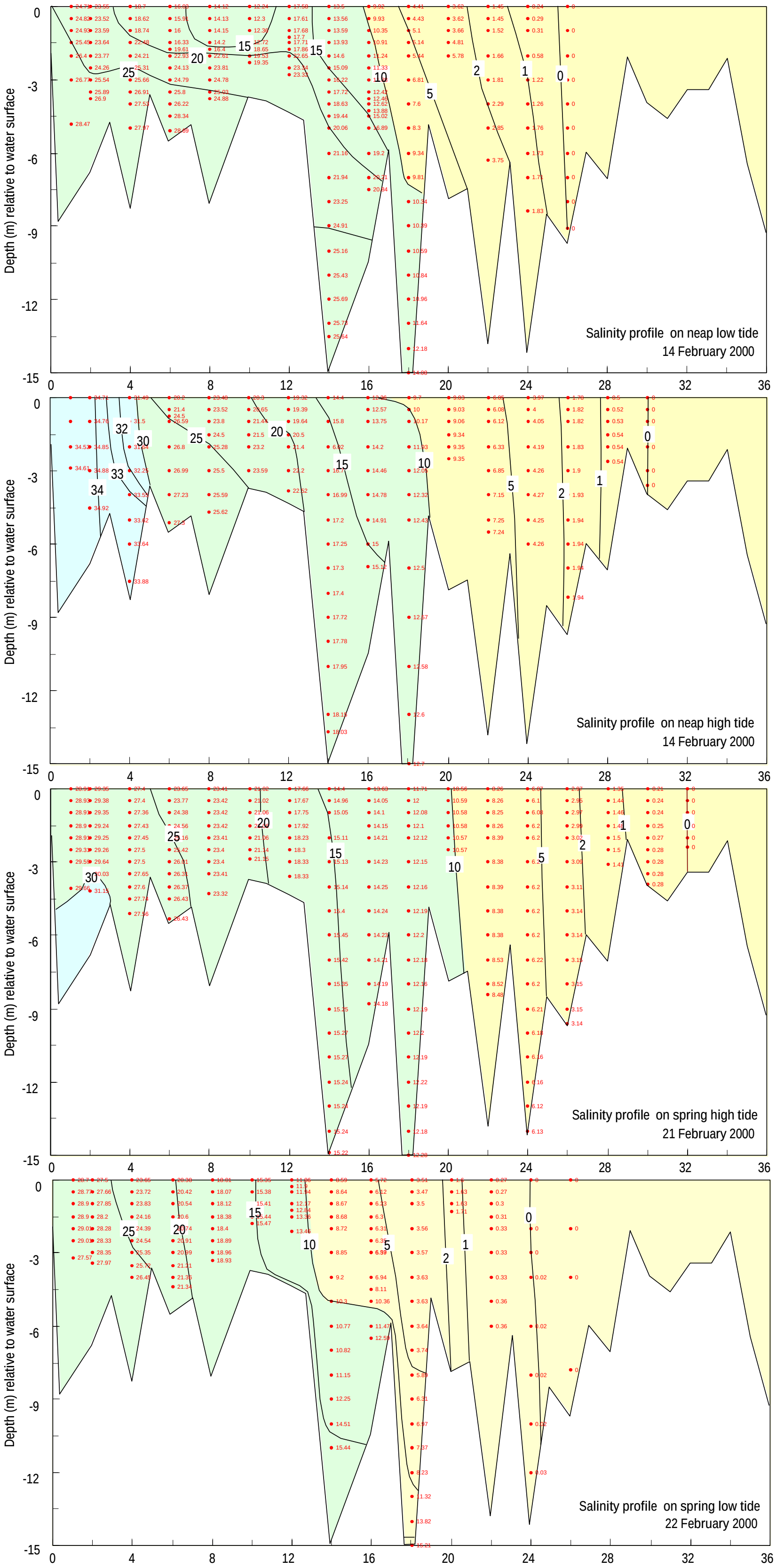


Figure 9. Salinity profiles (in ppt) taken during the summer survey in February 2000

During the subsequent spring high tide, the water column in the estuary were vertically well mixed, with the 5 ppt contour line situated 25 km from the mouth and salinities of 1 ppt still being measured 29 km upstream. On the low tide of 22 February 2000, there was a significant change in the upstream salinity distribution patterns compared with the previous day's high tide distribution pattern. The 5 ppt contour line moved to 16 km (surface waters) and 18 km (bottom waters) from the mouth, about 7 km further downstream compared to high tide. Although this could be attributed to high/low tidal variation during spring tides, such large differences were not observed during the spring tide measurements in 1996 (about 1 km difference between flood [high] and ebb [low] tide). It , therefore, is likely that increased river inflow during the night of 21 February 2000 also contributed to this phenomenon, reflecting the rapid response of the Breede River Estuary to an increase in river inflow. As mentioned before, there can be up to a day's delay before the measured river inflow at the gauging station upstream reaches the estuary.

During a spring low tide on 18/19 March 2000 (Figure 10), the 5 ppt contour line moved slightly further downstream to about 15 km from the mouth, compared to being about 17 km downstream during the spring low tide in February 2000, probably indicative of increased river inflow to the estuary at the onset of the rainy season, i.e. winter.

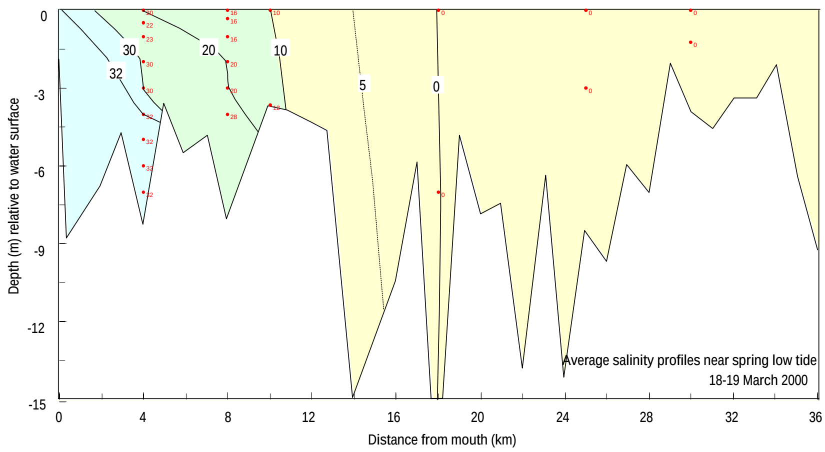


Figure 10. Salinity profiles (in ppt) taken during March 2000

The longitudinal salinity profile measured on March 2000 clearly reflects the high river inflows (> 20 m³/s) recoded at the gauging stations for 2 to 20 March 2000 (Table 3b). As indicated before, these higher flows ranges (20 – 95 m³/s) recoded for the period are able to flush and reset the estuary completely during a tidal cycle.

5.1.5 Salinity distribution in estuary - August 2000 (winter survey)

Longitudinal salinity profiles taken during winter (i.e August 2000) are illustrated in Figure 11. Measurements were taken on a neap high tide and a neap low tide on 23 August 200 and 24 August 200, respectively.

On 5 to 8 August 2000 the estuary was completely flushed by river flows ranging on average between 50 and 108 m³/s (Table 3b). After which the flows decreased to values ranging between 10 – 20 m³/s, which was maintained for about 10 days before the longitudinal salinity profile on 22 and 24 August was taken.

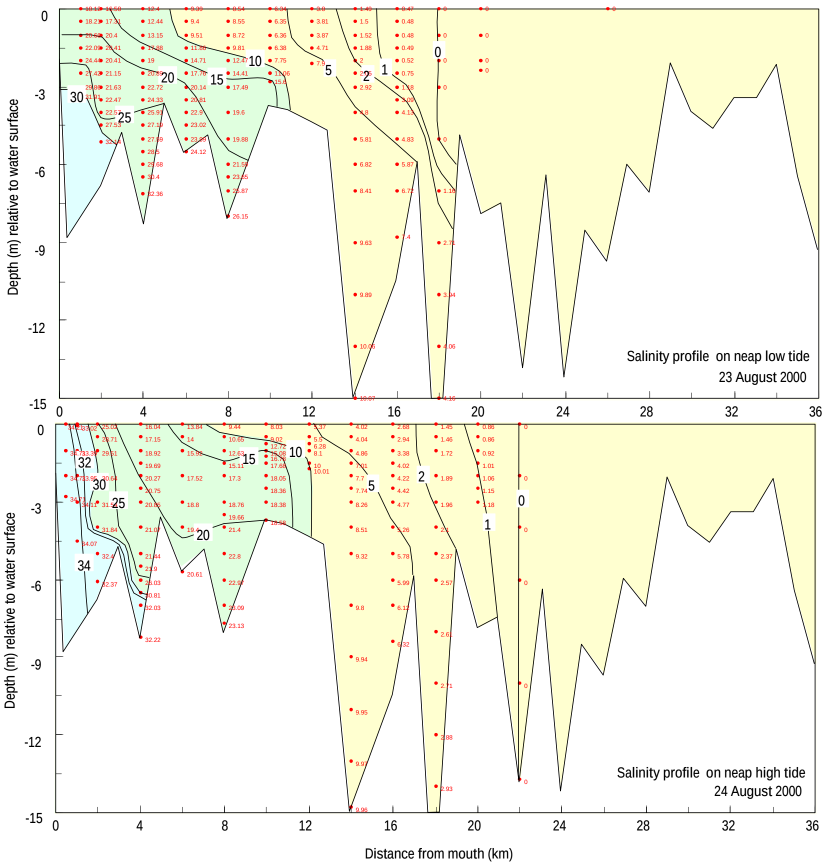


Figure 11. Salinity profiles taken the winter survey in August 2000

Typical of neap tide conditions in the Breede River Estuary, the estuary showed vertical stratification up to about 20 km from the mouth during both the low and high tide surveys.

During the low tide, salinities at the mouth were about 30 ppt with the 5 ppt contour line at 12 km (surface waters) and 17 km (bottom waters) from the mouth. Salinities of 1 ppt were still measured at 16 km (surface waters) and 18 km (bottom waters) from the mouth. During high tide, the intrusion of new seawater was clearly reflected in the 34 ppt salinities measured in the mouth area. The effect of tidal intrusion is also evident further upstream in the change in the shape of the salinity contour lines, compared with those of the low tide. Although position of the 5 ppt contour line were more or less the same as for the low tide, the 1 ppt contour line moved slightly further upstream, i.e. from about 17 km from the mouth during low tide to about 21 km from the mouth during high tide.

5.2 Simulated Relationships between Salinity Distribution and River Inflows

5.2.1 Model set-up and calibration

A major concern of the planned developments in the catchment is that changes in low flow conditions and more particularly reduction in baseflow and longer duration of low flow periods would result in increased salinities upstream in the estuary. A mathematical model utilizing the Mike 11 modelling system was therefore applied to the estuary to simulate the effects of low flow conditions on the salinities.

The Mike 11 modelling system, which was developed in the 1970s at the Danish Hydraulics Institute and is regularly upgraded, has been applied worldwide in various investigations. It is an advanced and user-friendly one-dimensional dynamic modelling system for rivers and estuaries. The hydrodynamic module is the basic module in Mike 11; additional modules can be used for simulations of transport dispersion, water quality and sediment transport amongst others. The hydrodynamic and transport-dispersion modules were used in the investigations described in this report.

The Mike 11 system can be operated on a microcomputer for simulations periods of several months, dependent on the size of the small models. The model of the Breede Estuary was set up on the Windows version of the Mike 11 modelling system at the CSIR in Stellenbosch.

***Hydrodynamic module*.** The hydrodynamic module is based on the solution of the Saint Venant equations of continuity and momentum for one-dimensional flow by implicit finite difference techniques. These equations are:

The continuity equation:

$$\delta Q/\delta x + \delta A/\delta t = q \qquad (1)$$

The momentum equation:

$$\delta((\alpha Q^2)/A)/\delta x + \delta Q/\delta t + gA(\delta h/\delta x) + (gQ\ Q\ )/C^2AR) = 0 \qquad (2)$$

Such a model is usually driven by the tidal variation of water levels at the downstream open boundary at the mouth and by the river flow at the upstream open boundary condition. The calibration of the hydrodynamic model is done by adjusting the bottom roughness until a satisfactory agreement is reached between simulated and measured water level variations.

***Transport dispersion module*.** The transport dispersion module can be used to simulate, amongst others, the effects of the intrusion of seawater on salinities in an estuary, based on tidal flows at the mouth and the inflow of freshwater upstream. The transport dispersion formula used in the Mike 11 modelling system is:

$$\delta(AC)/\delta t + \delta(QC)/\delta x - \delta(AD(\delta C/\delta x))/\delta x = -AKC + C_2q \qquad (3)$$

The transport dispersion module is operated separately in Mike 11, using the same topographical information as the hydrodynamic model. The results of the latter are stored in data files and are used as input to the transport dispersion module.

The open boundary conditions on both sides are time series of concentrations associated with the hydrodynamic boundaries, i.e. the concentrations of sea salinity at the mouth and normally zero salinities of the river flow upstream.

The transport dispersion model is usually calibrated by adjusting the dispersion coefficients until a satisfactory agreement is reached between the computed and measured salinity concentrations.

The Mike II model was calibrated as follows:

Tidal variations. The model was calibrated in terms of water levels using the field data collected by the CSIR (CSIR, unpublished report). In general an acceptable agreement between measured and simulated water level variations was obtained.

Salinity distribution. To calibrate the model in terms of salinity distribution in the estuary a relatively constant flow over the period that the data were collected is required.

5.2.2 Calibration

The bathymetric data collected by the CSIR in 1996 (CSIR, 2000) was used for the set-up of the model.

To calibrate the Mike 11 model of the Breede River Estuary, data sets were used including water level data (1996), recorded river inflow data and salinity data (1996 and 2000).

Predicted water level variations for Mossel Bay were used for the downstream open boundary condition of the model.

Water level data, collected on 14 and 20 January 1996 at 2.0 km, 16.0 km, 27.0 km and 40.0 km from the mouth (Figure 12, was used to calibrate the hydrodynamic module of the model.

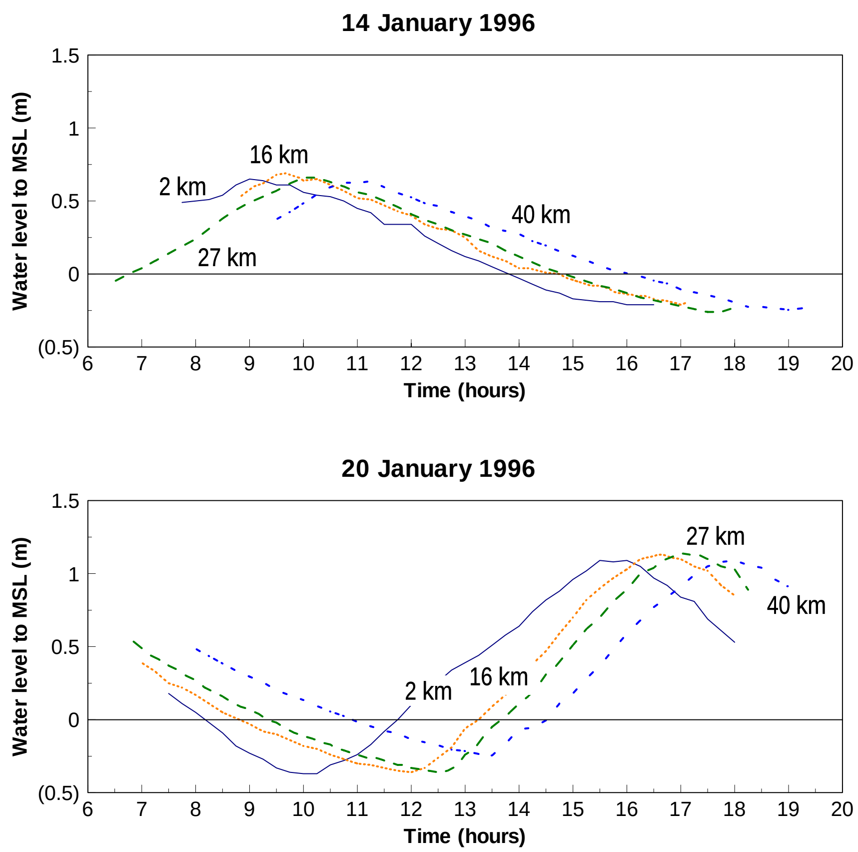


Figure 12. Water levels data collected at 2.0 km, 16.0 km, 27.0 km and 40.0 km from the mouth at a neap tide (14 January 1996) and a spring tide (20 January 1996)

The comparison of water level variations obtained from model simulations with the recorded water level variations for the spring tide, 20 January 1996, is shown in Figure 13. In general, an acceptable agreement between measured and simulated water levels variations were obtained.

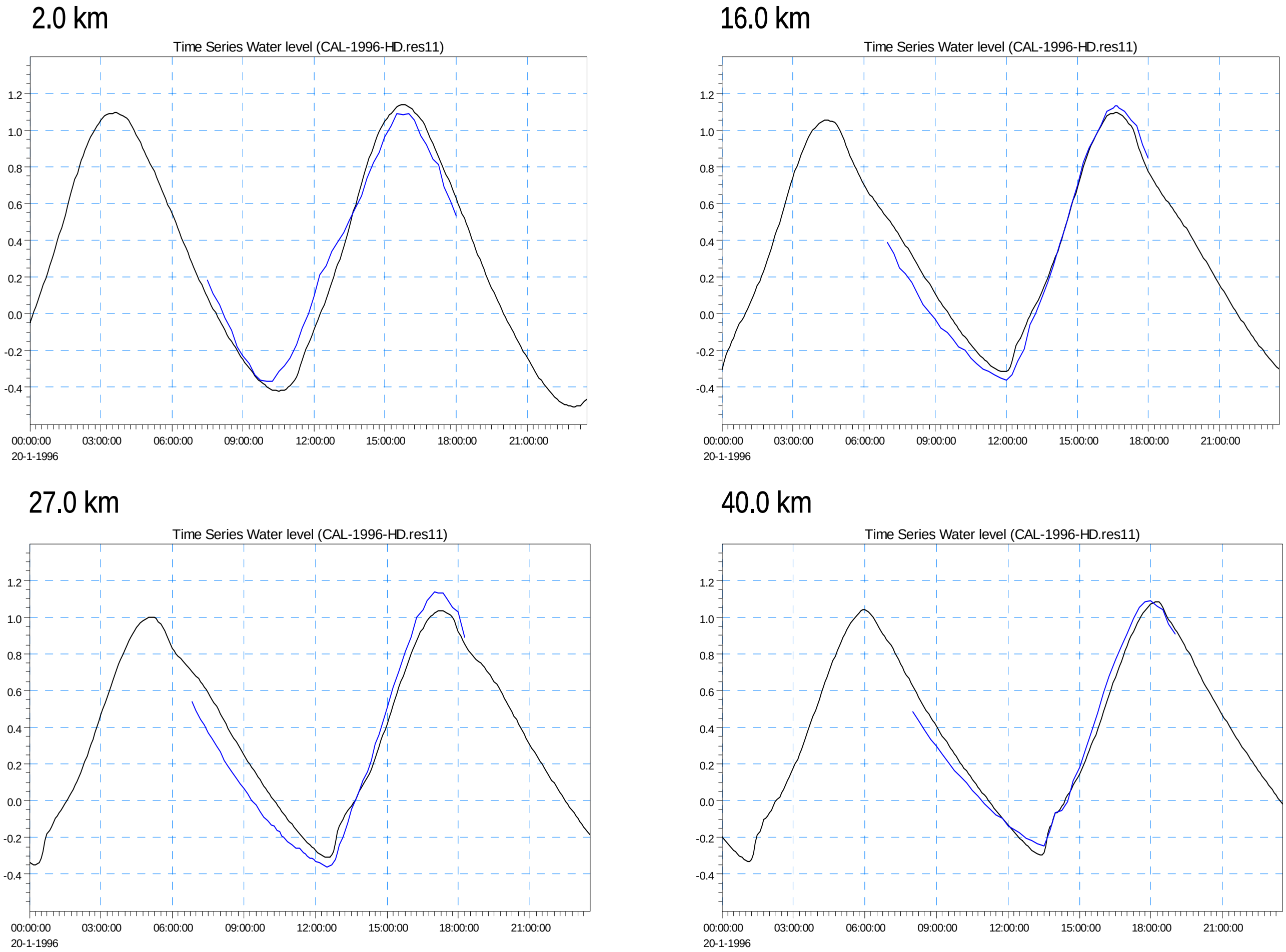


Figure 13. Comparison of water level variations obtained from model simulations with the recorded water level variations for the spring tide, 20 January 1996

The advection and dispersion module of the model was calibrated using the measured river inflow data from December 1995 to January 1996 and salinity distributions measured on 20 January 1996.

December 1995 was a high runoff month, with flows varying between 17.4 m³/s and 122.9 m³/s. At such high flows the estuary will be nearly completely fresh during a low tide and this condition with salinity concentrations being zero was therefore used as the starting condition for the estuary in the model.

River flow recorded upstream in the Breede River during December 1995 and January 1996 was used for the upstream open boundary of the model.

The best comparison of model results with measured salinity distribution data on 20 January 1996 was obtained at a dispersion coefficient of 60 used throughout the model and this dispersion coefficient was therefore used for further model simulations.

5.2.3 Salinity distributions of specific flow ranges

Five flow ranges have been selected, based on typical flows and salinity distributions characteristic to the Breede River Estuary. The flow ranges selected are:

- Flows greater than 20 m^3/s.
- Flows between 10 and 20 m^3/s
- Flows between 3 and 10 m^3/s
- Flows between 0,5 and 3 m^3/s
- Flows less than 0,5 m^3/s.

For each flow range, two graphs are provided to illustrate the extent of saline penetration for the highest and lowest flow in the range. The graphs depict a spring high tide and spring low tide after a model simulation period of 4 months at a constant flow rate. *For the purposes of this study, the River-Estuarine-Interface Zone (REI) is defined as the area in the estuary where salinities are < 10ppt.*

i. Flows greater than 20 m^3/s

Figure 14 shows the salinity distribution at high water and at low water during spring tide at a flow of 20 m^3/s after a period of 4 months.

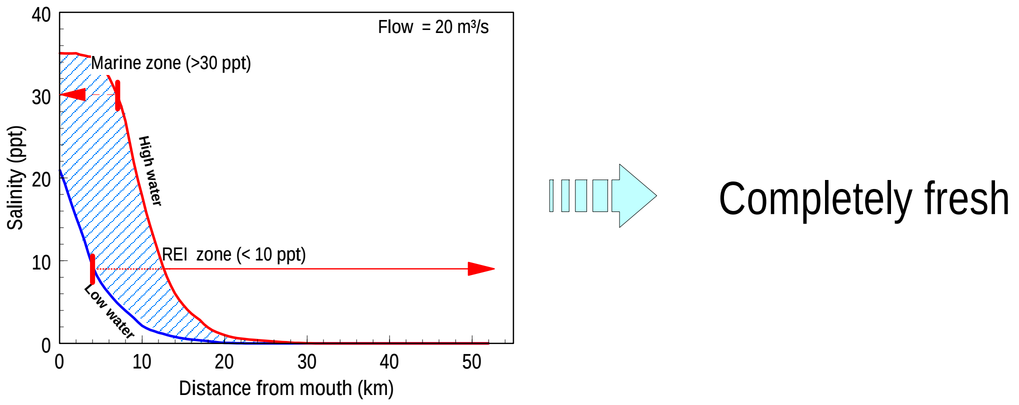


Figure 14. **Predicted band of salinity distribution at spring tide along the Breede River Estuary at flows >20 m^3/s**

Only limited saline intrusion is present at low tide and the position of the 10 ppt, concentration, which is the considered to be the lower limit of the REI zone, is only 4 km upstream of the mouth. At high tide the 10 ppt concentration is at approximately 12 km upstream of the mouth.

The saline intrusion is even less at flows greater than 20 m^3/s., with the estuary being pre-dominantly fresh.

ii. *Flows between 10 and 20 m³/s*

Figure 15 shows the salinity distribution ranges at spring tide for flows from 10 m³/s to 20 m³/s, simulated over 4 months. Although the salinity distributions are still dominated by river inflow, there is significant saline intrusion in the lower reaches of the estuary.

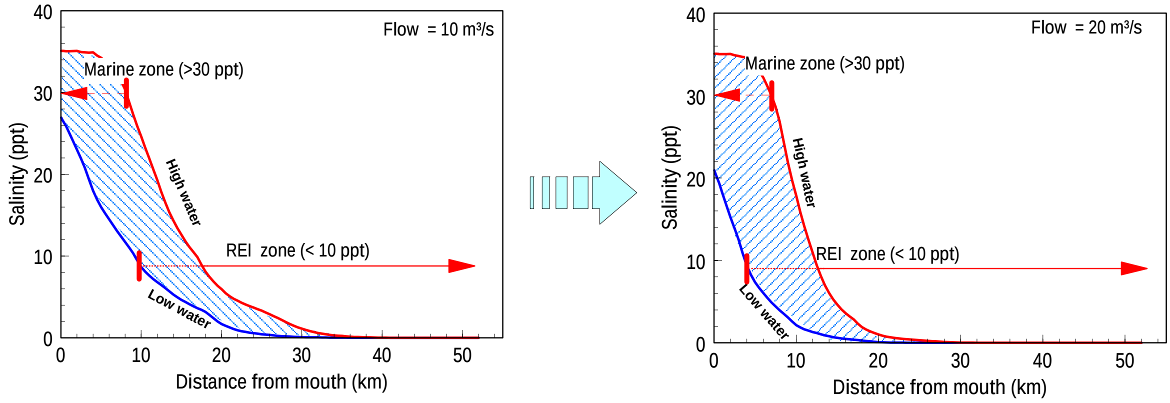


Figure 15. Predicted band of salinity distribution at spring tide along the Breede River Estuary at flows between 10 - 20 m³/s.

The saline intrusion at the flow of 20 m³/s has already been described under (i) above. Saline intrusion has increased at the flow of 10 m³/s and at low tide the 10 ppt concentration is approximately 10 km upstream and at high tide it is at approximately 20 km from the mouth. The salinity distributions in the estuary are therefore still strongly dominated by the river flow, but significant saline intrusion takes place in the lower estuary and a long REI zone is present in the middle regions and upstream in the estuary.

iii. *Flows between 3 and 10 m³/s*

Figure 16 shows the salinity distribution ranges at spring tide for flows from 3 m³/s to 10 m³/s, simulated over 4 months. Although the salinity distributions are still dominated by river inflow, there is significant saline intrusion in the lower reaches of the estuary.

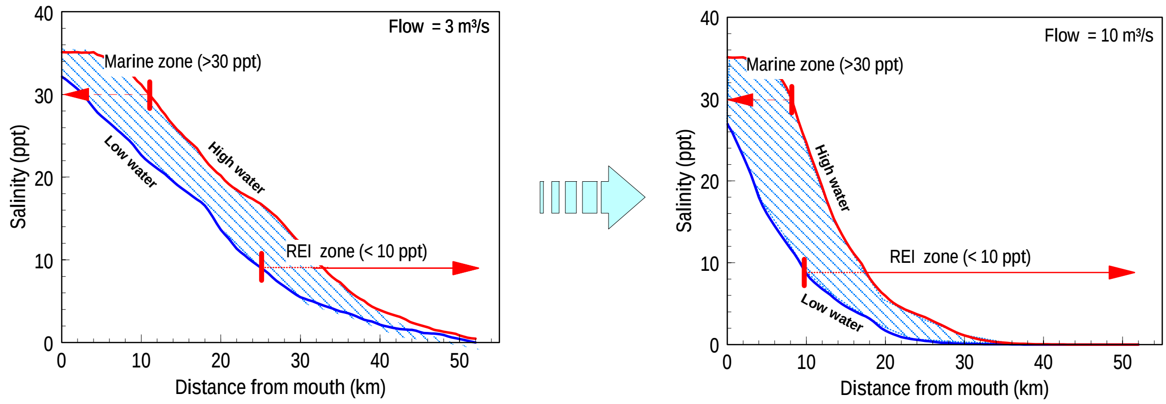


Figure 16. Predicted band of salinity distribution at spring tide along the Breede River Estuary at flows between 3 – 10 m³/s.

The saline intrusion at the flow of 10 m³/s has already been described under (ii) above. Saline intrusion has increased at the flow of 3 m³/s and at low tide the 10 ppt concentration is approximately 24 km upstream and at high tide it is at approximately 32 km from the mouth.

A strongly developed salinity gradient is present in the middle reaches of the estuary and it is considered that a balance exist with almost equal influences of river flow and intrusion of seawater. A well-developed REI zone is present in the upstream regions of the estuary.

iv. Flows between 0.5 and 3 m³/s

Figure 17 shows the salinity distribution ranges at spring tide for flows from 0.5 m³/s to 3 m³/s, simulated over 4 months. Although the salinity distributions are still dominated by river inflow, there is significant saline intrusion in the lower reaches of the estuary.

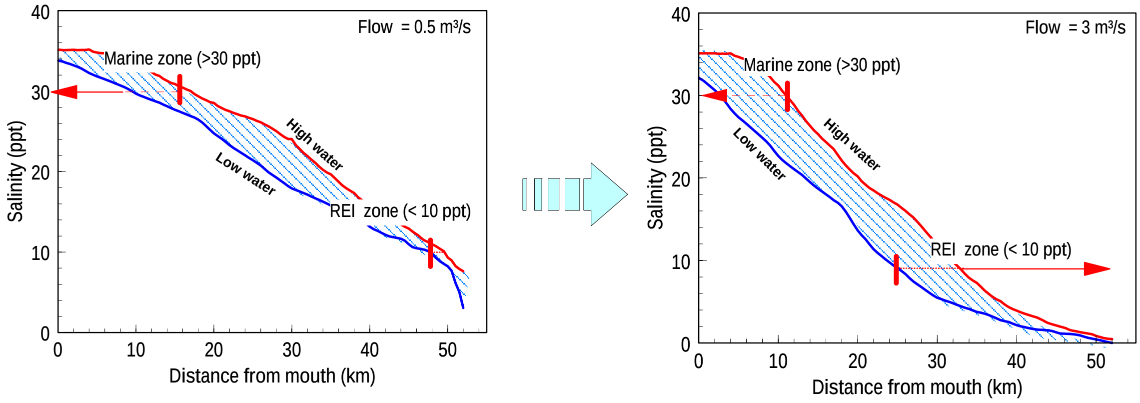


Figure 17. Predicted band of salinity distribution at spring tide along the Breede River Estuary at flows between 0.5 - 3 m³/s.

The saline intrusion at the flow of 3 m³/s has already been described under (iii) above. Saline intrusion has further increased at the flow of 0.5 m³/s and at low tide the 10 ppt concentration is approximately 46 km upstream and at high tide it is almost at the upstream end of the estuary.

The salinity distributions in the estuary are therefore strongly dominated by the intrusion of seawater and a considerably reduced REI zone is present upstream in the estuary.

It must, however, be considered that at flows between 0.5 and 3 m³/s time delay effects start playing a role and it can take a few months before an equilibrium is reached.

v. Flows less than 0,5 m³/s

Figure 18 shows the salinity distribution at high water and at low water during spring tide at a flow of 0.5 m³/s after a period of 4 months.

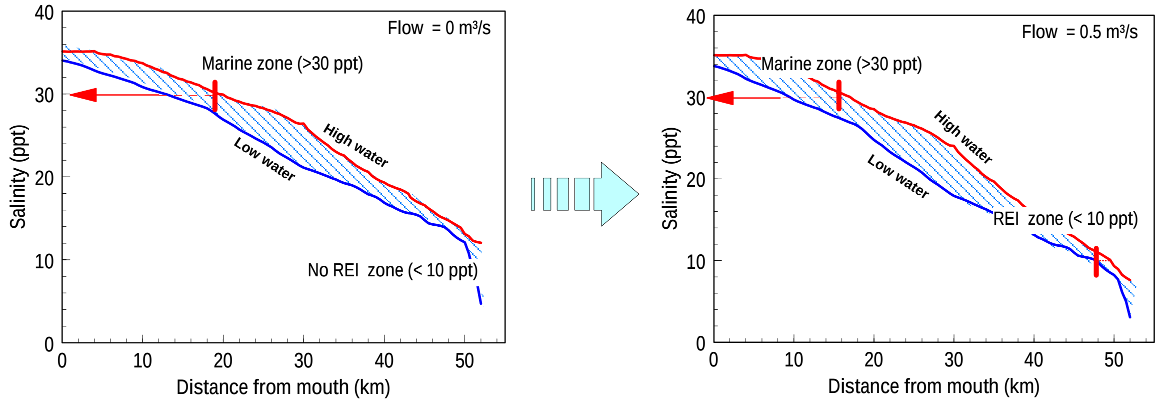


Figure 18. Predicted band of salinity distribution along the Breede River Estuary at flows < 0.5 m³/s.

The salinity distributions in the estuary are determined by the saline intrusion and the very small river flow will only have limited effect high upstream in the estuary. An REI zone with salinity concentrations below 10 ppt is almost not present any more. The real danger exists that the Breede River Estuary will loose its functioning as an estuary and will become an arm of the sea.

Again it must be considered that time delay effects are important at these conditions and high salinity concentrations high upstream in the estuary will only be reached after several months.

6. Assessment of Water Quality Characteristics

For the assessment of spatial and seasonal variations in the water quality (WQ) characteristics of the Breede River Estuary, the relationship between the concentrations of different WQ parameters versus salinity, obtained from three surveys, i.e. January 1996, February 2000 and August 2000, were used. Salinities of river and seawater, i.e. the two major water sources of estuaries, are distinctly different. Being a conservative parameter, the relationship with salinity, therefore, can be used as a means of to characterising the transport and fate of other chemical constituents within an estuary. For example, a linear relationship would indicate that concentrations along the estuary are a function of the extent of mixing between river and seawater, as well as the concentration of a particular constituent in the two sources. To be able to orientate oneself in terms of the spatial distribution of WQ concentrations along the estuary during the different surveys, WQ concentration versus salinity plots can be compared with the corresponding longitudinal salinity profiles provided in Chapter 5.

The WQ survey of January 1996 (summer), was done at the same time as the salinity profiles of 20 and 21 January 1996 (refer to Figure 8), the WQ survey February 2000 survey was done at the same time as the salinity profiles of 21 February 2000 (Figure 9), while the WQ survey in August 2000 was done at the same time as the salinity profiles of 23 August 2000 (Figure 10).

6.1 System Variables

6.1.1 Temperature

Temperatures are not measured for the Breede River, but it is anticipated that these will have a strong seasonal signal, i.e. high in summer and low in winter. Surface seawater temperatures over most of the along the south Coast, where the Breede River Estuary enters the sea, are usually between 20-21 ^{o}C in summer and 16-17^{o}C during winter (DWAF, 1995). The relationship between salinity and temperature measurements taken in the Breede River Estuary during two summer surveys (i.e. January 1996and February 2000), and one winter survey (i.e. August 2000) are provided in Figure 19.

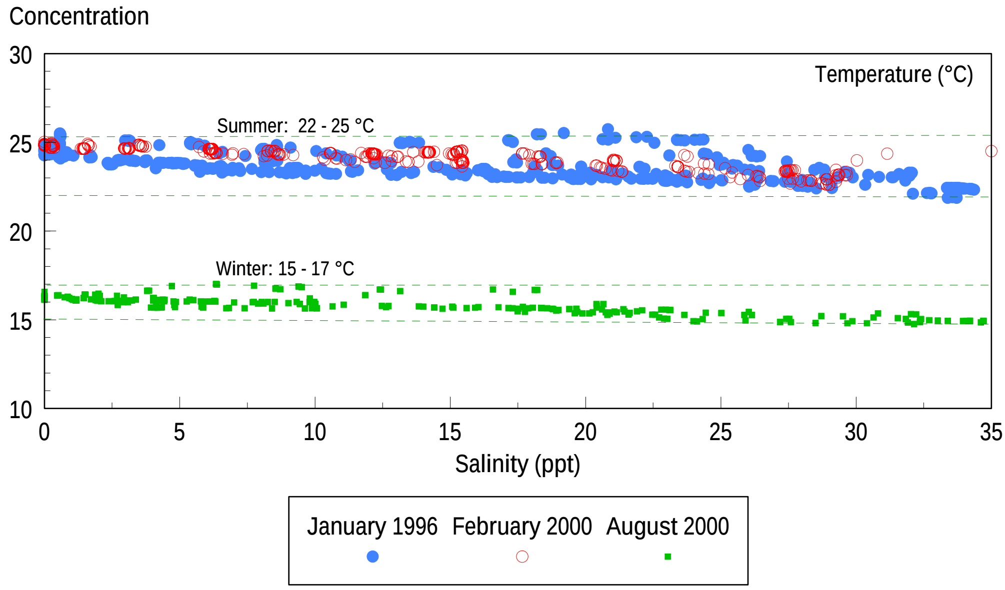


Figure 19. Relationship between temperature and salinity measured in the Breede River Estuary during summer (January 1996 and February 2000) and winter (August 2000).

From Figure 19, it is apparent that there was no marked temperature difference within the estuary on any one of the surveys or between the two summer surveys. Summer temperatures in the Breede River Estuary, therefore, appear to be fairly uniform, typically varying between 21°C and 25 °C. Similar to the summer situation winter temperatures in the estuary were fairly uniform throughout the system, ranging between 15°C and 17°C. These are substantially lower than the summer temperatures, reflecting the seasonal variation patterns of the two sources, i.e. the river and sea (see above).

6.1.2 Dissolved oxygen

Dissolved oxygen measurements are not collected at the Breede River monitoring station near Swellendam. Based on the DO levels measured in the upper reaches of the estuary (see below), it, however, is expected that DO levels in the inflowing river water are well-oxygenated. Although data on typical DO concentration for the south coast could not be obtained, surface water in unpolluted and fairly turbulent areas, such as the surf zone adjacent to the Breede River mouth, is usually well-oxygenated.

The relationship between salinity and dissolved oxygen concentrations measured in the Breede River Estuary during two summer surveys (i.e. January 1996and February 2000), an d one winter survey (i.e. August 2000) are provided in Figure 20.

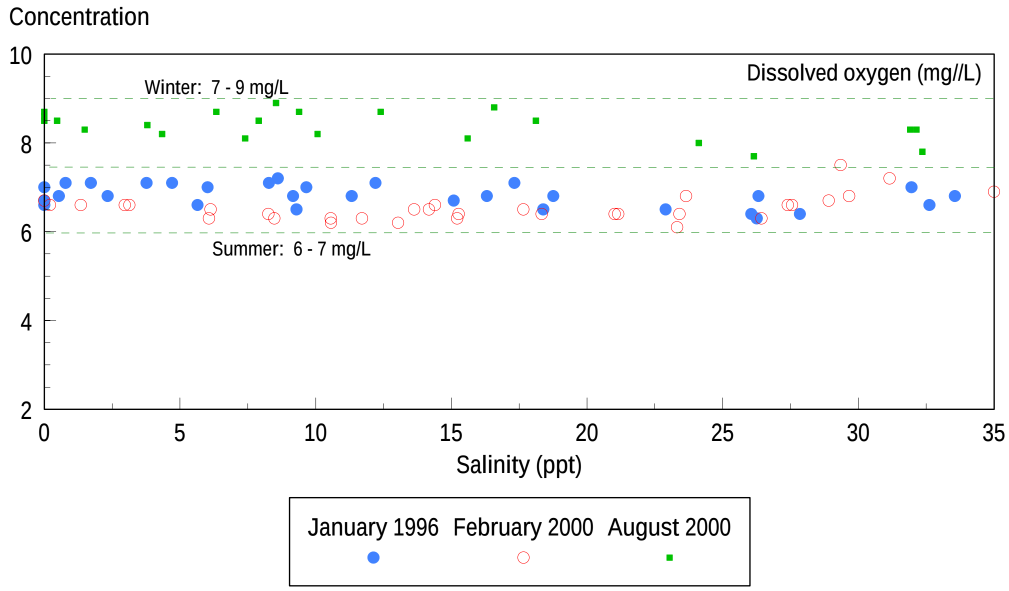


Figure 20. Relationship between dissolved oxygen concentrations and salinity measured in the Breede River Estuary during summer (January 1996 and February 2000) and winter (August 2000).

Results from both the two summer surveys and the winter survey show that the Breede River Estuary is well-oxygenated throughout the water column. Even in the deeper areas in the middle reaches of the estuary, e.g. water depths greater than 10 m, where one could expect for hypoxic conditions to develop this was not the case. These well-oxgenated conditions are most likely the consequence of weak stratification in the water column, as well as and short residence times of water in the estuary, even the deeper areas. The distinction between the winter survey and two summer surveys, is attributed to temperature differences, i.e. oxygen is more soluble in colder water (i.e. during winter), resulting in the winter oxygen concentration being higher (7 – 9 mg/L) than the summer concentrations (6-7 mg/L). Although salinity also has an effect on the solubility of oxygen in water, i.e. oxygen is more soluble in lower salinity water this was not evident in the results form the Breede River Estuary.

6.1.3 Suspended solids

Suspended solid (SS) measurements are not collected at the Breede River monitoring station near Swellendam. It, however, is anticipated that SS loads from the river will be higher during the winter months that during the low flow periods in summer. During winter, the SS concentrations will probably also show large variation depending on the river flow. Data on SS concentrations in seawater along the south Coast could also not be obtained. It, however, is anticipated for these to be low, e.g. typically below 10 mg/L .

Suspended solid concentrations were only measured in the Breede River Estuary during the winter survey of August 2000. The relationship with salinity measurements is shown in Figure 21.

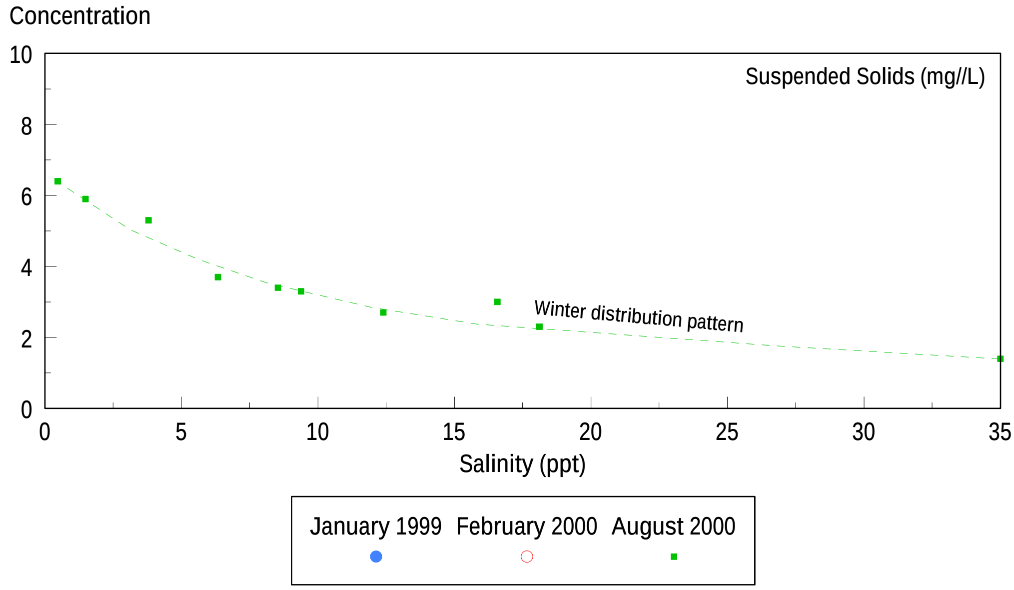


Figure 21. Relationship between suspended solids and salinity measured in the Breede River Estuary during summer (January 1996 and February 2000) and winter (August 2000).

Results indicate that during winter, the river inflow is a source of suspended material, although during the August 2000 survey SS concentrations were not considered exceptionally high in river inflow (about 6 mg/L), but it expected that these are likely to increase markedly during times of stronger river inflows. The relationship between salinity and SS concentrations (Figure 8) suggests that there is removal of SS from the water column (e.g. through flocculation) in the upper reaches where fresh river water first mixes with saline estuarine water.

6.2 Inorganic Nutrients

6.2.1 Dissolved nitrite/nitrate

The seasonal variation in nitrite/nitrate concentrations as represented by the monthly data collected from 1995 to 1999 at the Breede River monitoring station near Swellendam (H7H006Q01), is listed in Table 5. Results show a distinct seasonal signal, with winter concentrations (e.g. May to October) being markedly higher than those measured during the summer months (e.g. November to April). These higher concentrations correspond to period of higher rainfall and river runoff when excess nutrients from the adjacent agricultural areas are washed into the river.

TABLE 5. Monthly variation in nitrite/nitrate concentrations in the Breede River at Swellendam, based on monthly data sets collected by the DWAF from 1995 to 1999.

MONTH	DISSOLVED NITRITE/NITRATE (µg/L as N)		
	MINIMUM	MEDIAN	MAXIMUM
January	7	78	123
February	0	15	22
March	7	53	68
April	0	20	355
May	39	395	1420
June	207	337	419
July	286	517	1150
August	265	471	695
September	238	278	285
October	85	205	464
November	26	182	279
December	5	126	296

Average nitrite-N and nitrate-N concentrations, reported for the south Coast of South Africa, are 2.8 µg/L and 81 µg/L, respectively (DWAF, 1995).

Results from both the two summer surveys and the winter survey show that dissolved nitrite-N concentration in the Breede River Estuary were low, i.e. < 10 µg/L, as would be expected for a relatively unpolluted and well-oxygenated system. The relationship between salinity and dissolved nitrate concentrations measured in the Breede River Estuary during two summer surveys (i.e. January 1996 and February 2000), and one winter survey (i.e. August 2000) are provided in Figure 22.

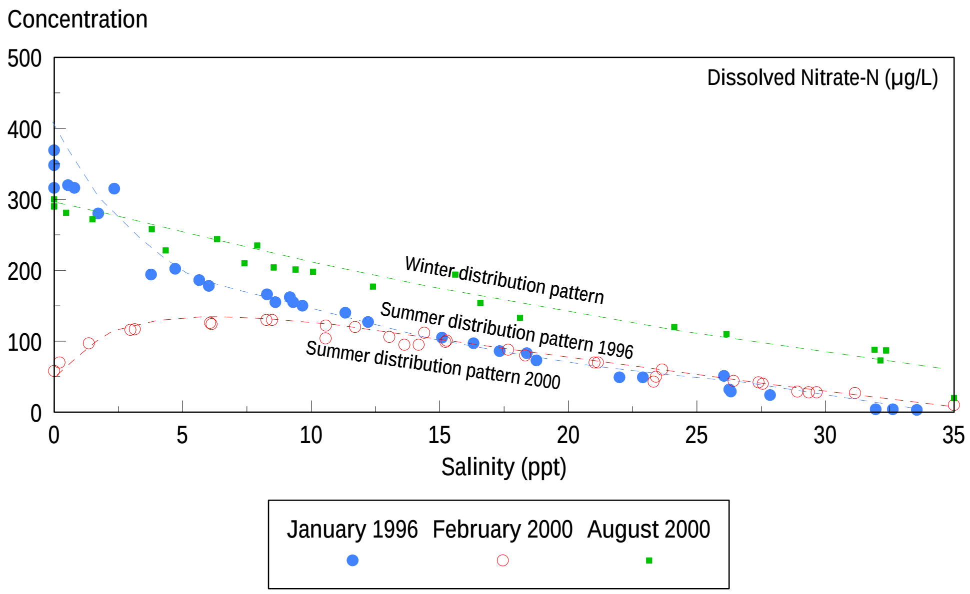


Figure 22. Relationship between dissolved nitrate concentrations and salinity measured in the Breede River Estuary during summer (January 1996 and February 2000) and winter (August 2000).

Results from both the two summer surveys and the winter survey indicate that the river is a source of nitrate-N to the estuary, but that there are likely to be large seasonal and inter-seasonal variations in the levels of nitrate-N concentrations entering the estuary through river inflow. In turn, these are correlated to agricultural activities in the catchment, such as the timing of fertilizer applications.

The variability in nitrate concentrations in river inflow (Table 5) is probably also the cause for the deviations form the dilution line in the upper reaches of the estuary during the two summer surveys (Figure 22).

6.2.2 Dissolved total ammonia

The seasonal variation in total ammonia concentrations, as represented by the monthly data collected from 1995 to 1999 at the Breede River monitoring station near Swellendam (H7H006Q01), is listed in Table 6. Results show no distinct seasonal signal.

TABLE 6. Monthly variation in total ammonia concentrations in the Breede River at Swellendam, based on monthly data sets collected by the DWAF from 1995 to 1999.

MONTH	DISSOLVED TOTAL AMMONIA (µg/L as N)		
	MINIMUM	MEDIAN	MAXIMUM
January	8	11	12
February	9	24	35
March	2	14	42
April	18	21	29
May	3	38	46
June	3	6	11
July	0	17	45
August	11	17	25
September	24	51	69
October	7	17	39
November	1	19	45
December	0	25	64

In unpolluted, well-oxygenated seawater total ammonia concentrations is expected to be low (DWAF, 1995).

The relationship between salinity and total ammonia concentrations measured in the Breede River Estuary during two summer surveys (i.e. January 1996and February 2000), and one winter survey (i.e. August 2000) are provided in Figure 23.

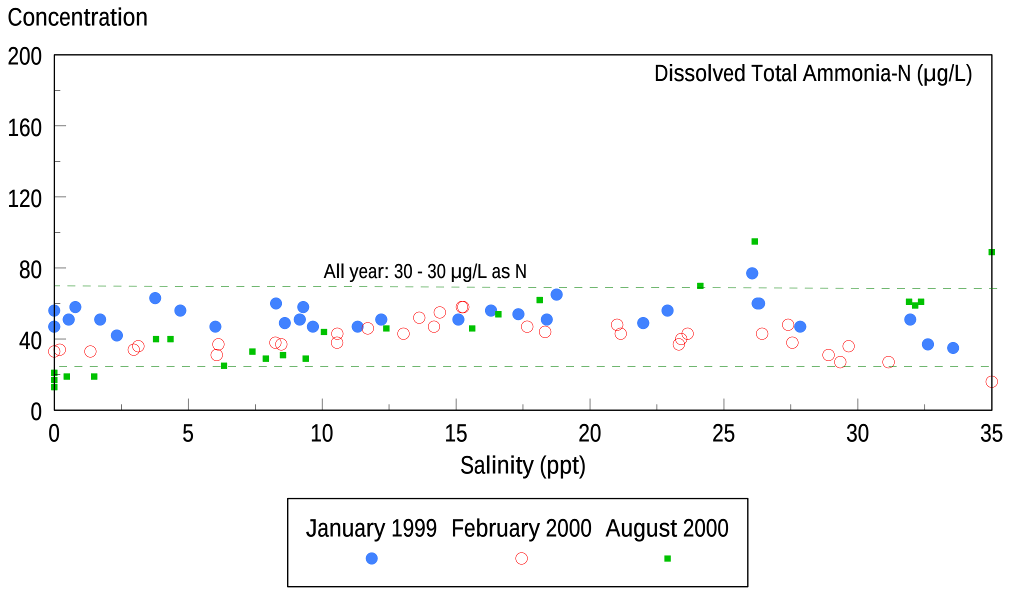


Figure 23. Relationship between dissolved total ammonia concentrations and salinity measured in the Breede River Estuary during summer (January 1996 and February 2000) and winter (August 2000).

Results from the water quality surveys in the Breede River Estuary did not show any marked variability throughout the water column of the estuary. No seasonal variations were also evident, with total ammonia-N concentrations typically ranging between 30 and 70 µg/L. These concentrations are relatively low, as would be expected for a system that is well-oxygenated that does not receive major waste water inputs such as sewage effluents.

6.2.3 Dissolved reactive phosphate

The seasonal variation in reactive phosphate concentrations as represented by the monthly data collected from 1995 to 1999 at the Breede River monitoring station near Swellendam (H7H006Q01), is listed in Table 7. Unlike for nitrite/nitrate, there is not a marked seasonal signal in the phosphate-P concentrations entering the estuary from the river.

TABLE 7. Monthly variation in reactive phosphate concentrations in the Breede River at Swellendam, based on monthly data sets collected by the DWAF from 1995 to 1999.

MONTH	DISSOLVED REACTIVE PHOSPHATE (µg/L as P)		
	MINIMUM	MEDIAN	MAXIMUM
January	9	17	19
February	11	15	17
March	5	9	14
April	19	19	47
May	11	16	25
June	21	23	24
July	1	17	29
August	14	20	35
September	12	21	27
October	5	16	19
November	10	21	31
December	7	14	36

Average reactive phosphate-P concentrations reported for the south coast of South Africa is 37 µg/L.

The relationship between salinity and temperature measurements taken in the Breede River estuary during two summer surveys (i.e. January 1996and February 2000), and one winter survey (i.e. August 2000) are provided in Figure 24.

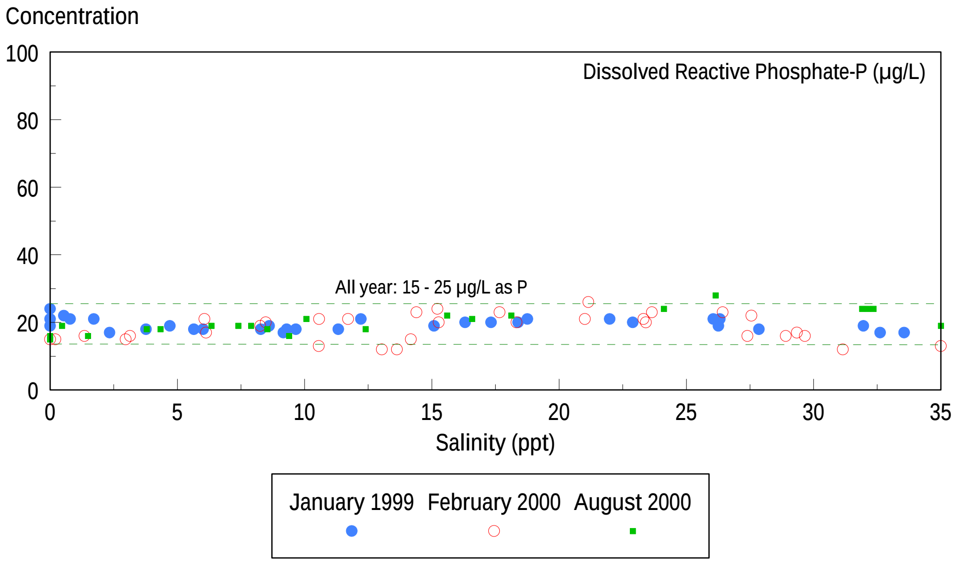


Figure 24. Relationship between dissolved reactive phosphate concentrations and salinity measured in the Breede River Estuary during summer (January 1996 and February 2000) and winter (August 2000).

Based on measurements taken during the two summer surveys and one winter survey, there was no marked spatial variability in dissolved reactive phosphate concentration in the Breede River Estuary in any of the surveys. Seasonal variations were also evident, with reactive phosphate-P 15 and 25 µg/L, within the ranges reported for both the river and seawater (see above).

6.2.4 Dissolved reactive silicate

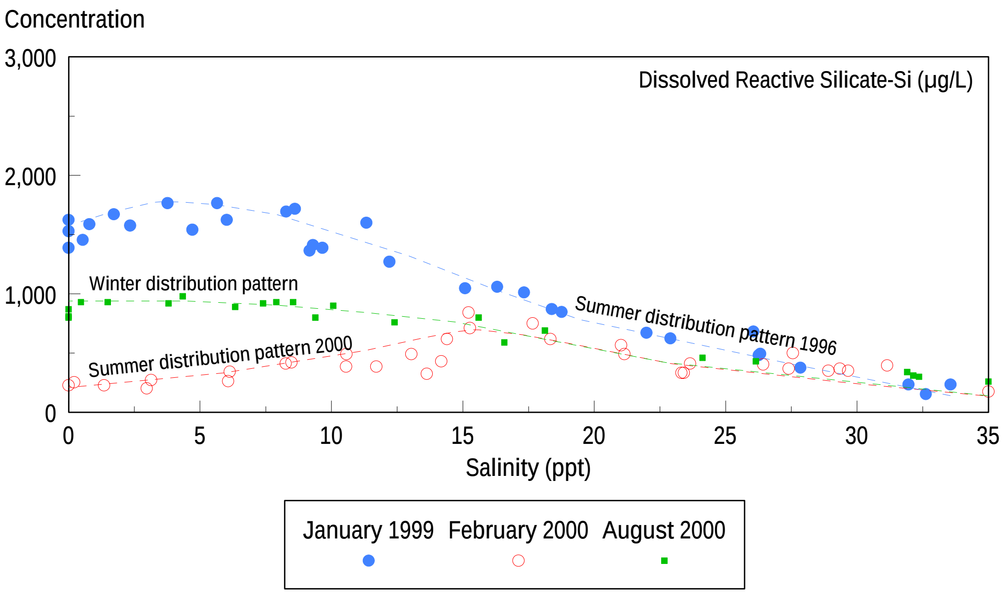
The seasonal variation in reactive silicate concentrations as represented by the monthly data collected from 1995 to 1999 at the Breede River monitoring station near Swellendam (H7H006Q01), is listed in Table 8. Although there seems to be large inter-seasonal variation, the results show a distinct seasonal signal, with winter concentrations (e.g. May to October) being markedly higher than those measured during the summer months (e.g. November to April). These higher concentrations correspond to period of higher rainfall and river runoff, a natural variation rather than the result of anthropogenic inputs, e.g. agricultural activities.

TABLE 8. Monthly variation in reactive silicate concentrations in the Breede River at Swellendam, based on monthly data sets collected by the DWAF from 1995 to 1999.

MONTH	DISSOLVED REACTIVE SILICATE (µg/L as Si)		
	MINIMUM	MEDIAN	MAXIMUM
January	460	1205	1710
February	220	970	1330
March	340	765	1120
April	340	1460	1840
May	380	1945	4720
June	1560	1920	2170
July	1370	1665	2640
August	1140	1500	2040
September	1070	1140	1250
October	320	925	1370
November	250	1005	1270
December	540	1620	3010

Average reactive silicate-Si concentrations reported for the south coast of South Africa is 146 µg/L.

The relationship between salinity and temperature measurements taken in the Breede River estuary during two summer surveys (i.e. January 1996 and February 2000), and one winter survey (i.e. August 2000) are provided in Figure 25.



igure 25.
Relationship between dissolved reactive silicate concentrations and salinity measured in the Breede River Estuary during summer (January 1996 and February 2000) and winter (August 2000).

Results from both the two summer surveys and the winter survey indicate that the river is a source of reactive silicate-Si to the estuary, as would be expected if one compares the concentration levels of the two sources (see above).

With river inflow and silicate-Si concentrations in river water being higher during winter, it is expected for silicate concentration in the estuary, on average, to be higher during winter than during summer. Higher concentration can, however, also occur during summer, as is illustrated in the results of February 2000 and the maximum concentrations recorded in the river during summer (Table 8). Such occurrences are typically associated with rain events in the catchment.

The large variability in silicate concentration in river inflow during summer (Table 8) is probably also the cause for the deviations form the dilution line in the upper reaches of the estuary during the two summer surveys (Figure 25).

7. PRELIMINARY ASSESSMENT OF SEDIMENT PROCESSES

7.1 Introduction

Sedimentation and erosion inside an estuary are determined by the balance of sediments imported into the estuary and those flushed from the estuary during floods. Sediments are transported from the catchment to the estuary by river flow. Marine sediments are transported upstream from the mouth by tidal flows.

The perception amongst the local community is that considerable sedimentation has taken place in the lower estuary in recent years. Accurate historical data on sedimentation and erosion in the Breede River estuary is, however, not available. A comparison was made of the maximum depths of the surveys from 1982 and 1996 (Table 9).

TABLE 9. Comparison of maximum depths at indicated distances from the mouth in 1982 and 1996 along the estuary.

DISTANCE FROM MOUTH (km)	MAXIMUM DEPTH (m)		DISTANCE FROM MOUTH (km)	MAXIMUM DEPTH (m)	
	1996	1982		1996	1982
1	3.8	4.9/7.7	26	3.9	3.9
2	6.8	3.5/11.6	27	6.0	6.0
3	4.7	2.6	28	7.1	10.7
4	7.3	8.6	29	2.1	-
5	3.7	3.2	30	2.6	2.4
6	5.0	4.5	31	4.6	8.6
7	4.9	4.1	32	3.6	4.4
8	3.8	2.8	33	3.5	-
9	3.4	3.2	34	2.2	7.6
10	2.9	2.5	35	6.6	3.5
11	4.0	2.0	36	9.5	8.2
12	4.3	3.4	37	3.2	2.5
13	3.4	2.8	38	5.0	-
14	3.1	7.7	39	2.2	17.6
15	2.9	3.4	40	6.7	-
16	6.0	8.1	41	1.8	-
17	6.0	-	42	0.9	-
18	4.0	10.0	43	7.1	-
19	4.9	-	44	1.4	-
20	7.9	2.2	45	1.4	-
21	7.6	-	46	7.9	-
22	5.7	4.0	47	2.0	-
23	6.5	7.3	48	1.8	-
24	4.0	4.8			
25	8.6	-			

Proper MSL reference levels were not available for these surveys, but a rough comparison of these depths was undertaken. Holes with depths up to 17 metres are present, which could strongly affect averages based on these data. For each year, the three largest depths were therefore ignored. The averages for all the depths from the mouth up to 40 km upstream were determined. The average for the 1982 survey was 4.7 m and for the 1996 survey 4.6 m, which is very close. This therefore does not confirm that significant sedimentation or erosion has taken place over the whole estuary between 1982 and 1996. Similar averages were determined for the lower 18 km of the estuary. For this stretch the average maximum depth in 1982 and 1996 was 4.4 m. This does not indicate either that significant sedimentation or erosion took place in the lower estuary.

7.2 Sediment characteristics of the Breede River Estuary

Comprehensive sediment surveys were undertaken by the CSIR in 1982 (CSIR, 1983). Figure 26 summarizes particle size, mud and sand composition data as well as the concentration of calcium carbonate to the sediment.

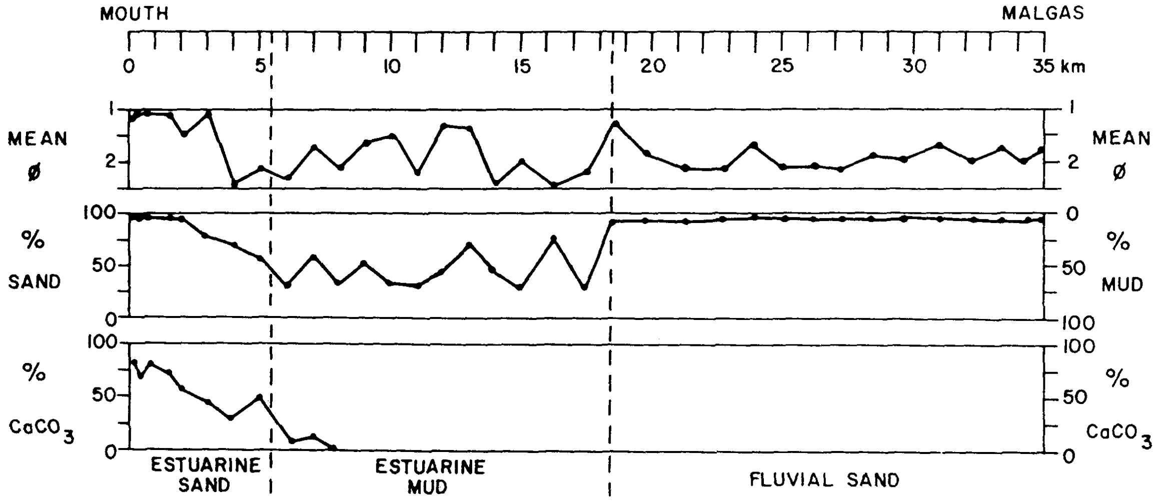


Figure 26. Sediment particle size, mud and sand composition, as well as calcium carbonate concentrations in the Breede River Estuary sediments (taken from CSIR, 1983)

i. <u>The estuarine sand zone:</u> This zone extends from the mouth to 5,5 km upstream. Particle sizes vary from coarse close to the mouth to finer sediment ca. 5 km upstream. The coarse sediments near the mouth are predominantly sand with muds making a larger contribution further upstream. The calcium carbonate content, derived from marine and/or estuarine organisms, is highest near the mouth and thereafter decreases with increasing distance upstream.

ii. <u>The estuarine mud zone</u>: This zone extents from 5,5 to 18,5 km upstream. Sediments are not so coarse near the mouth but vary from medium to fine. The sediments in this zone contain the highest proportion of mud. The calcium carbonate content is low and in fact drops to zero 8 km from the mouth.

iii. <u>The fluvial sand zone</u>: This zone extends from 18,5 km to Malgas 35 km upstream. Sediments are of medium size and the contribution of mud is low.

The sediment distributed displayed in Figure 25 demonstrates two major features:

- In 1982 marine and estuarine sediments occurred quite far upstream (8.5 km) as is shown by the calcium carbonate distribution.

- Typically fine sediments (muds) settle out where the gradient in salinity occurs. This is due to flocculation caused by ionisation. The distribution of muds in Figure 25 shows that in 1982 the salinity gradient varied in position over approximately 13 km (estuarine mud zone). This variation in position is obviously due to the interaction of saline seawater and fresh river water. It is apparent that in 1982 seawater generally did not extent further than 18.5 km upstream.

Reduction in river flow will result in a further movement upstream of the salinity gradient, which can then result in a deposition of fine sediments (muds) further upstream than was measured in 1982.

7.3 Occurrence of river floods

Impoundments will catch sediments eroded upstream from the catchment. This can therefore result in a reduction of sediments transported to the estuary, which in turn could result in a deepening of the estuary. They also will reduce the magnitudes of river floods in the estuary and therefore indirectly reduce the scouring of sediments during floods, which could result in increased sedimentation. It is difficult to quantify these effects, but to obtain some indication on the effects of dams an evaluation was undertaken on the occurrence of floods in the Breede River by analysing the highest average monthly simulated river flows for the various scenarios.

7.3.1 Analysis of highest average monthly flows

It was attempted to obtain a first impression by analysing the frequency and magnitude of the highest monthly flows in the simulated monthly datasets for the different scenarios. In Table 10, the 13 highest monthly flows for the reference (or natural) conditions obtained from the datasets of simulated monthly flows are listed and these are compared with the flows in the same months for the other scenarios.

It is likely that during a month with such a high average flow a major flood with a much higher peak flow would have occurred. This analysis gives therefore only an indication on the occurrence of major floods under the different scenarios. The following observations made based on the results in Table 10:

- The highest average monthly flows have been reduced by 21.6 per cent at present compared to reference conditions.
- These reductions will increase to 25,8 per cent for the limited development scenario, to 28.7 per cent for the moderate development scenario, which is a comparatively small further reduction.
- These reductions will increase to 34,6 per cent for the high development scenario including the Le Chasseur Dam and to 33,1 per cent for the alternative high development scenario including the Bromberg Dam, which are significant.

The strongest reductions have therefore occurred already between the reference condition, and the present condition and lesser further reductions will take place for the various future scenarios.

The flushing of sediments during floods has probably significantly been reduced between reference and present conditions which could substantiate the local perception that sedimentation is occurring in the lower reaches of the estuary.

Significant further reduction in flushing of sediments during floods can be expected for the high development scenarios including the Le Chasseur Dam or the Bromberg. More detailed investigations on the effects of these dams on the sediment dynamics of the estuary will be required if any of these schemes will be considered for implementation.

TABLE 10. A comparison of the reduction in average monthly flows for the different scenarios for the months with the highest average monthly flows (> 300 m³/s) as they occurred under reference (or natural) conditions.

YEAR/MONTH	SIMULATED RUNOFF SCENARIOS					
	Reference (Natural)	Present	Limited Development	Moderate Development	Bromberg	Le Chasseur
June 1942	321	194	186	174	162	115
July 1954	344	240	221	213	195	217
August 1954	303	260	222	220	216	224
August 1955	344	271	252	241	239	245
June 1957	337	244	232	210	195	188
August 1962	565	436	428	420	370	424
August 1974	744	577	569	562	525	435
May 1977	313	230	222	211	198	169
June 1977	310	211	201	194	190	197
July 1977	352	328	284	273	274	278
August 1977	367	352	343	312	312	315
August 1986	338	310	297	283	259	285
July 1991	314	227	216	208	183	148
Average	381	99	283	271	255	249
% of Reference	100	78.4	74.2	71.3	66.9	65.4

7.3.2 Flood estimates provided by Ninham Shand

Flood hydrographs for different occurrences were not available for the study, but Ninham Shand provided a limited number of flood estimates. Details are included in Annexure C-4.

The potential impacts of future development options on the magnitude and occurrence of floods entering the Breede River estuary were assessed through a comparison of the present flow regime with flow regimes resulting from three future development scenarios (limited, moderate and high future water infrastructure development). The scenarios, included in this assessment are for the Present, Limited Future, Moderate Future and High Future include Le Chasseur scenarios.

The reduction in annual maximum floods, based on average daily flows under the three development scenarios compared to the Present Day conditions, are:

FLOOD RETURN PERIOD (YEARS)	PEAK DISCHARGE (m³/s) (1)			
	PRESENT	LIMITED FUTURE	MODERATE FUTURE	HIGH FUTURE
2	523 (100 %)	518 (99 %)	489 (94 %)	437 (84 %)
10	1108 (100 %)	1097 (99 %)	1055 (95 %)	982 (89 %)
20	1317 (100 %)	1301 (99 %)	1257 (95 %)	1175 (89 %)
50	1553 (100 %)	1534 (99 %)	1485 (96 %)	1392 (90 %)

Notes : (1) Based on average daily flows. Actual peak discharges could be under estimated by up to 25%

These results therefore indicate that insignifant further reduction in the magnitude of floods will occur at the Limited Development Scenario compared to present day conditions. Reductions of approximately 5 % in highest average daily flows are expected at the Moderate Development Scenario compared to Present conditions. At the High Future Development Scenario including the Le Chasseur Scheme reductions of approximately 16 % are expected for the 1:2 year floods and reductions of approximately 10 % at the floods with longer return periods.

These results differ to some extent from those of the earlier analysis of the highest monthly flows.

A significant further reduction in flushing of sediments during floods can therefore be expected for the high development scenarios including the Le Chasseur Dam. More detailed investigations on the effects of these dams on the sediment dynamics of the estuary will be required if any of these schemes will be considered for implementation.

8. ABIOTIC CHARACTERISTICS OF THE BREEDE RIVER ESTUARY

8.1 Different Abiotic States

Based on the assessments and evaluations conducted for this specialist report, five Abiotic States were derived for the Breede River Estuary, of which the occurrence and duration varies depending on river inflow rate these states are:

- State 1: Strongly freshwater dominated
- State 2: Freshwater dominated with significant saline intrusion in lower reaches
- State 3: Marine and freshwater influence on the estuary is balanced, with a well-developed REI zone
- State 4: Marine dominated, where the REI zone is variable, depending on the flow rate and duration
- Sate 5: Strongly marine dominated, with no REI zone.

For the purposes of this study, the River-Estuarine-Interface Zone (REI) is defined as the area in the estuary where salinities are < 10ppt.

8.1.1 State 1: Strongly freshwater dominated

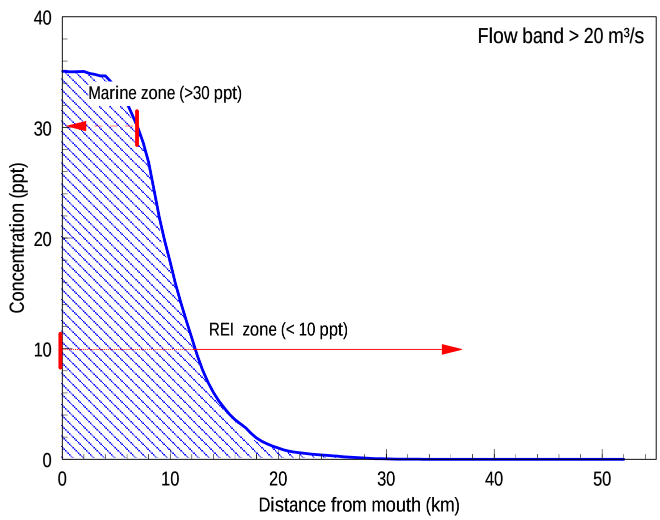
i. *Typical flow patterns*. Typical flow rates for State 1 are greater than 20 m^3/s. These flows usually occur during the winter (June to October).

ii. *State of the mouth*. The estuary mouth is wide open.

iii. *Flood plain inundation patterns*. The Breede River Estuary does not have extensive flood plains such as, for example the Olifants or Berg River estuaries.

iv. *Amplitude of tidal variation* (indicative of exposure of inter-tidal areas during low tide). Tidal variation could range between 0.9 (at neap tide) and 1.5 m (at spring tide).

v. *Salinity distributions in the estuary*. Average salinity distributions at spring high tide along the length of the estuary during State 1 are shown below. During State 1, the estuary will be freshwater dominated (low tides), but during high tides there is marked saline intrusion into the lower reaches, even at relatively high flow (e.g. 40 m^3/s).



vi. *Temperature, pH, suspended solids and dissolved oxygen*. The following estimates on system variable were derived from on (a) measurements taken in the Breede River Estuary, (b) estimates for sea water quoted in the *South African water quality guidelines for coastal waters* and (c) measurements collected by the DWAF at the Breede River monitoring station near Swellendam (refer to Chapter 6).

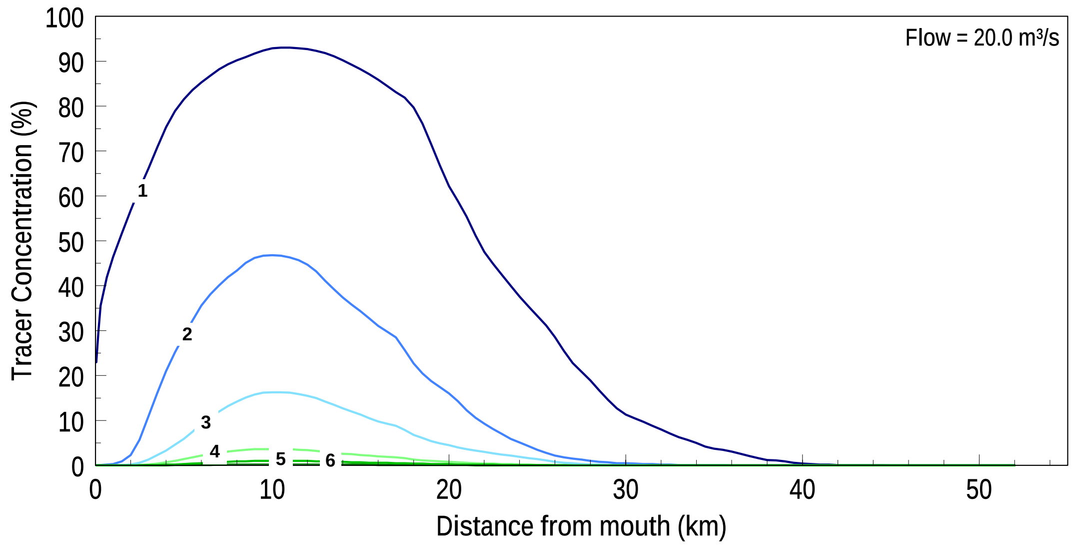
VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	Middle salinity ranges	< 10 ppt (REI zone)
Temperature (°C)	15-17 throughout the estuary (winter)		
pH	> 8	7-8	~ 7
Suspended solids (mg/l)	<10	Because of flocculation SS should be less than in the <10ppt zone, but may still be higher than in the >30 ppt zone	Depend on levels in river inflow, which is expected to increase during winter (no data available)
Dissolved oxygen	Well oxygenated through estuary		

vii. *Nutrients*. The following estimates on nutrients were derived from on (a) measurements taken in the Breede River Estuary, (b) estimates for sea water quoted in the *South African water quality guidelines for coastal waters* and (c) measurements collected by the DWAF at the Breede River monitoring station near Swellendam (refer to Chapter 6).

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	Middle salinity ranges	< 10 ppt (REI zone)
Nitrite-N (µg/l) Nitrate-N (µg/l)	<100	100 – 400*	200 - 500
Total Ammonia-N (µg/l)	Low	30 – 70	<20
Reactive phosphate-P (µg/l)	40	15 – 25	<20
Reactive Silicate-Si (µg/l)	150	150 – 1 500*	1 500 - 2000

* *The minimum salinity is this range is 10 ppt, thus the high nitrate/silicate river water has already been diluted with lower nitrate/silicate seawater. The upper limit estimated for this range take this dilution into account (assuming conservative behaviour). A salinity of 10 ppt represents 1 part seawater plus 2.5 part freshwater, thus upper limit, for nitrate, for example is calculated as follows: [(1 x100) +(2.5.500)]/3.5 ~ 400).*

viii. To provide an estimate of the retention times of water masses in the estuary during State 1, the Mike II model was used to simulate the changes in concentration and distribution of a conservative tracer at a steady flow of 20 m³/s over a 6-week period. The simulation indicated that the maximum retention was in the region 5 to 15 km upstream from the mouth, where already after about 2 weeks less than 50% of the original water mass remains.



8.1.2 State 2: Freshwater dominated with significant saline intrusion in lower reaches

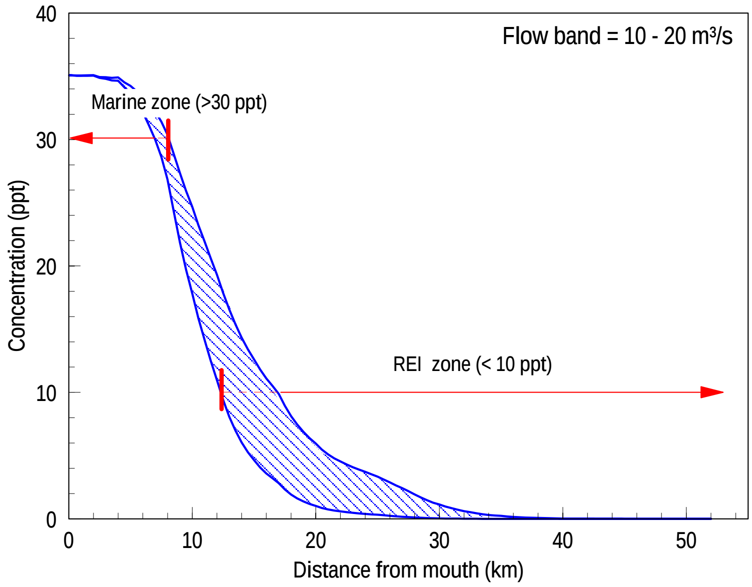
i. *Typical flow patterns*. Flow rates for State 2 are between 10 and 20 m³/s and are common during autumn and winter (May to October).

ii. *State of the mouth.* The estuary mouth is wide open.

iii. *Flood plain inundation patterns.* Not applicable to the Breede River Estuary.

iv. *Amplitude of tidal variation*. Tidal variation could typically range between 0.9 m (at neap tide) and 1.5 m (at spring tide).

v. *Salinity distributions in the estuary.* Average salinity distributions at spring high tide along the length of the estuary during State 2 are shown below. Although there is still marked freshwater inflow, saline intrusion becomes more significant and saline water remain in the estuary even during low tides.



vi. *Temperature, pH, suspended solids and dissolved oxygen.* The following estimates on system variable were derived from on (a) measurements taken in the Breede River Estuary, estimates for sea water quoted in the South African water quality guidelines for coastal waters and measurements collected by the DWAF at the Breede River monitoring station near Swellendam (refer to Chapter 6).

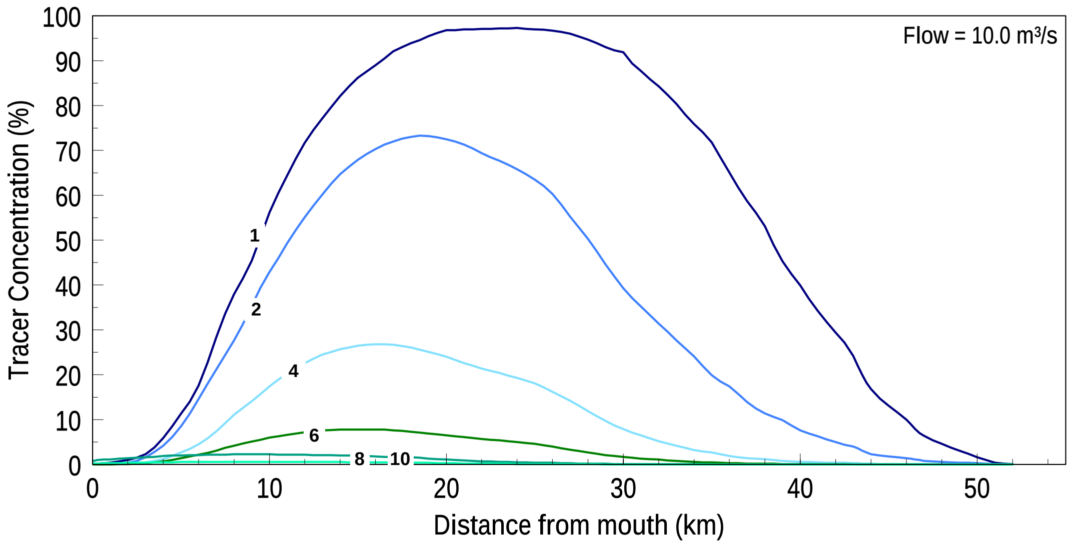
VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	Middle salinity ranges	< 10 ppt (REI zone)
Temperature (ºC)	15-17 throughout the estuary (winter)		
pH	> 8	7-8	~ 7
Suspended solids (mg/l)	<10	Because of flocculation SS should be less than in the <10ppt zone, but may still be higher than in the >30 ppt zone	Depend on levels in river inflow, which is expected to increase during winter (no data available)
Dissolved oxygen	Well oxygenated through estuary		

vii. *Nutrients.* The following estimates on system variable were derived from on (a) measurements taken in the Breede River Estuary, estimates for sea water quoted in the South African water quality guidelines for coastal waters and measurements collected by the DWAF at the Breede River monitoring station near Swellendam (refer to Chapter 6).

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	Middle salinity ranges	< 10 ppt (REI zone)
Nitrite-N (µg/l) Nitrate-N (µg/l)	<100	100 – 400*	200 - 500
Total Ammonia-N (µg/l)	Low	30 – 70	<20
Reactive phosphate-P (µg/l)	40	15 – 25	<20
Reactive Silicate-Si (µg/l)	150	150 – 1 500*	1 500 - 2000

* *The minimum salinity is this range is 10 ppt, thus the high nitrate/silicate river water has already been diluted with lower nitrate/silicate seawater. The upper limit estimated for this range take this dilution into account (assuming conservative behaviour). A salinity of 10 ppt represents 1 part seawater plus 2.5 part freshwater, thus upper limit, for nitrate, for example is calculated as follows: [(1 x100) +(2.5 x 500)]/3.5 ~ 400).*

viii. To provide an estimate of the retention times of water masses in the estuary during State 2, the Mike II model was used to simulate the changes in concentration and distribution of a conservative tracer at a steady flow of 10 m³/s over a 10-week period. The simulation indicated that the maximum retention was in the region 15 to 25 km upstream from the mouth, where already after 2 to 4 weeks less than 50% of the original water mass remains.



8.1.3 <u>State 3</u>: Marine and freshwater influence on the estuary is balanced

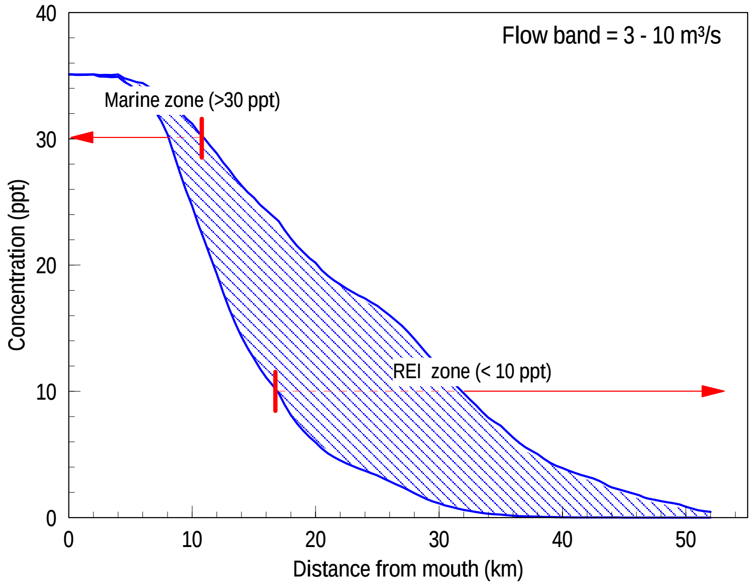
i. *Typical flow patterns*. Flow rates for State 3, is typically between 3 and 10 m³/s, which is common in summer (November to April).

ii. *State of the mouth*. The estuary mouth is open.

iii. *Flood plain inundation patterns*. Not applicable to the Breede River Estuary.

iv. *Amplitude of tidal variation*. Tidal variation could typically range between 0.9 m (at neap tide) and 1.5 m (at spring tide).

v. *Salinity distributions in the estuary*. Average salinity distributions at spring high tide along the length of the estuary during State 3 are shown below. The influence of the river and the sea is balanced, with a well-developed REI zone, ranging from 20 to 30 km.



vi. *Temperature, pH, dissolved oxygen and Suspended solids*. The following estimates on system variable were derived from on (a) measurements taken in the Breede River Estuary, (b) estimates for sea water quoted in the *South African water quality guidelines for coastal waters* and (c) measurements collected by the DWAF at the Breede River monitoring station near Swellendam (refer to Chapter 6).

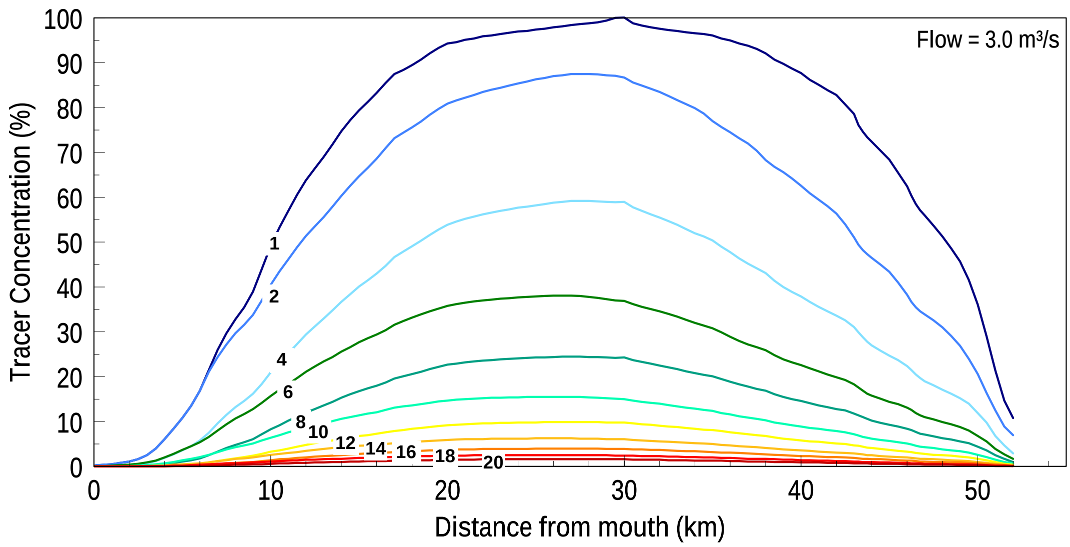
VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	Middle salinity ranges	< 10 ppt (REI zone)
Temperature (ºC)	21 - 25 (summer)		
pH	8	7-8	7-8
Suspended solids (mg/l)	< 10	<10	< 10
Dissolved oxygen	Well-oxygenated throughout the estuary		

vii. *Nutrients*. The following estimates on nutrients were derived from on (a) measurements taken in the Breede River Estuary, (b) estimates for sea water quoted in the *South African water quality guidelines for coastal waters* and (c) measurements collected by the DWAF at the Breede River monitoring station near Swellendam (refer to Chapter 6).

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	Middle salinity ranges	< 10 ppt (REI zone)
Nitrite-N (µg/l) / Nitrate-N (µg/l)	<100	20 – 170*	20 - 200
Total Ammonia-N (µg/l)	Low	30 – 70	<20
Reactive phosphate-P (µg/l)	40	15 – 25	<20
Reactive Silicate-Si (µg/l)	150	150 – 900*	700 - 1200

** The minimum salinity is this range is 10 ppt, thus the high nitrate/silicate river water has already been diluted with lower nitrate/silicate seawater. The upper limit estimated for this range take this dilution into account (assuming conservative behaviour). A salinity of 10 ppt represents 1 part seawater plus 2.5 part freshwater, thus upper limit, for nitrate, for example is calculated as follows: [(1 x100) +(2.5 x 200)]/3.5 ~ 170).*

viii. To provide an estimate of the retention times of water masses in the estuary during State 3, the Mike II model was used to simulate the changes in concentration and distribution of a conservative tracer at a steady flow of 3 m^3/s over a 20-week period. The simulation indicated that the maximum retention was in the region 15 to 35 km upstream from the mouth, where already after about 4 weeks only 50% of the original water mass remains.



8.1.4 State 4: Marine dominated

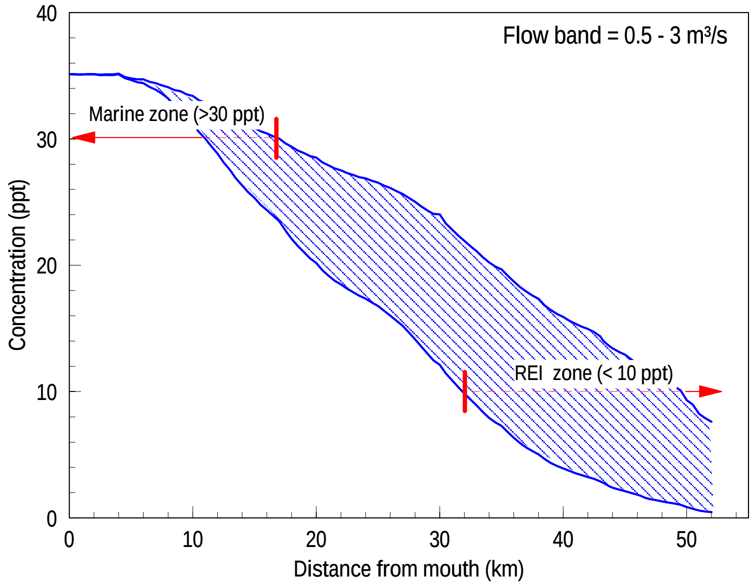
i. *Typical flow patterns*. Flow rates for State 4, is typically between 0.5 to 3 m³/s, which is common in summer (November to April).

ii. *State of the mouth*. The estuary mouth is open.

iii. *Flood plain inundation patterns*. Not applicable to the Breede River.

iv. *Amplitude of tidal variation*. Tidal variation could typically range between 0.9 m (at neap tide) and 1.5 m (at spring tide).

v. *Salinity distributions in the estuary*. Average salinity distributions at spring high tide along the length of the estuary during State 4 are shown below. The estuary become marines dominated and the size of the REI zone varies quite extensively, depending on the flow rate and the duration of low flow. There is a marked decrease in the size of the REI compared with State 3.



vi. *Temperature, pH, dissolved oxygen and Suspended solids*. The following estimates on system variable were derived from on (a) measurements taken in the Breede River Estuary, (b) estimates for sea water quoted in the *South African water quality guidelines for coastal waters* and (c) measurements collected by the DWAF at the Breede River monitoring station near Swellendam (refer to Chapter 6).

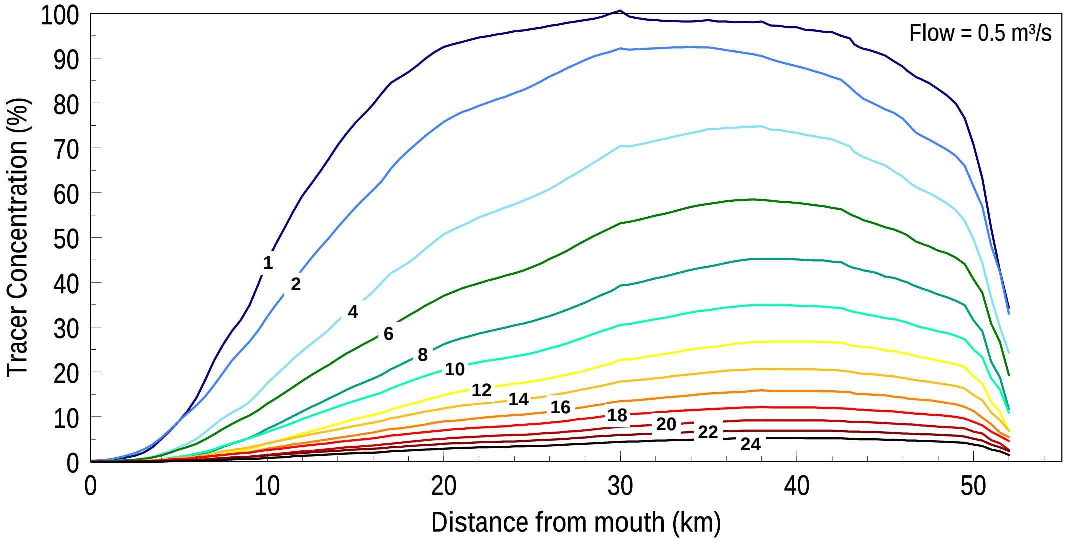
VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	Middle salinity ranges	< 10 ppt (REI zone)
Temperature (°C)	21 - 25 (summer)		
PH (estimates)	8	7-8	7-8
Suspended solids (mg/l)	< 10	<10	< 10
Dissolved oxygen	Oxygenated throughout the estuary		

vi. *Nutrients*. The following estimates on nutrients were derived from on (a) measurements taken in the Breede River Estuary, (b) estimates for sea water quoted in the *South African water quality guidelines for coastal waters* and (c) measurements collected by the DWAF at the Breede River monitoring station near Swellendam (refer to Chapter 6).

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	Middle salinity ranges	< 10 ppt (REI zone)
Nitrite-N (µg/l)	<100	20 – 170*	20 - 200
Nitrate-N (µg/l)			
Total Ammonia-N (µg/l)	Low	30 – 70	<20
Reactive phosphate-P (µg/l)	40	15 – 25	<20
Reactive Silicate-Si (µg/l)	150	150 – 900*	700 - 1200

* *The minimum salinity is this range is 10 ppt, thus the high nitrate/silicate river water has already been diluted with lower nitrate/silicate seawater. The upper limit estimated for this range take this dilution into account (assuming conservative behaviour). A salinity of 10 ppt represents 1 part seawater plus 2.5 part freshwater, thus upper limit, for nitrate, for example is calculated as follows: [(1 x100) +(2.5 x 200)]/3.5 ~ 170).*

viii. To provide an estimate of the retention times of water masses in the estuary during State 4, the Mike II model was used to simulate the changes in concentration and distribution of a conservative tracer at a steady flow of 0.5 m^3/s over a 24-week period. The simulation indicated that the maximum retention was in the region 30 to 50 km upstream from the mouth, where already after about 6 weeks only 50% of the original water mass remains.



8.1.5 State 5: Strongly marine dominated

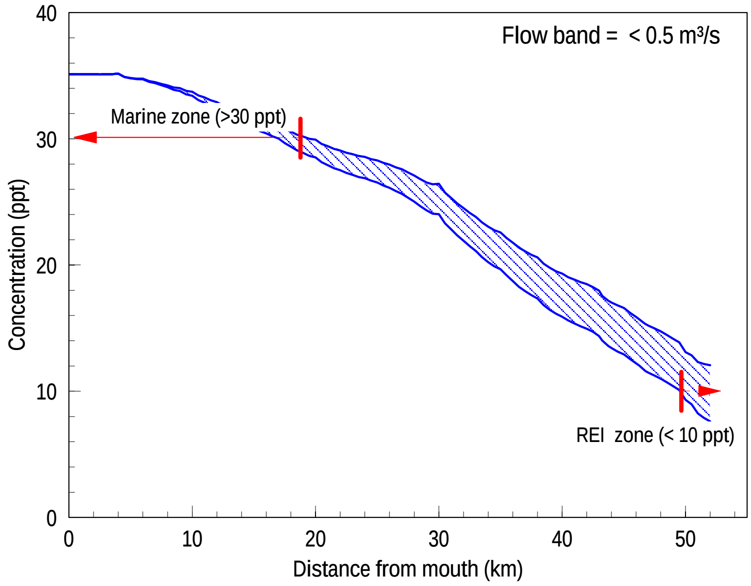
i. *Typical flow patterns*. During State 5 the flow rate are typically less than 0.5 m^3/s. This state occurs only in summer (November to April).

ii. *State of the mouth*. The estuary mouth is open.

iii. *Flood plain inundation patterns*. Not applicable to the Breede River

iv. *Amplitude of tidal variation*. Tidal variation could typically range between 0.9 m (at neap tide) and 1.5 m (at spring tide).

v. *Salinity distributions in the estuary*. Average salinity distributions at spring high tide along the length of the estuary during State 5 are shown below. The estuary is strongly marine dominated, with salinities of up to 20 ppt at the head of the estuary. There is no REI zone present.



vi. *Temperature, pH, dissolved oxygen and Suspended solids*. The following estimates on system variable were derived from on (a) measurements taken in the Breede River Estuary, (b) estimates for sea water quoted in the *South African water quality guidelines for coastal waters* and (c) measurements collected by the DWAF at the Breede River monitoring station near Swellendam (refer to Chapter 6).

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	Middle salinity ranges	< 10 ppt (REI zone)
Temperature (°C)	21 - 25 (summer)		
pH	8	7-8	7-8
Suspended solids (mg/l)	< 10	<10	< 10
Dissolved oxygen	Oxygenated	Although no data are available, bottom water in these salinity ranges may start to show reduced oxygen levels owing to limited flushing	

vi. *Nutrients*. The following estimates on nutrients were derived from on (a) measurements taken in the Breede River Estuary, (b) estimates for sea water quoted in the *South African water quality guidelines for coastal waters* and (c) measurements collected by the DWAF at the Breede River monitoring station near Swellendam (refer to Chapter 6).

VARIABLE	ESTIMATED CONCENTRATIONS		
	> 30ppt (Seawater dominated)	Middle salinity ranges	< 10 ppt (REI zone)
Nitrite-N (µg/l) Nitrate-N (µg/l)	<100	20 – 170*	20 - 200
Total Ammonia-N (µg/l)	Low	30 – 70	<20
Reactive phosphate-P (µg/l)	40	15 – 25	<20
Reactive Silicate-Si (µg/l)	150	150 – 900*	700 - 1200

** The minimum salinity is this range is 10 ppt, thus the high nitrate/silicate river water has already been diluted with lower nitrate/silicate seawater. The upper limit estimated for this range take this dilution into account (assuming conservative behaviour). A salinity of 10 ppt represents 1 part seawater plus 2.5 part freshwater, thus upper limit, for nitrate, for example is calculated as follows: [(1 x100) +(2.5 x 200)]/3.5 ~ 170).*

viii. To provide an estimate of the retention times of water masses in the estuary during State 5, the Mike II model was used to simulate the changes in concentration and distribution of a conservative tracer at a steady flow of 0 m^3/s over a 24-week period. The simulation indicated that the maximum retention was in the region 30 to 50 km upstream from the mouth, where already after about 6 weeks only 50% of the original water mass remains.

8.2 Occurrence and Duration of Abiotic States within Different Scenarios

8.2.1 Reference Condition

To estimate the occurrence and duration of the different Abiotic States during the Reference Condition, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively (Figure 27).

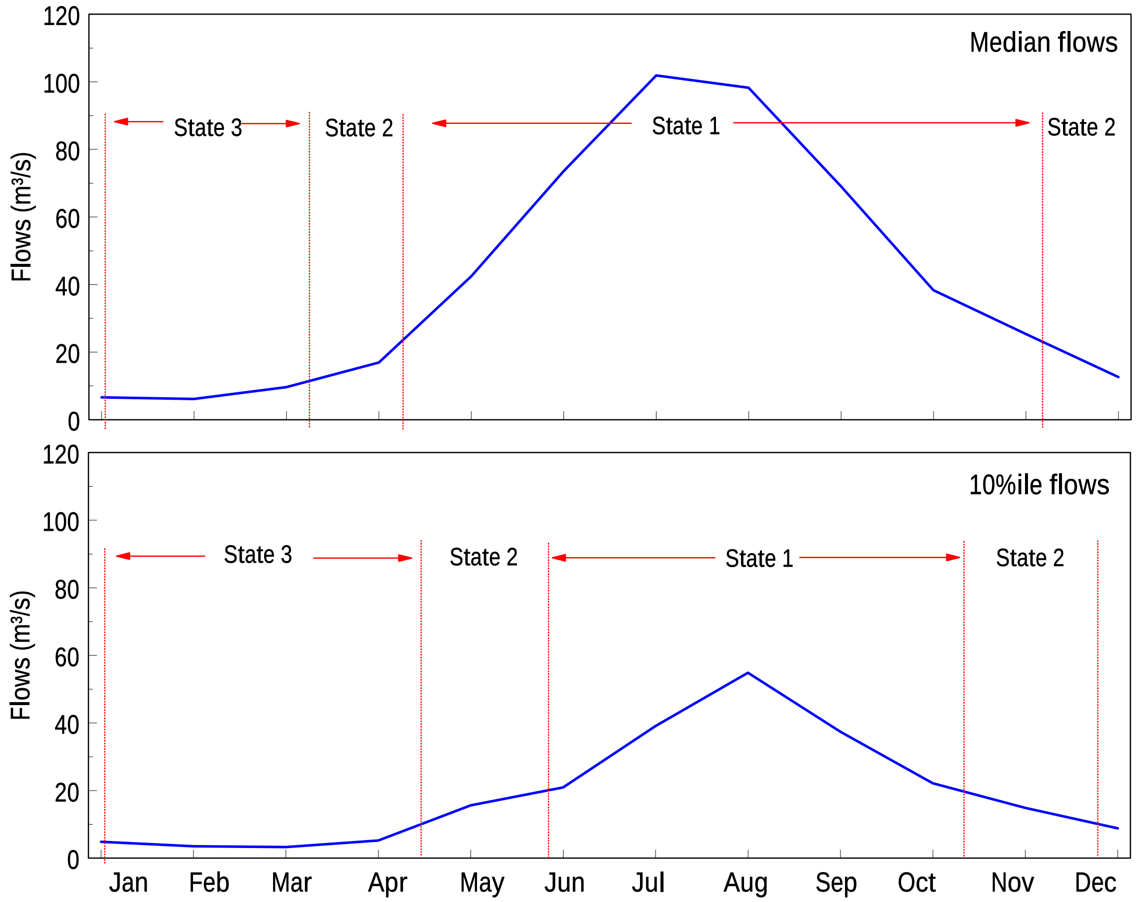


Figure 27. Occurrence and duration of different Abiotic States during the Reference Condition, using median monthly flows and 10%ile flows (simulated for the 64-year period), to predict variations during normal and drought periods, respectively.

8.2.2 Present State

To estimate the occurrence and duration of the different Abiotic States during the Present State, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively (Figure 28).

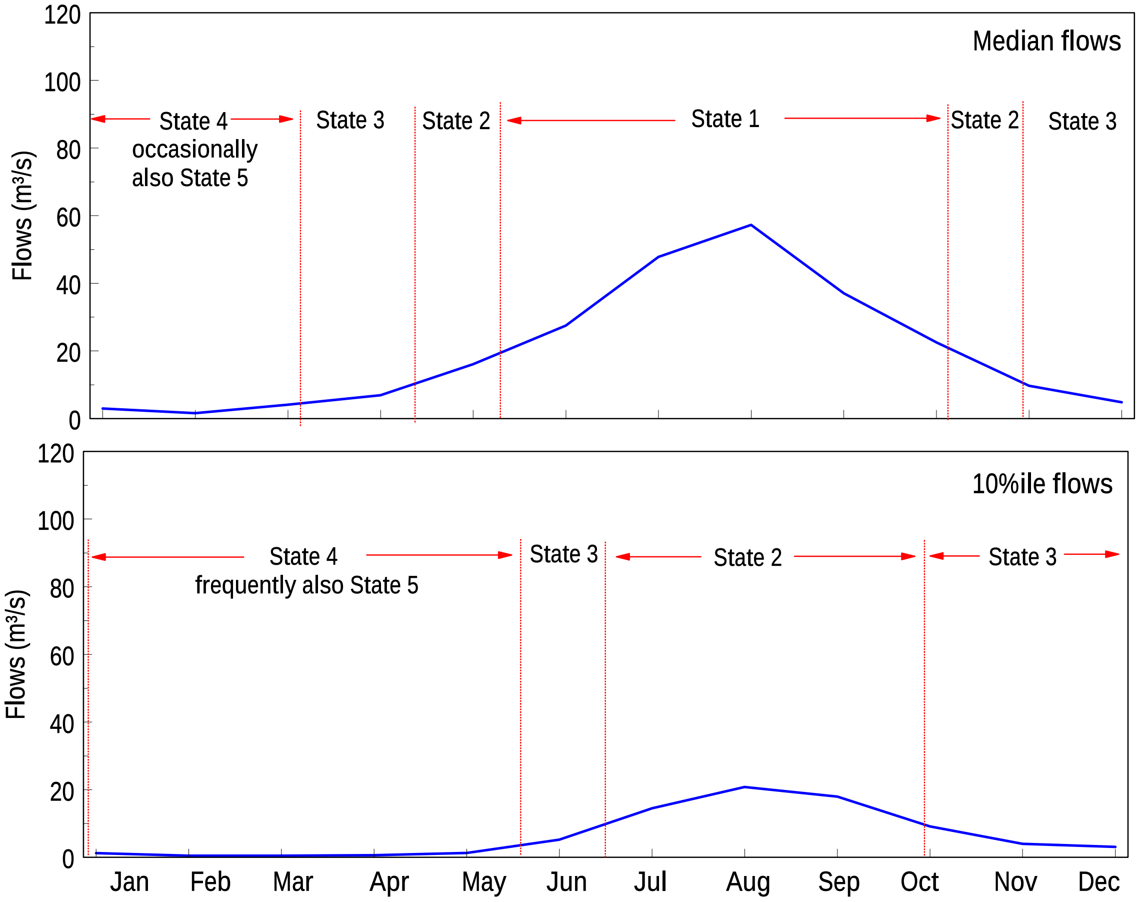


Figure 28. Occurrence and duration of different Abiotic States during the Present State, using median monthly flows and 10%ile flows (simulated for the 64-year period), to predict variations during normal and drought periods, respectively.

8.2.3 Limited Development Scenario

To estimate the occurrence and duration of the different Abiotic States during the Limited Future Development Scenario, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively (Figure 29).

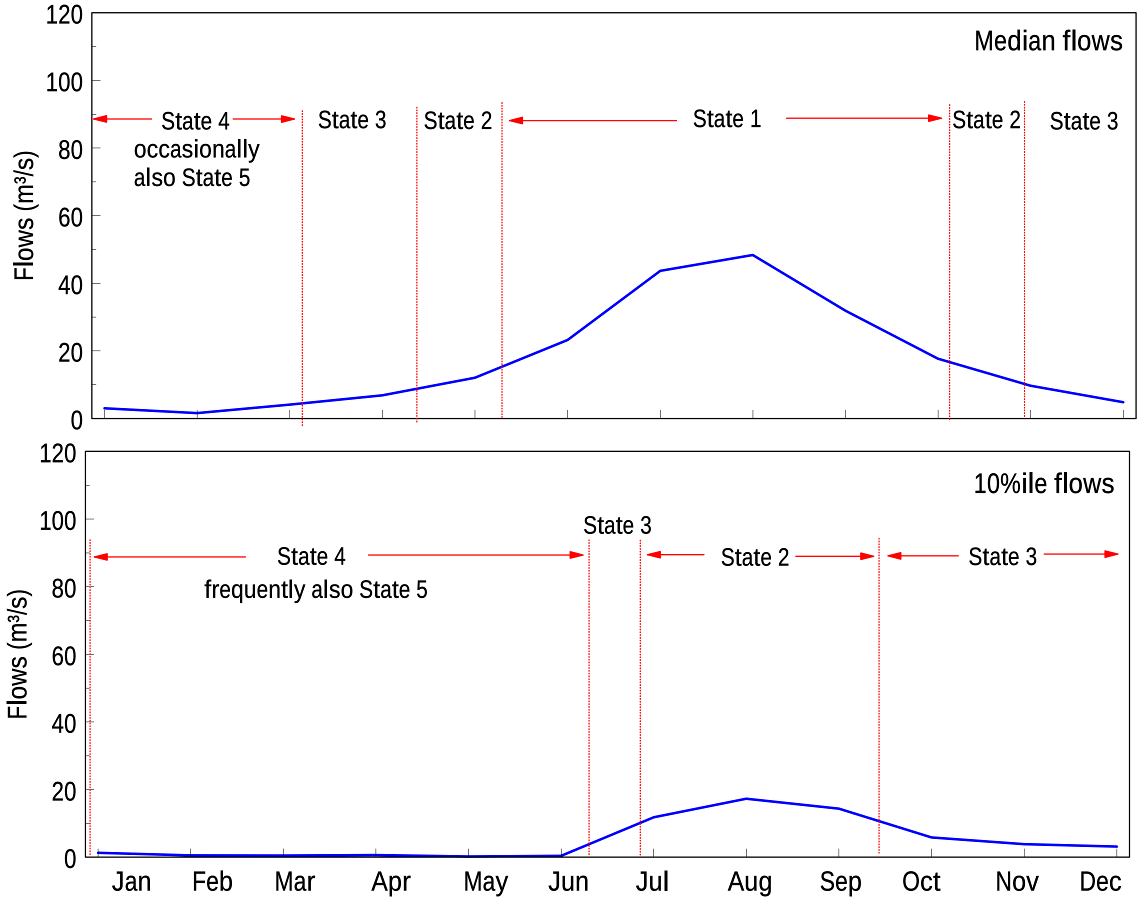


Figure 29. Occurrence and duration of different Abiotic States during the Limited Future Development Scenario, using median monthly flows and 10%ile flows (simulated for the 64-year period), to predict variations during normal and drought periods, respectively.

8.2.4 Moderate Development Scenario

To estimate the occurrence and duration of the different Abiotic States during the Moderate Future Development Scenario, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively (Figure 30).

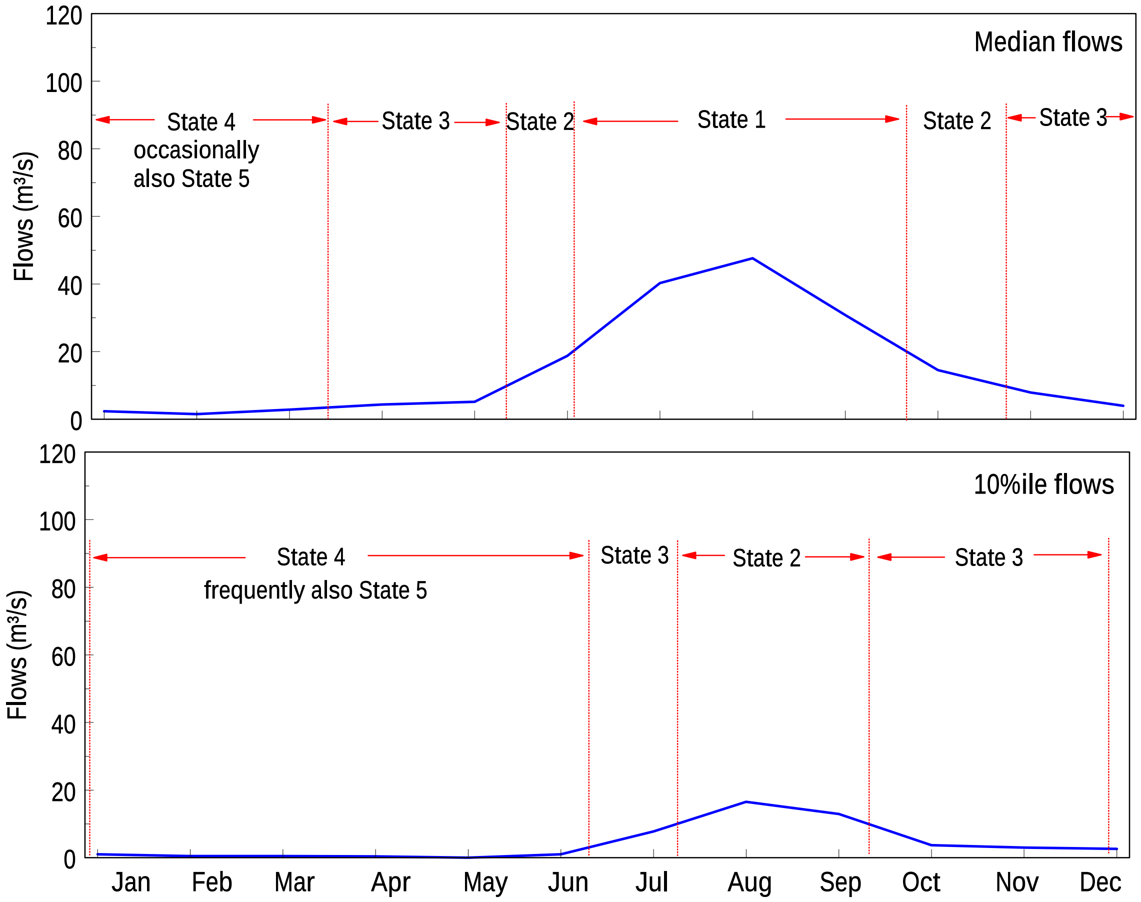


Figure 30. Occurrence and duration of different Abiotic States during the Moderate Future Development Scenario, using median monthly flows and 10%ile flows (simulated for the 64-year period), to predict variations during normal and drought periods, respectively.

8.2.5 Bromberg Future Development Scenario

To estimate the occurrence and duration of the different Abiotic States during the Bromberg Future Development Scenario, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively (Figure 31).

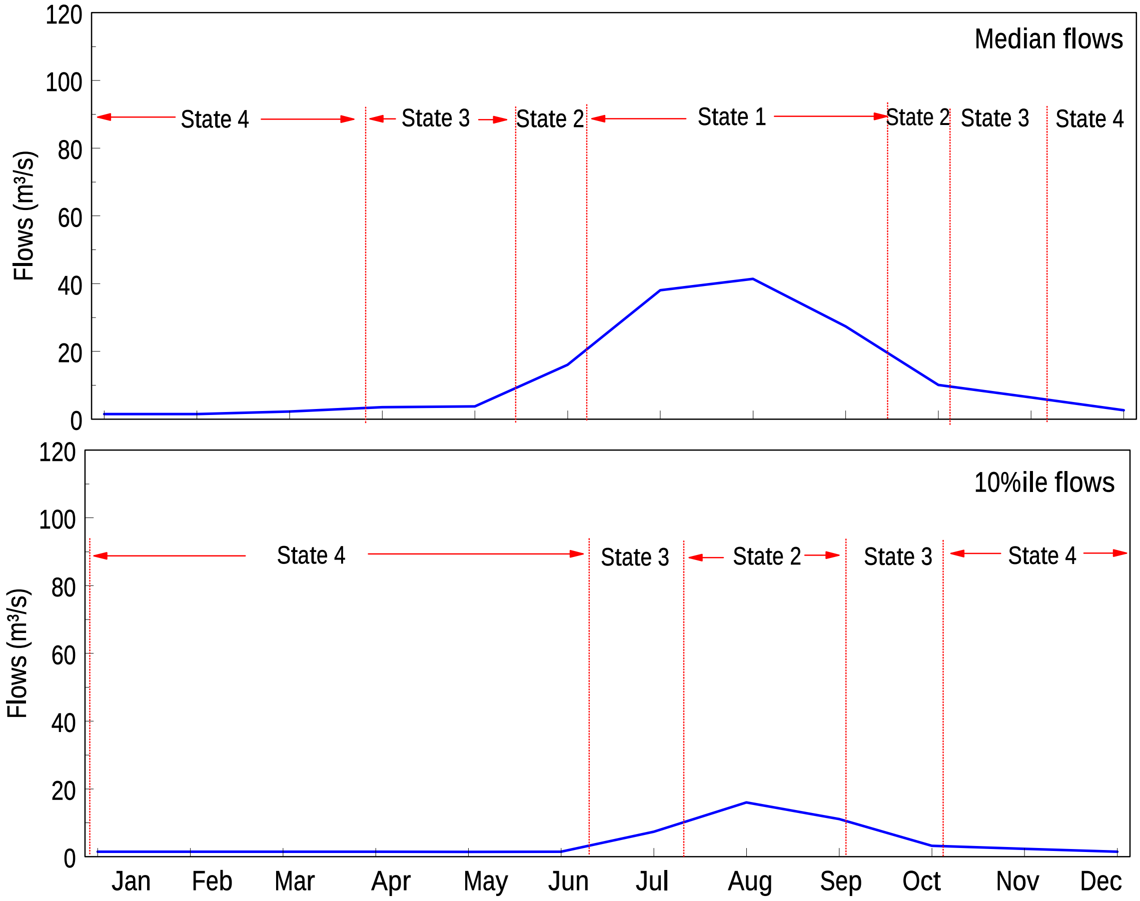


Figure 31. Occurrence and duration of different Abiotic States during the Bromberg Future Development Scenario, using median monthly flows and 10%ile flows (simulated for the 64-year period), to predict variations during normal and drought periods, respectively.

8.2.6 Le Chasseur Future Development Scenario

To estimate the occurrence and duration of the different Abiotic States during the Le Chasseur Future Development Scenario, median monthly flows and 10%ile flows, simulated for the 64-year period (1927 to 1990), were used to predict the situation for normal and drought periods, respectively (Figure 32).

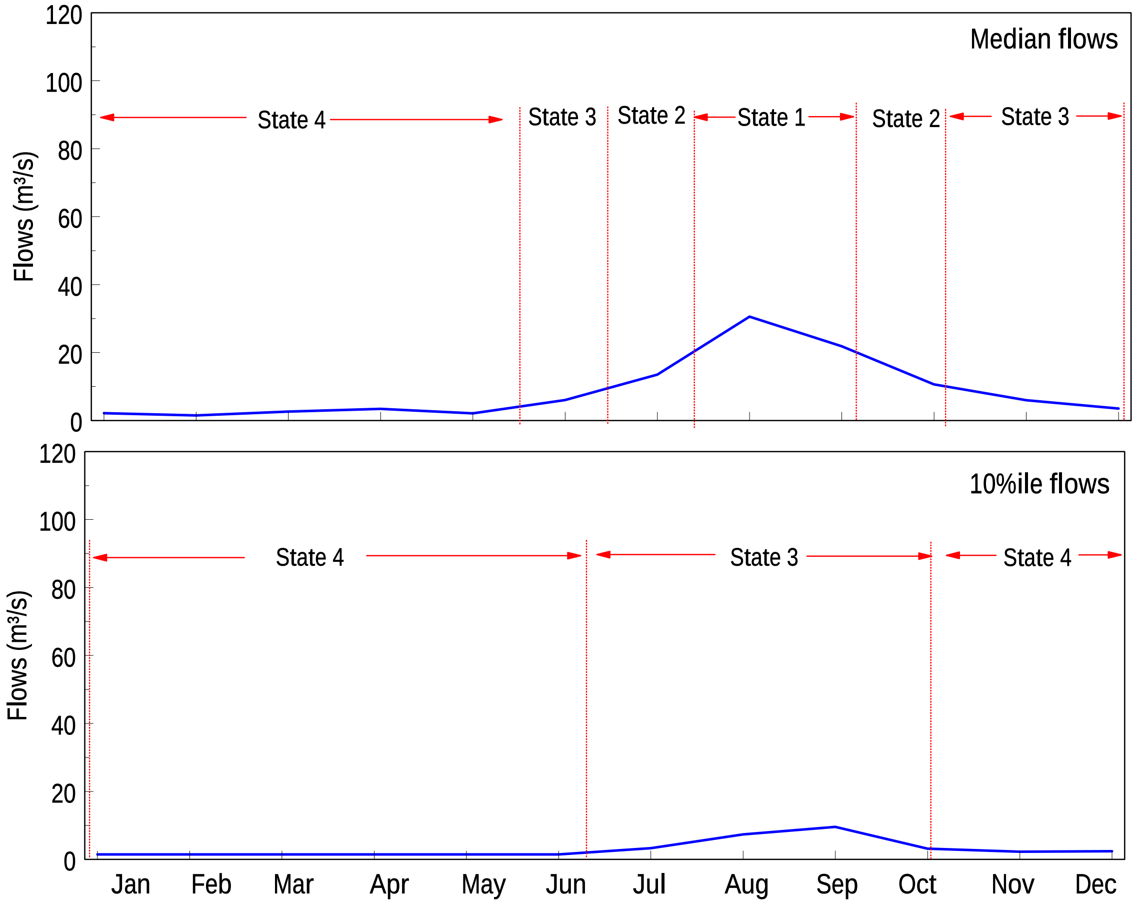


Figure 32. Occurrence and duration of different Abiotic States during the Le Chasseur Future Development Scenario, using median monthly flows and 10%ile flows (simulated for the 64-year period), to predict variations during normal and drought periods, respectively.

8.2.7 Comparison of Abiotic States among different scenarios

A comparison of the distribution and occurrence of Abiotic States among the different runoff scenarios is presented in Tables 11.

TABLE 11. Comparison of the distribution and occurrence of abiotic states among the different runoff scenarios, representative of normal (median) flow conditions (states representing low flow periods , i.e. flows of < 10 m^3/s are shaded)

SCENARIO	STATE 1	STATE 2	STATE 3	STATE 4	STATE 5
Reference Condition	7	2	3	None	None
Present State	5	1	4	2	Occurs
Limited Future Development	4	2	4	2*	Occurs
Moderate Future Development	3	2	4	3	Occurs
Bromberg Future Development	3	2	3	4	Less
Le Chasseur Future Development	2	2	3	5	None

* *Included the flow of 3.04 m^3/s in State 4 doe the value is just above the cut off and has a State 4 effect on the salinity distribution when seen in context*

SCENARIO	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Reference Condition	3	3	3	2	1	1	1	1	1	1	1	2
Present State	4	4	3	3	2	1	1	1	1	1	3	3
Limited Future Development	4	4	3	3	2	1	1	1	1	2	3	3
Moderate Future Development	4	4	4	3	3	2	1	1	1	2	3	3
Bromberg Future Development	4	4	4	3	3	2	1	1	1	2	3	4
Le Chasseur Future Development	4	4	4	3	4	3	2	1	1	2	3	3

8.3 Effects of Prolonged Low Flows under Different Scenarios

During the low flow periods (assumed to be the months when flows are less than 10 m^3/s) salinity distribution patterns in the estuary do not necessarily reach a steady state, but tend to progressively increase upstream until river flows increase towards the end of the low flow period. Figure 33 illustrates the progressive saline intrusion that occurs during the low flow period for the different scenarios, using both the median flows (assumed to be representative of normal flow periods) and the 10%ile flows (assumed to be representative of drought periods) obtained from the 64-year simulated run-off datasets. The duration of the low flow period for each of the scenarios is indicated on the figures. The net evaporation for the estuary was taken in consideration by subtracting the evaporation rate (m^3/s) for the month (refer to Table 2) from the simulated flow rate.

i. Reference Condition

Normal flows. The simulation was done for a 3-month period (January to March) and flows ranged between 10-20 m^3/s.

Droughts. The simulation was done for a 5-month period (December to April) with flow ranging between 3-10 m^3/s.

ii. Present State

Normal flows. The simulation was done for a 6-month period (November to April). The median flows varied between 3-10 m^3/s (4 months) and 0.5-3 m^3/s (2 months). The results show a significant further intrusion of salinities compared to the reference conditions.

Droughts. The simulation was done for a 9-month period (October to June) of which 2 months were within the 0.5 m^3/s flow range, 3months in the 0.5-3 m^3/s range and 4 months between 3-10 m^3/s. Much stronger saline intrusion is observed, usually when flows were <0.5 m^3/s.

iii. Limited Development Scenario

Normal flows. The simulation was done for a 6-month period (November to April). The median flows varied between 3-10 m^3/s (4 months) and 0.5-3 m^3/s (2 months). The results show a significant further intrusion of salinities compared to the reference conditions. This is similar to the Present Condition.

Droughts. The simulation was done for a 9-month period (October to June) of which 2 months were within the 0.5 m^3/s flow range, 3months in the 0.5-3 m^3/s range and 4 months between 3-10 m^3/s. This is similar to the Present Condition.

iv. Moderate Development Scenario

Normal flows. The simulation was done for a 7-month period (November to May) of which 3 months were within 0.5-3 m^3/s range and 4 months between 3-10 m^3/s.

Droughts. The simulation was done for a 10-month period (October to July) of which 4 months were within the 0.5 m^3/s flow range, 4 months in the 0.5-3 m^3/s range and 2 months between 3-10 m^3/s.

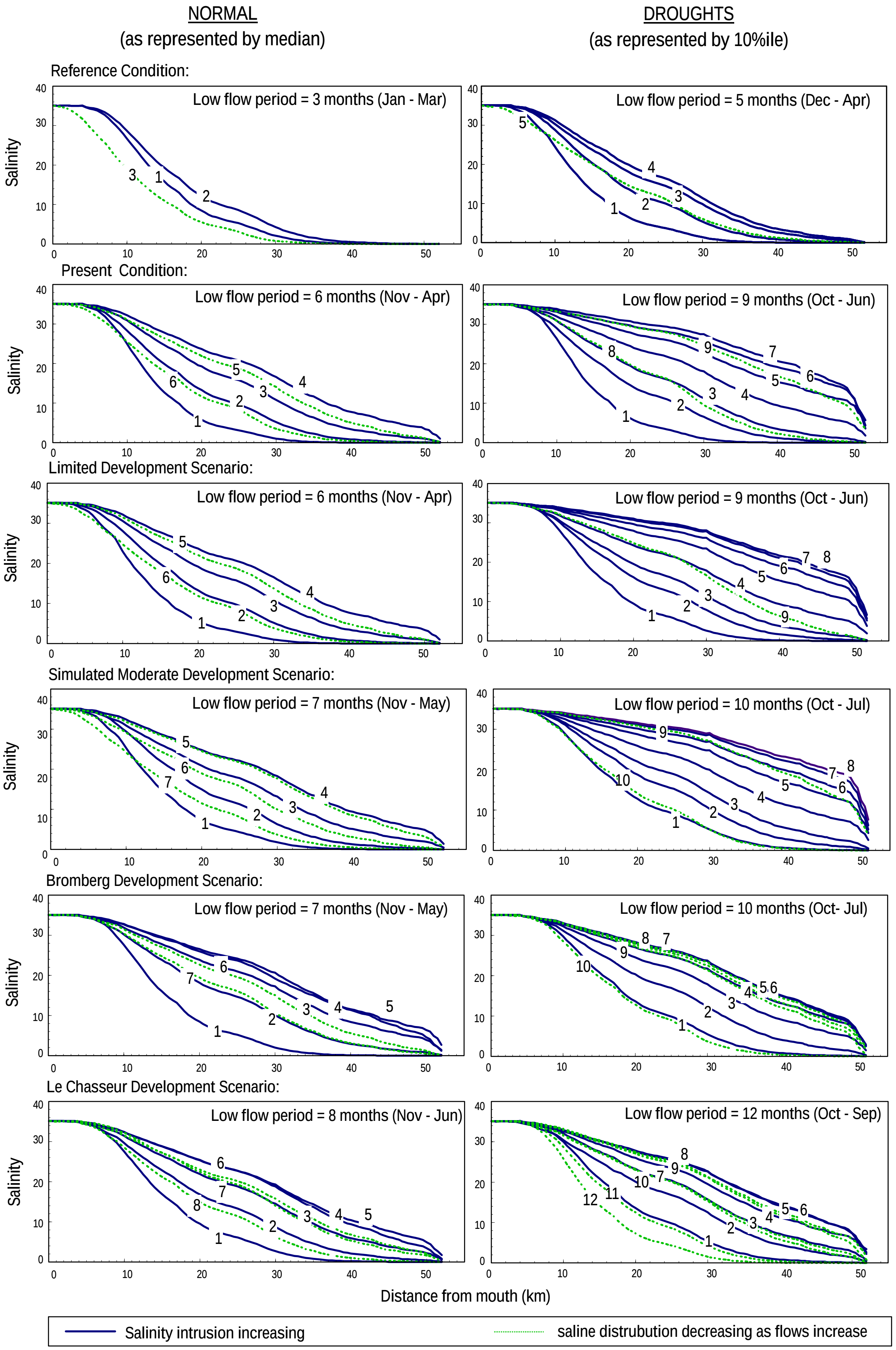


Figure 33. Progressive saline intrusion during the low flow periods (< 10 m^3/s) for the different scenarios (figure on lines indicate the number of months into the low flow period)

v. Bromberg Future Development Scenario

Normal flows. The simulation was done for a 7-month period (November to May) of which 4 months were within 0.5-3 m^3/s range and 3 months between 3-10 m^3/s.

Droughts. The simulation was done for a 10-month period (October to July) of which 8 months fall within the 0.5-3 m^3/s range and 2 months between 3-10 m^3/s.

vi. Le Chasseur Future Development Scenario

Normal flows. The simulation was done for a 8-month period (November to June) of which 3 months were within 0.5-3 m^3/s range and 5 months between 3-10 m^3/s.

Droughts. The simulation was done for a 12-month period of which 8 months fall within the 0.5-3 m^3/s range and 4 months between 3-10 m^3/s.

Noteworthy, is the fact that although the low flow period under the drought conditions, in the Le Chasseur Scenario (12 months) last longer in comparison with the Moderate Development Scenario (10 months), the maximum salinity penetration in the former is less due to the elevated base flows, i.e. flows seldom fall within the 0.5 m^3/s range.

A summary of predicted salinity distribution patterns in the estuary during the low flow period, for the different scenarios, are presented in Tables 12 to 14.

TABLE 12. A summary of the average, as well as the maximum distances (in km), at which certain salinities penetrate during the low flow period (< 10 m^3/s) for the different runoff scenarios

SALINITY (ppt)	DISTANCE FROM MOUTH (KM)		SALINITY (ppt)	DISTANCE FROM MOUTH (KM)	
	Average	Maximum		Average	Maximum
Reference Condition: Normal flows (median)			Droughts (10%ile)		
30	7	9	30	9	11
20	12	14	20	15	20
10	19	22	10	26	31
Present State: Normal flows (median)			Droughts (10%ile)		
30	9	12	30	11	22
20	16	26	20	25	42
10	28	37	10	39	None
Limited Future Development: Normal flows (median)			Droughts (10%ile)		
30	9	12	30	12	23
20	16	26	20	27	43
10	28	37	10	41	None
Moderate Future Development: Normal flows (median)			Droughts (10%ile)		
30	9	13	30	13	27
20	17	28	20	28	46
10	30	40	10	45	None
Bromberg Future Development: Normal flows (median)			Droughts (10%ile)		
30	11	14	30	12	17
20	20	31	20	27	34
10	34	44	10	40	47
Le Chasseur Future Development: Normal flows (median)			Droughts (10%ile)		
30	10	14	30	11	17
20	20	30	20	22	34
10	32	42	10	35	47

TABLE 13. A summary of the average and maximum salinities at the head of the estuary (about 52 km from the mouth) during the low flow period (< 10 m^3/s) for the different scenarios

SCENARIO	NORMAL FLOWS (MEDIAN) Salinities (ppt) at head of estuary		DROUGHTS (10%ile) Salinities (ppt) at head of estuary	
	Average	Maximum	Average	Maximum
Reference Condition	<1	<1	<1	<1
Present State	<1	~3	~2	~14
Limited Future Development	<1	~3	~2.5	~14
Moderate Future Development	<1	~4	~3	~17
Bromberg Future Development	<1	~5	~1.5	~7
Le Chasseur Future Development	<1	~5	~1	~6

TABLE 14. A summary of the average and maximum salinities at 12 km from the mouth during the low flow period (< 10 m^3/s) for the different scenarios

SCENARIO	NORMAL FLOWS (MEDIAN) Duration of specific saline conditions at a point 12 km from the mouth		DROUGHTS (10%Ile) Duration of specific saline conditions at a point 12 km from the mouth	
	Salinity (ppt)	Months	Salinity (ppt)	Months
Reference Condition	20	Move past with tide	20	3
	30	None	30	None
Present State	20	4 - 5	20	6 - 7
	30	None	30	6
Limited Future Development	20	4 - 5	20	7 - 8
	30	Few tidal cycles	30	4
Moderate Future Development	20	5	20	8
	30	Few tidal cycles	30	5 - 6
Bromberg Future Development	20	5 - 6	20	9
	30	2	30	6
Le Chasseur Future Development	30	7	30	10
	20	3	20	7

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Annexure C-1

Accumulated Areas and Volumes simulated for the Breede River Estuary

Accumulated area (m²) and accumulated volume (m³) for distance from the mouth for Breede River Estuary

The Mike 11 numerical model was used to calculate the volume of the estuary based on the 1996 bathymetry data set

DISTANCE FROM MOUTH (m)	AREA			MAXIMUIM VOLUME		MINIMUIM VOLUME	
	Width (m)	Area (m²)	Accumulated Area (m²)	Volume (m³)	Accumulated Volume (m³)	Volume (m³)	Accumulated Volume (m³)
1000	500	875000	875 000	2 534 497	2 500 000	769 685	800 000
2000	1250	1125000	2 000 000	2 995 602	5 500 000	1 031 432	1 800 000
3000	1000	880000	2 880 000	3 430 841	9 000 000	1 756 426	3 600 000
4000	760	595000	3 475 000	2 356 967	11 300 000	1 101 414	4 700 000
5000	430	540000	4 015 000	1 596 142	12 900 000	871 555	5 500 000
6000	650	475000	4 490 000	2 037 305	15 000 000	970 776	6 500 000
7000	300	290000	4 780 000	1 391 301	16 300 000	900 556	7 400 000
8000	280	440000	5 220 000	1 322 489	17 700 000	865 475	8 300 000
9000	600	505000	5 725 000	2 434 040	20 100 000	1 463 868	9 700 000
10000	410	415000	6 140 000	1 482 355	21 600 000	822 655	10 600 000
11000	420	440000	6 580 000	1 477 128	23 100 000	800 232	11 400 000
12000	460	485000	7 065 000	1 454 918	24 500 000	719 804	12 100 000
13000	510	455000	7 520 000	1 898 957	26 400 000	1 093 270	13 200 000
14000	400	365000	7 885 000	1 461 842	27 900 000	825 046	14 000 000
15000	330	340000	8 225 000	1 177 414	29 100 000	658 063	14 700 000
16000	350	250000	8 475 000	1 214 831	30 300 000	666 134	15 300 000
17000	150	235000	8 710 000	702 712	31 000 000	471 080	15 800 000
18000	320	220000	8 930 000	1 907 851	32 900 000	1 410 582	17 200 000
19000	120	180000	9 110 000	1 256 265	34 100 000	1 070 271	18 300 000
20000	240	240000	9 350 000	934 428	35 100 000	562 779	18 800 000
21000	240	180000	9 530 000	1 146 094	36 200 000	773 781	19 600 000
22000	120	120000	9 650 000	614 073	36 800 000	430 053	20 000 000
23000	120	120000	9 770 000	611 186	37 400 000	429 300	20 500 000
24000	120	130000	9 900 000	564 388	38 000 000	385 235	20 800 000
25000	140	145000	10 045 000	590 533	38 600 000	383 030	21 200 000
26000	150	165000	10 210 000	852 107	39 400 000	630 059	21 900 000
27000	180	155000	10 365 000	657 123	40 100 000	391 164	22 300 000
28000	130	135000	10 500 000	740 519	40 800 000	548 651	22 800 000
29000	140	200000	10 700 000	732 454	41 600 000	525 680	23 300 000
30000	260	210000	10 910 000	612 824	42 200 000	236 795	23 600 000
31000	160	150000	11 060 000	541 271	42 700 000	311 814	23 900 000
32000	140	145000	11 205 000	604 203	43 300 000	403 923	24 300 000
33000	150	180000	11 385 000	542 523	43 900 000	327 868	24 600 000
34000	210	165000	11 550 000	776 224	44 700 000	474 090	25 100 000
35000	120	145000	11 695 000	325 637	45 000 000	154 676	25 200 000
36000	170	150000	11 845 000	768 235	45 700 000	523 731	25 800 000
37000	130	125000	11 970 000	699 832	46 400 000	511 610	26 300 000
38000	120	170000	12 140 000	300 080	46 700 000	127 177	26 400 000
39000	220	185000	12 325 000	894 268	47 600 000	571 298	27 000 000
40000	150	120000	12 445 000	410 949	48 100 000	189 360	27 200 000
41000	90	120000	12 565 000	468 110	48 500 000	333 088	27 500 000
42000	150	150000	12 715 000	360 124	48 900 000	133 792	27 600 000
43000	150	57500	12 772 500	193 555	49 100 000	34 150	27 700 000
43500	80	55000	12 827 500	229 029	49 300 000	170 789	27 800 000
44000	140	140000	12 967 500	600 688	49 900 000	447 103	28 300 000
45000	140	125000	13 092 500	289 182	50 200 000	84 844	28 400 000
46000	110	47500	13 140 000	173 222	50 400 000	52 158	28 400 000
46500	80	52500	13 192 500	163 126	50 500 000	103 720	28 500 000
47000	130	125000	13 317 500	590 472	51 100 000	444 685	29 000 000
48000	120	120000	13 437 500	333 545	51 500 000	153 758	29 100 000
49000	120	120000	13 557 500	254 971	51 700 000	72 833	29 200 000
50000	120	120000	13 677 500	227 414	51 900 000	44 547	29 200 000

Annexure C-2

Raw Data

Breede River Estuary - 21 February 2000

TIME	Station	Depth	Salinity (ppt)	Temp °C	DO mg/L	NO3-N µg/L	NO2-N µg/L	NH3-N µg/L	PO4-P µg/L	SiO4-Si µg/L
13:29	Sea	0.00	35	24.5	6.9	<10	<10	15.8	13.1	175
13:34	2	4.10	29.66	23.15	6.8	27.8	<10	35.8	16.4	351
		3.00	29.59	23.15						
		2.50	29.31	22.99						
		2.00	28.91	22.91						
		1.50	28.9	22.91						
		1.00	28.91	22.91						
		0.50	28.93	22.91						
		0.00	28.91	22.91	6.7	29.2	<10	30.8	16.4	351
13:58	3	4.20	31.15	24.36	7.2	27.1	<10	26.7	11.5	395
		3.50	30.03	23.98						
		3.00	29.64	23.33						
		2.50	29.26	23.45						
		2.00	29.25	22.77						
		1.50	29.24	23.13						
		1.00	29.35	23.16						
		0.50	29.38	23.17						
		0.00	29.35	23.18	7.5	27.8	<10	26.7	17.2	368
14:26	5	5.10	27.56	23.42	6.6	40.3	<10	38.3	22.1	500
		4.50	27.74	23.42						
		4.00	27.6	23.42						
		3.50	27.65	23.43						
		3.00	27.5	23.41						
		2.50	27.5	23.35						
		2.00	27.45	23.37						
		1.50	27.43	23.33						
		1.00	27.36	23.36						
		0.50	27.4	23.37						
		0.00	27.4	23.41	6.6	42.4	<10	48.3	16.4	368
15:00	7	5.30	26.43	23.04	6.3	44.4	<10	42.5	23	404
		4.50	26.43	23.04						
		4.00	26.37	23.09						
		3.50	26.31	23.1						
		3.00	26.01	23.15						
		2.50	25.42	23.3						
		2.00	25.16	23.54						
		1.50	24.56	23.76						
		1.00	24.38	23.81						
		0.50	23.77	24.2						
		0.00	23.65	24.28	6.8	60.1	<10	42.5	23	412
15:21	9	4.30	23.32	23.67	6.1	43.1	<10	36.7	20.5	333
		3.50	23.41	23.62						
		3.00	23.4	23.62						
		2.50	23.4	23.61						
		2.00	23.41	23.62						
		1.50	23.42	23.63						
		1.00	23.42	23.62						
		0.50	23.42	23.62						
		0.00	23.41	23.61	6.4	50	<10	40	19.7	333
15:40	11	2.90	21.15	23.97	6.4	70.3	<10	43.3	26.2	491
		2.50	21.14	23.96						
		2.00	21.06	23.95						
		1.50	21.06	23.95						
		1.00	21.06	24.01						
		0.50	21.02	24.01						
		0.00	21.02	23.94	6.4	70.3	<10	48.3	20.5	566
15:57	13	3.60	18.33	24.19	6.4	79.7	<10	44.2	19.7	618
		3.00	18.33	24.2						
		2.50	18.3	24.19						
		2.00	18.23	24.2						
		1.50	17.92	24.27						
		1.00	17.75	24.37						
		0.50	17.67	24.37						
		0.00	17.66	24.37	6.5	87.8	<10	46.7	23	750
16:25	15	14.90	15.22	24.46	6.3	98.7	<10	58.3	23.8	842
		14.00	15.24	24.46						
		13.00	15.24	24.46						
		12.00	15.24	24.47						
		11.00	15.27	24.48						
		10.00	15.27	24.47	6.4	101.4	<10	57.9	19.7	711
		9.00	15.25	24.45						
		8.00	15.35	24.5						
		7.00	15.42	24.52						
		6.00	15.45	24.53						
		5.00	15.4	24.43						
		4.00	15.14	24.33						
		3.00	15.13	24.33						
		2.00	15.11	24.28						
		1.00	15.05	24.34						
		0.50	14.96	24.37						
		0.00	14.4	24.47	6.6	111.5	<10	54.6	23	618

TIME	Station	Depth	Salinity (ppt)	Temp °C	DO mg/L	NO3-N µg/L	NO2-N µg/L	NH3-N µg/L	PO4-P µg/L	SiO4-Si µg/L
17:00	17	8.80	14.18	24.42	6.5	94.6	<10	46.7	14.8	430
		8.00	14.19	24.43						
		7.00	14.21	24.44						
		6.00	14.23	24.44						
		5.00	14.24	24.44						
		4.00	14.25	24.44						
		3.00	14.23	24.44						
		2.00	14.21	24.45						
		1.50	14.15	24.44						
		1.00	14.1	24.44						
		0.50	14.05	24.44						
		0.00	13.63	24.45	6.5	94.6	<10	51.9	11.5	325
17:20	19	20.00	13.04	24.17	6.2	106.1	<10	42.5	11.5	491
		19.00	13.07	24.19						
		18.00	12.84	24.21						
		17.00	12.72	24.25						
		16.00	12.25	24.31						
		15.00	12.28	24.32						
		14.00	12.18	24.33						
		13.00	12.19	24.33						
		12.00	12.22	24.33						
		11.00	12.19	24.34						
		10.00	12.2	24.34						
		9.00	12.19	24.35						
		8.00	12.16	24.36						
		7.00	12.18	24.36						
		6.00	12.2	24.35						
		5.00	12.19	24.35						
		4.00	12.16	24.35						
		3.00	12.15	24.36						
		2.00	12.12	24.37						
		1.50	12.1	24.37						
		1.00	12.08	24.38						
		0.50	12	24.38						
		0.00	11.71	24.4	6.3	120.3	<10	45.8	20.5	386
17:45	21	2.50	10.57	24.38	6.2	121.6	<10	43.3	20.5	491
		2.00	10.57	24.39						
		1.50	10.58	24.39						
		1.00	10.58	24.39						
		0.50	10.59	24.39						
		0.00	10.56	24.39	6.3	104.1	<10	37.5	13.1	386
17:57	23	8.40	8.48	24.49	6.3	130.4	<10	37.1	19.7	421
		8.00	8.52	24.5						
		7.00	8.53	24.5						
		6.00	8.38	24.51						
		5.00	8.38	24.51						
		4.00	8.39	24.51						
		3.00	8.38	24.51						
		2.00	8.39	24.51						
		1.50	8.26	24.51						
		1.00	8.25	24.51						
		0.50	8.26	24.51						
		0.00	8.26	24.51	6.4	129.7	<10	37.5	18.9	412
18:15	25	14.00	6.13	24.61	6.5	124.4	<10	36.7	17.2	342
		13.00	6.12	24.61						
		12.00	6.16	24.61						
		11.00	6.16	24.62						
		10.00	6.18	24.62						
		9.00	6.21	24.62						
		8.00	6.2	24.62						
		7.00	6.22	24.62						
		6.00	6.2	24.62						
		5.00	6.2	24.62						
		4.00	6.2	24.62						
		3.00	6.2	24.62						
		2.00	6.2	24.62						
		1.50	6.2	24.62						
		1.00	6.08	24.62						
		0.50	6.1	24.63						
		0.00	6.07	24.62	6.3	125.6	<10	30.8	20.5	263
18:40	27	9.60	3.14	24.65	6.6	116.9	<10	35.8	15.6	272
		9.00	3.15	24.66						
		8.00	3.15	24.66						
		7.00	3.15	24.66						
		6.00	3.14	24.65						
		5.00	3.14	24.67						
		4.00	3.11	24.67						
		3.00	3.09	24.66						
		2.00	3.02	24.66						
		1.50	2.99	24.65						
		1.00	2.97	24.66						
		0.50	2.95	24.66						
		0.00	2.97	24.64	6.6	116.3	<10	33.8	14.8	202
18:55	29	3.10	1.41	24.65						
		2.50	1.5	24.65						
		2.00	1.5	24.65						
		1.50	1.48	24.65						
		1.00	1.46	24.65						
		0.50	1.44	24.65						
		0.00	1.35	24.63	6.6	96.9	<10	32.5	16.4	228

TIME	Station	Depth	Salinity (ppt)	Temp °C	DO mg/L	NO3-N µg/L	NO2-N µg/L	NH3-N µg/L	PO4-P µg/L	SiO4-Si µg/L
19:11	31	3.90	0.28	24.7						
		3.50	0.28	24.71						
		3.00	0.28	24.71						
		2.50	0.28	24.71						
		2.00	0.27	24.71						
		1.50	0.25	24.71						
		1.00	0.24	24.71						
		0.50	0.24	24.71						
		0.00	0.21	24.69	6.6	70	<10	34.2	14.8	254
19:23	33	2.40	0	24.84						
		2.00	0	24.85						
		1.50	0	24.84						
		1.00	0	24.84						
		0.50	0	24.84						
		0.00	0	24.82	6.7	57.5	<10	32.9	14.8	228

Breede River Estuary - 21 February 2000

Time	Station	Depth	Salinity (ppt)	Temp °C
12:20	2	3.20	27.57	22.68
		2.50	29.01	22.61
		2.00	29.01	22.61
		1.50	28.9	22.62
		1.00	28.9	22.63
		0.50	28.77	22.69
		0.00	28.7	22.7
12:27	3	3.40	27.97	22.8
		3.00	28.35	22.82
		2.50	28.33	22.84
		2.00	28.28	22.86
		1.50	28.2	22.86
		1.00	27.85	22.92
		0.50	27.66	22.95
		0.00	27.5	22.95
12:37	5	4.00	26.45	22.82
		3.50	25.72	22.93
		3.00	25.35	23.04
		2.50	24.54	23.22
		2.00	24.39	23.24
		1.50	24.16	23.26
		1.00	23.83	23.34
		0.50	23.72	23.36
		0.00	23.65	23.4
12:49	7	4.40	21.34	23.34
		4.00	21.36	23.35
		3.50	21.21	23.38
		3.00	20.99	23.41
		2.50	20.91	23.45
		2.00	20.74	23.51
		1.50	20.6	23.56
		1.00	20.54	23.59
		0.50	20.42	23.68
		0.00	20.38	23.69
12:58	9	3.30	18.93	23.82
		3.00	18.96	23.86
		2.50	18.89	23.86
		2.00	18.4	23.77
		1.50	18.38	23.78
		1.00	18.12	23.78
		0.50	18.07	23.79
		0.00	18.01	23.8
13:07	11	1.80	15.47	23.96
		1.50	15.44	24
		1.00	15.41	24.01
		0.50	15.38	24.02
		0.00	15.35	24.04
13:15	13	2.10	13.46	23.9
		1.50	13.36	23.92
		1.00	12.17	24.1
		1.25	12.84	23.96
		0.50	11.94	24.18
		0.25	11.9	24.18
		0.00	11.86	24.2

Time	Station	Depth	Salinity (ppt)	Temp °C
13:38	15	11.00	15.44	23.64
		10.00	14.51	23.72
		9.00	12.25	23.86
		8.00	11.15	23.99
		7.00	10.82	24.08
		6.00	10.77	24.1
		5.00	10.3	24.16
		4.00	9.2	24.28
		3.00	8.85	24.32
		2.00	8.72	24.31
		1.50	8.68	24.32
		1.00	8.67	24.32
		0.50	8.64	24.31
		0.00	8.59	24.36
13:50	17	6.50	12.59	23.84
		6.00	11.47	23.9
		5.00	10.36	24.02
		4.00	6.94	24.3
		4.50	8.11	24.22
		3.00	6.59	24.36
		3.00	6.37	24.4
		2.50	6.35	24.4
		2.00	6.31	24.4
		1.50	6.3	24.39
		1.00	6.23	24.37
		0.50	6.12	24.37
		0.00	5.72	24.74
14:02	19	20.10	15.49	23.85
		19.00	15.47	23.85
		18.00	15.46	23.85
		17.00	15.43	23.85
		16.00	15.27	23.84
		15.00	15.21	23.85
		14.00	13.82	23.92
		13.00	11.32	24.04
		12.00	8.23	24.26
		11.00	7.37	24.34
		10.00	6.97	24.38
		9.00	6.31	24.44
		8.00	5.89	24.49
		7.00	3.74	24.75
		6.00	3.64	24.77
		5.00	3.63	24.78
		4.00	3.63	24.78
		3.00	3.57	24.79
		2.00	3.56	24.8
		1.00	3.5	24.82
		0.50	3.47	24.86
		0.00	3.51	24.87
14:18	21	1.30	1.71	24.76
		1.00	1.63	24.82
		0.50	1.63	24.84
		0.00	1.6	24.92
14:26	23	6.00	0.36	24.69
		5.00	0.36	24.79
		4.00	0.33	24.77
		3.00	0.33	24.78
		2.00	0.33	24.78
		1.50	0.31	24.81
		1.00	0.3	24.84
		0.50	0.27	24.91
		0.00	0.27	24.95
14:34	25	12.00	0.03	24.83
		10.00	0.02	24.85
		8.00	0.02	24.86
		6.00	0.02	24.85
		4.00	0.02	24.82
		3.00	0	24.81
		2.00	0	24.81
		0.00	0	24.87
14:48	27	7.80	0	24.88
		4.00	0	24.9
		2.00	0	24.89
		0.00	0	25.02

Breede River Estuary - 23 August 2001

Time	Station	Depth	Salinity (ppt)	Temp °C	DO mg/l	NH3-N µg/L	NO3-N µg/L	NO2-N µg/L	PO4-P µg/L	SiO4-Si µg/L	SS mg/l
14:05	Sea	0	35	-	-	89	20	10	19	260	1.4
14:05	2	3.4	31.91	14.85	8.3	61	88	10	24	340	
		3	29.86	14.92							
		2.5	27.42	15.06							
		2	24.44	15.4							
		1.5	22.09	15.54							
		1	20.66	15.88							
		0.5	18.21	16.68							
		0	18.12	16.69	8.5	62	133	6	22	690	2.3
14:31	3	5.1	32.14	14.76	8.3	59	73	11	24	310	-
		4.5	27.53	15.06							
		4	22.57	15.29							
		3.5	22.47	15.29							
		3	21.63	15.39							
		2.5	21.15	15.42							
		2	20.41	15.68							
		1.5	20.41	15.8							
		1	20.4	15.89							
		0.5	17.31	16.58							
		0	16.58	16.71	8.8	54	154	5	21	590	3.0
14:53	5	7.1	32.36	14.88	7.8	61	87	11	24	300	
		6.5	30.4	14.81							
		6	29.68	14.81							
		5.5	28.5	14.82							
		5	27.59	14.87							
		4.5	27.19	14.88							
		4	25.91	14.96							
		3.5	24.33	15.04							
		3	22.72	15.14							
		2.5	20.89	15.34							
		2	19	15.55							
		1.5	17.88	15.65							
		1	13.15	16.62							
		0.5	12.44	16.7							
		0	12.4	16.71	8.7	46	177	5	18	760	2.7
15:20	7	5.5	24.12	14.91	8	70	120	9	24	460	
		5	23.99	14.92							
		4.5	23.02	15.06							
		4	22.9	15.07							
		3.5	20.81	15.28							
		3	20.14	15.36							
		2.5	17.76	15.45							
		2	14.71	15.62							
		1.5	11.86	16.39							
		1	9.51	16.84							
		0.5	9.4	16.87							
		0	9.39	16.88	8.7	29	201	5	16	800	3.3
15:47	9	8	26.15	15.27	7.7	95	110	10	28	430	
		7	25.87	15.27							
		6.5	23.65	15.28							
		6	21.59	15.3							
		5	19.88	15.36							
		4	19.6	15.37							
		3	17.49	15.48							
		2.5	14.41	15.7							
		2	12.47	15.79							
		1.5	9.81	16.21							
		1	8.72	16.72							
		0.5	8.55	16.75							
		0	8.54	16.77	8.9	31	204	5	18	930	3.4
16:10	11	2.8	15.6	15.66	8.1	46	194	4	22	800	
		2.5	11.06	15.85							
		2	7.75	16.92							
		1.5	6.38	16.99							
		1	6.36	17							
		0.5	6.35	17.01							
		0	6.34	17.01	8.7	25	244	5	19	890	3.7
16:28	13	2.1	7.9	15.91	8.5	29	235	5	19	930	
		1.5	4.71	16.9							
		1	3.87	16.65							
		0.5	3.81	16.64							
		0	3.8	16.63	8.4	40	258	4	18	920	5.3

Time	Station	Depth	Salinity (ppt)	Temp °C	DO mg/l	NH3-N µg/L	NO3-N µg/L	NO2-N µg/L	PO4-P µg/L	SiO4-Si µg/L	SS mg/l
16:49	15	15	10.07	15.65	8.2	44	198	4	21	900	
		13	10.06	15.65							
		11	9.89	15.65							
		9	9.63	15.64							
		7	8.41	15.64							
		6	6.82	15.67							
		5	5.81	15.74							
		4	4.8	15.83							
		3	2.92	15.99							
		2.5	2.05	16.35							
		2	2	16.47							
		1.5	1.88	16.42							
		1	1.52	16.42							
		0.5	1.5	16.43							
		0	1.49	16.43	8.3	19	272	5	16	930	5.9
17:15	17	8.8	7.4	15.65	8.1	33	210	5	19	920	
		7	6.72	15.65							
		6	5.87	15.68							
		5	4.83	15.72							
		4	4.13	15.79							
		3.5	3.09	15.99							
		3	1.18	16.16							
		2.5	0.75	16.27							
		2	0.52	16.38							
		1.5	0.49	16.38							
		1	0.48	16.36							
		0.5	0.48	16.37							
		0	0.47	16.37	8.5	19	281	3	19	930	6.4
17:41	19	21.1	4.34	15.71	8.2	40	228	4	18	980	
		19	4.32	15.69							
		17	4.2	15.68							
		15	4.16	15.68							
		13	4.06	15.68							
		11	3.94	15.69							
		9	2.71	15.84							
		7	1.16	16.09							
		5	0	16.33							
		3	0	16.35							
		2	0	16.35							
		1	0	16.34							
		0	0	16.33	8.5	13	290	4	16	870	4.0
18:02	21	2.4	0	16.25							
		2	0	16.27							
		1	0	16.27							
		0	0	16.26	8.7	21	290	3	15	810	2.7
18:30	27	0	0	16.57	8.6	17	300	3	15	800	2.6

Breede River Estuary - 24 August 2000

Station	Time	Depth	Salinity (ppt)	Temp °C
Sea	09:30	0.00	34.61	14.86
1	09:57	2.80	34.71	14.94
		2.00	34.71	14.94
		1.00	34.71	14.94
		0.00	34.21	14.95
2	10:04	4.50	34.07	14.94
		3.00	34.11	14.94
		2.00	33.95	14.93
		1.00	33.39	14.94
		0.05	33.02	14.96
		0.00	32.7	14.98
3	10:08	6.10	32.37	15.01
		5.00	32.4	15.04
		4.00	31.84	15.05
		3.00	31.54	15.09
		2.00	30.64	15.13
		1.00	29.51	15.2
		0.50	28.71	15.21
		0.00	25.02	15.38
5	10:17	8.20	32.22	15.31
		7.00	32.03	15.32
		6.50	30.81	15.36
		6.00	26.03	15.44
		5.50	21.9	15.48
		5.00	21.44	15.47
		4.00	21.07	15.46
		3.00	20.85	15.42
		2.50	20.75	15.42
		2.00	20.27	15.43
		1.50	19.69	15.45
		1.00	18.92	15.52
		0.50	17.15	15.66
		0.00	16.04	15.72

Station	Time	Depth	Salinity (ppt)	Temp °C
7	10:31	5.70	20.61	15.59
		4.00	19.4	15.61
		3.00	18.8	15.61
		2.00	17.52	15.63
		1.00	15.92	15.68
		0.50	14	15.74
		0.00	13.84	15.76
9	10:39	7.70	23.13	15.55
		7.00	23.09	15.56
		6.00	22.97	15.57
		5.00	22.8	15.57
		4.00	21.4	15.6
		3.50	19.66	15.62
		3.00	18.76	15.63
		2.00	17.3	15.65
		1.50	15.11	15.68
		1.00	12.63	15.72
		0.50	10.65	15.76
		0.00	9.44	15.9
11	10:51	3.70	18.58	15.65
		3.00	18.38	15.66
		2.50	18.36	15.67
		2.00	18.05	15.68
		1.50	17.68	15.73
		1.25	16.78	15.71
		1.00	15.08	15.74
		0.75	12.72	15.78
		0.50	9.02	15.94
		0.00	8.03	16.01
13	11:04	1.70	10.01	15.9
		1.50	10	15.89
		1.00	8.1	15.92
		0.75	6.28	16.07
		0.50	5.5	16.11
		0.00	5.37	16.14
15	11:24	14.80	9.96	15.98
		13.00	9.97	16
		11.00	9.95	16
		9.00	9.94	16
		7.00	9.8	16
		5.00	9.32	16.01
		4.00	8.51	16.01
		3.00	8.26	16
		2.50	7.74	16
		2.00	7.7	15.99
		1.50	7.01	15.98
		1.00	4.86	16.01
		0.50	4.04	16.23
		0.00	4.02	16.24
17	11:43	8.40	6.32	16.03
		7.00	6.12	16.03
		6.00	5.99	16.03
		5.00	5.78	16.04
		4.00	5.26	16.04
		3.00	4.77	16.04
		2.50	4.42	16.05
		2.00	4.22	16.06
		1.50	4.02	16.08
		1.00	3.38	16.14
		0.50	2.94	16.27
		0.00	2.68	16.35
19	11:52	23.80	4.44	16.13
		22.00	4.37	16.14
		20.00	4.15	16.12
		18.00	3.24	16.09
		16.00	3.16	16.09
		14.00	2.93	19.08
		12.00	2.88	16.07
		10.00	2.71	16.06
		8.00	2.61	16.06
		6.00	2.57	16.05
		5.00	2.37	16.05
		4.00	2.1	16.05
		3.00	1.96	16.07
		2.00	1.89	16.11
		1.00	1.72	16.16
		0.50	1.46	16.23
		0.00	1.45	16.23
21	12:01	3.00	1.18	16.09
		2.50	1.15	16.1
		2.00	1.06	16.13
		1.50	1.01	16.17
		1.00	0.92	16.23
		0.50	0.86	16.28
		0.00	0.86	16.3
23	12:09	13.70	0	16.17
		10.00	0	16.14
		6.00	0	16.14
		4.00	0	16.14
		2.00	0	16.15
		0.00	0	16.17

Annexure C-3

Monthly simulated runoff scenario
Tables

Table 1a: Simulated monthly flows of the Reference Conditions in m³/s to the Breede Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	19.73	22.34	8.78	5.66	3.73	22.73	9.87	2.93	135.91	55.15	60.61	68.53	34.66
1928	23.12	61.22	26.83	5.72	3.59	10.86	23.92	37.26	46.83	150.91	122.34	39.74	46.03
1929	21.77	12.70	17.27	10.18	47.11	26.03	9.70	7.70	8.61	24.44	79.66	128.36	32.79
1930	38.87	22.03	9.44	8.21	6.02	10.12	115.85	67.19	23.89	92.12	168.82	86.87	54.12
1931	90.67	33.50	46.62	18.97	51.02	10.75	4.54	45.06	58.20	91.00	50.01	185.25	57.13
1932	69.05	19.32	10.03	4.95	4.75	3.96	3.19	26.27	155.92	187.03	119.08	47.14	54.22
1933	26.92	20.98	10.36	8.87	9.87	9.30	4.58	27.26	39.00	49.53	81.50	83.79	31.00
1934	115.19	60.39	15.76	5.52	6.71	5.54	21.99	68.77	63.09	81.43	69.80	53.70	47.32
1935	23.66	28.12	11.39	8.31	4.95	4.18	3.11	29.97	19.35	75.89	99.90	73.92	31.90
1936	30.93	120.09	68.42	12.09	5.32	20.44	17.88	40.93	153.81	176.07	51.58	36.99	61.21
1937	23.51	17.42	16.66	14.69	4.44	11.42	33.27	57.76	37.05	47.46	64.26	73.60	33.46
1938	30.54	25.49	12.73	5.61	36.92	30.58	19.04	53.62	21.94	33.66	145.71	65.64	40.12
1939	21.38	13.61	7.90	4.39	43.01	20.64	45.86	30.73	83.84	53.20	32.91	36.49	32.83
1940	20.69	46.32	15.65	11.40	5.51	3.01	78.10	188.11	244.41	137.99	130.90	227.46	92.46
1941	76.04	31.44	12.56	11.47	6.12	3.22	3.56	89.87	321.08	60.20	84.25	30.67	60.87
1942	30.00	16.66	25.72	57.77	23.49	14.00	17.09	16.82	54.65	104.71	141.46	103.61	50.50
1943	42.35	65.69	23.83	5.65	3.36	6.76	8.43	77.85	227.57	83.16	128.04	101.65	64.53
1944	50.67	23.52	10.59	4.81	3.19	2.11	7.84	179.69	268.44	280.06	189.66	51.03	89.30
1945	108.49	47.15	10.19	4.97	3.65	45.50	22.52	15.71	15.09	31.51	55.19	130.41	40.86
1946	37.65	13.56	5.79	3.20	2.83	45.42	19.17	21.91	20.52	165.62	75.15	41.90	37.73
1947	33.10	20.29	8.96	5.58	3.83	17.76	16.38	43.95	40.24	101.77	41.34	139.32	39.38
1948	160.31	57.10	8.84	5.06	3.18	1.84	20.37	18.90	31.28	62.62	79.89	68.41	43.15
1949	41.06	168.89	54.37	5.38	3.10	1.87	43.76	8.76	12.31	183.48	36.93	93.20	54.43
1950	38.51	68.02	24.18	45.44	18.88	5.83	37.13	17.88	185.86	104.46	59.95	90.10	58.02
1951	40.22	31.74	9.49	5.11	5.25	3.57	4.88	63.62	46.00	101.60	215.58	173.85	58.41
1952	50.57	118.04	35.80	6.80	4.34	2.53	123.84	118.29	39.11	157.03	96.25	39.32	65.99
1953	36.96	33.03	13.01	5.52	3.72	4.75	30.24	244.07	141.82	344.42	303.16	89.37	104.17
1954	36.93	18.73	11.13	8.82	126.66	32.28	8.44	7.64	70.74	177.79	344.35	66.49	75.83
1955	63.94	31.16	10.69	5.71	4.44	8.06	6.52	54.95	141.96	114.33	128.42	45.30	51.29
1956	36.33	17.38	13.74	6.57	35.29	13.66	10.46	204.67	337.21	274.38	219.35	88.38	104.78
1957	120.01	35.43	9.87	4.61	8.12	12.81	11.04	180.72	94.14	25.70	111.47	41.38	54.61
1958	31.00	18.10	7.75	9.15	12.01	9.20	101.65	279.34	45.47	80.36	147.45	54.06	66.29
1959	79.13	28.66	9.23	6.31	3.95	6.63	8.13	41.73	119.09	39.09	26.30	27.96	33.02
1960	17.98	11.77	11.69	15.67	6.93	5.08	10.31	32.88	56.94	53.59	96.67	127.75	37.27
1961	39.43	17.12	7.52	6.42	8.23	17.23	28.70	14.77	292.12	110.65	565.61	151.01	104.90
1962	158.12	78.44	24.03	8.41	4.85	24.69	14.10	27.87	35.32	104.21	201.38	47.06	60.71
1963	27.38	22.46	14.73	10.20	17.29	22.97	14.44	17.49	161.64	97.07	139.65	55.90	50.10
1964	38.16	49.68	16.94	6.90	9.16	20.67	26.64	71.96	45.85	53.86	67.40	35.39	36.88
1965	59.37	43.79	19.17	10.58	5.28	16.40	13.03	16.60	68.24	122.79	147.29	81.59	50.34
1966	24.98	10.99	6.20	4.04	4.94	8.63	186.41	97.55	187.30	67.31	59.90	47.21	58.79
1967	44.23	25.30	10.62	5.68	3.38	2.52	15.50	97.22	131.30	137.72	120.83	39.35	52.80
1968	87.23	29.41	11.95	8.02	5.86	3.82	23.40	15.61	35.83	39.11	54.78	71.63	32.22
1969	57.54	15.29	7.03	5.47	9.69	5.17	3.31	31.73	95.62	103.69	143.02	69.54	45.59
1970	32.60	15.86	11.79	5.31	12.08	14.38	46.25	25.52	29.50	161.52	168.19	48.84	47.65
1971	19.92	31.58	11.39	5.52	8.79	5.44	11.80	54.90	51.62	34.33	63.91	50.75	29.16
1972	20.41	17.79	9.39	4.39	3.53	6.85	11.29	7.78	9.99	151.63	80.37	48.70	31.01
1973	25.76	14.85	15.19	8.26	28.33	10.27	6.17	39.42	101.19	54.34	744.54	142.30	99.22
1974	54.88	30.65	12.59	7.80	5.44	5.15	16.84	119.48	76.46	112.48	118.24	52.60	51.05
1975	33.94	21.06	12.64	5.65	7.16	12.08	14.52	23.06	269.10	160.31	68.46	38.19	55.51
1976	50.78	118.16	41.03	16.34	22.93	12.91	66.83	313.63	310.63	352.27	367.76	75.14	145.70
1977	37.47	28.82	22.73	10.77	5.73	5.55	22.42	27.42	15.51	18.51	104.53	67.73	30.60
1978	43.47	22.19	15.28	6.67	37.40	18.87	6.34	40.96	97.78	70.36	85.55	76.72	43.47
1979	63.45	24.16	9.22	11.26	6.32	3.98	15.86	40.47	54.92	47.81	58.83	37.04	31.11
1980	31.07	78.34	42.00	202.39	59.26	22.92	63.42	45.93	33.78	135.74	171.90	182.06	89.07
1981	39.33	19.28	17.79	10.16	7.01	13.07	187.95	77.60	67.42	67.48	57.68	60.03	52.07
1982	34.47	16.41	13.40	5.60	9.22	9.84	6.38	116.84	187.18	243.71	81.76	116.06	70.07
1983	43.08	21.29	11.03	5.73	8.97	34.54	14.16	242.00	63.74	137.79	60.39	177.01	68.31
1984	82.02	36.32	21.59	23.04	16.92	36.19	32.81	33.07	133.94	223.28	159.33	54.09	71.05
1985	66.23	63.96	34.80	12.75	6.18	9.44	29.12	40.46	89.82	121.51	338.19	127.49	78.33
1986	41.77	27.79	10.64	7.57	3.75	4.63	47.44	108.19	112.76	90.10	161.53	77.73	57.82
1987	36.42	14.15	15.50	4.31	4.15	7.99	42.81	43.13	77.95	66.40	96.05	99.87	42.39
1988	32.55	15.59	10.56	5.52	5.63	26.15	87.90	61.39	83.90	102.06	132.38	186.12	62.48
1989	82.30	68.18	15.11	6.42	12.76	9.42	89.20	88.32	132.30	183.66	85.89	35.47	67.42
1990	27.10	15.07	12.78	9.71	10.11	5.44	6.76	45.75	153.88	314.72	83.12	114.32	66.56
Median	38.34	25.40	12.61	6.62	6.15	9.64	16.97	42.43	73.60	101.91	98.29	69.04	53.46
Average	48.79	36.78	16.87	12.33	13.52	12.96	32.10	68.58	102.62	117.00	135.10	82.48	56.59
10%ile	22.18	14.92	8.80	4.85	3.54	3.32	5.27	15.64	20.94	39.10	54.90	37.38	32.39
90%ile	85.75	68.13	32.41	15.37	36.43	26.11	84.96	180.41	239.36	212.41	218.22	148.40	89.23

< 0.5	0	0	0	0	0	0	0	0	0	0	0	0
0.5 - 3.0	0	0	0	0	1	5	0	1	0	0	0	0
3.0 -10.0	0	0	15	46	45	28	18	4	2	0	0	0
10.0 - 20.0	3	21	35	14	7	16	18	8	4	1	0	0
> 20.0	61	43	14	4	11	15	28	51	58	63	64	64

Table 1b: Simulated monthly flows of the Present Conditions in m³/s to the Breede Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	1.97	7.90	2.79	1.09	0.49	13.20	3.46	0.00	49.57	10.97	21.10	27.42	11.66
1928	8.83	48.60	17.27	2.47	0.94	5.13	6.94	8.24	15.41	76.96	71.26	21.82	23.66
1929	9.39	3.98	7.66	4.46	31.13	18.52	4.14	2.67	2.05	6.46	35.94	56.80	15.27
1930	23.77	7.37	3.82	3.43	1.53	5.29	69.77	40.06	9.50	59.89	103.97	44.60	31.08
1931	65.64	17.58	34.48	11.63	32.69	4.28	0.87	11.75	21.45	32.98	21.88	141.31	33.04
1932	50.58	7.70	4.31	1.81	1.08	1.11	0.64	2.47	55.89	100.96	68.18	26.16	26.74
1933	11.30	9.68	4.27	4.97	3.68	3.96	1.12	1.25	8.81	20.18	41.55	42.20	12.75
1934	90.47	40.79	6.77	2.41	1.98	1.27	7.04	25.49	25.06	39.63	39.90	28.24	25.75
1935	11.37	11.53	4.83	2.52	0.99	0.48	0.16	3.20	3.75	20.31	42.44	42.64	12.02
1936	17.59	100.95	41.86	5.98	1.61	9.92	4.87	7.22	56.07	94.13	30.09	19.24	32.46
1937	8.82	7.07	9.24	6.54	0.96	6.73	14.23	28.25	13.24	20.83	29.00	31.62	14.71
1938	16.34	12.10	5.88	2.30	20.26	21.01	7.62	15.92	5.89	13.74	94.37	42.09	21.46
1939	9.19	3.81	2.75	0.60	26.00	12.05	14.22	5.07	25.28	20.87	14.02	15.73	12.47
1940	7.32	26.20	6.25	2.97	0.69	0.23	38.03	93.17	147.44	74.37	72.45	147.97	51.42
1941	53.97	14.74	4.78	6.23	1.79	0.84	0.54	40.64	194.92	35.77	47.88	15.31	34.78
1942	17.05	6.11	14.77	45.05	15.21	5.78	6.21	4.30	17.62	48.81	75.83	71.60	27.36
1943	25.46	47.88	12.71	3.00	0.67	2.38	1.99	40.31	113.46	39.01	79.69	74.76	36.78
1944	32.57	8.63	3.66	1.94	0.46	0.38	1.07	96.56	162.80	244.33	171.49	33.76	63.14
1945	91.49	30.17	4.21	2.53	0.75	32.71	13.36	2.54	3.32	8.58	18.81	60.08	22.38
1946	21.34	3.59	2.27	0.74	0.50	26.81	10.20	4.67	5.00	75.20	34.92	24.69	17.49
1947	18.25	8.28	3.99	2.38	0.79	8.67	6.34	15.10	13.73	46.79	18.14	67.58	17.50
1948	137.55	40.10	3.62	2.28	0.59	0.41	7.77	2.08	11.17	22.89	34.79	29.09	24.36
1949	25.33	139.12	35.64	2.69	1.13	0.41	18.23	0.33	0.29	75.82	18.77	39.47	29.77
1950	23.23	46.84	11.15	32.65	10.02	2.50	13.13	2.81	79.94	57.97	33.14	46.08	29.95
1951	22.19	10.99	3.14	1.90	1.04	0.63	0.63	24.73	16.16	44.33	134.15	112.72	31.05
1952	32.58	90.77	19.15	3.65	1.42	0.49	70.39	50.91	16.53	93.09	51.73	24.29	37.92
1953	24.64	18.01	5.59	2.35	0.55	0.96	12.80	137.59	79.19	240.18	260.56	69.56	71.00
1954	19.76	5.82	4.40	5.14	82.58	21.89	1.67	0.00	27.45	96.68	271.84	48.25	48.79
1955	46.28	12.24	3.77	2.72	0.75	3.96	2.04	20.33	57.98	60.96	88.40	22.49	26.83
1956	21.46	6.01	6.28	3.20	18.97	5.97	2.26	103.39	244.41	243.21	196.81	69.13	76.76
1957	101.20	18.72	4.29	2.65	1.90	6.61	3.87	121.34	58.19	12.80	56.73	23.35	34.30
1958	15.96	5.43	3.27	4.23	5.56	4.65	66.36	168.01	27.55	64.67	97.73	34.86	41.52
1959	61.51	13.75	3.91	3.06	0.91	2.16	1.92	16.28	49.00	17.20	12.95	11.62	16.19
1960	6.23	4.36	6.51	7.04	2.70	1.32	2.27	10.05	18.48	21.72	49.49	68.04	16.52
1961	23.78	6.02	3.13	2.48	2.45	9.96	9.41	0.51	165.70	63.70	436.68	123.60	70.62
1962	126.29	57.34	11.49	4.43	1.48	17.14	9.19	17.84	19.43	36.19	113.52	26.72	36.76
1963	16.10	9.76	5.62	5.36	6.32	15.77	6.89	1.37	80.09	47.70	82.17	32.27	25.78
1964	22.93	29.16	7.79	3.74	2.35	7.75	8.43	25.34	16.89	23.95	33.28	16.11	16.48
1965	43.81	28.68	8.28	5.10	1.57	1.38	1.37	1.28	18.05	55.49	98.62	52.86	26.37
1966	13.06	3.05	2.88	1.20	1.75	4.52	150.51	77.85	105.66	35.86	33.24	26.10	37.97
1967	28.44	9.43	4.27	2.83	0.54	0.63	4.38	43.76	59.12	76.23	71.93	21.12	26.89
1968	60.89	14.90	4.57	3.67	1.28	0.92	8.79	5.45	15.99	16.13	20.71	28.85	15.18
1969	34.29	4.15	2.40	1.60	3.68	1.21	0.00	3.46	38.75	42.37	79.90	37.19	20.75
1970	16.00	4.77	3.79	1.08	4.42	6.10	21.04	15.07	13.24	103.79	117.67	33.15	28.34
1971	8.74	17.88	6.34	2.41	3.61	2.24	5.43	14.40	18.87	14.73	36.50	27.75	13.24
1972	9.17	4.30	2.81	0.86	0.19	0.47	0.70	0.00	0.08	68.74	29.01	17.38	11.14
1973	12.41	4.49	5.65	2.35	19.99	7.77	0.81	21.36	44.13	19.24	577.55	110.25	68.83
1974	37.58	9.96	4.29	3.81	0.79	0.77	4.87	48.00	26.58	53.42	67.81	33.01	24.24
1975	20.37	6.67	3.55	1.71	1.89	5.91	9.34	5.82	166.97	90.58	38.35	20.38	30.96
1976	32.15	79.82	19.67	9.53	18.15	7.56	43.67	230.56	211.30	328.19	352.30	55.91	115.73
1977	21.98	11.86	8.38	4.14	0.95	0.76	10.04	13.40	4.87	10.38	46.40	38.33	14.29
1978	21.57	6.11	6.39	3.23	33.77	11.09	0.58	12.54	41.06	26.06	44.80	34.96	20.18
1979	40.50	6.28	3.50	5.00	1.54	0.61	4.63	9.81	15.34	14.46	19.17	16.51	11.45
1980	13.89	60.47	17.22	156.97	38.19	13.12	49.11	21.34	11.99	55.64	106.85	103.90	54.06
1981	24.02	6.96	6.73	4.73	1.13	5.43	165.79	66.80	29.86	26.01	31.38	36.90	33.81
1982	21.58	5.47	4.85	1.22	2.08	1.01	0.26	43.43	92.41	164.10	57.82	81.64	39.66
1983	26.40	8.16	4.49	2.01	1.49	20.11	3.88	131.02	30.17	76.48	34.99	143.86	40.26
1984	65.24	16.60	7.51	12.34	8.91	19.61	17.64	17.23	63.90	150.13	147.09	35.62	46.82
1985	52.95	39.01	10.12	4.70	1.75	2.97	8.61	17.43	22.90	59.60	310.62	112.13	53.57
1986	24.09	8.64	3.78	3.38	0.50	0.50	32.52	60.02	51.47	44.70	114.59	60.24	33.70
1987	17.83	3.16	5.31	1.50	0.52	1.65	16.33	21.37	36.85	30.14	41.07	67.18	20.24
1988	14.31	3.37	3.55	1.34	0.71	12.73	57.09	33.46	30.75	47.94	72.86	143.47	35.13
1989	73.75	38.83	5.53	3.01	3.38	2.04	80.05	48.54	67.41	120.34	61.94	15.61	43.37
1990	10.95	3.71	4.31	2.83	1.70	0.79	0.96	9.45	58.67	227.94	63.51	96.18	40.08
Median	22.56	9.72	4.84	2.99	1.59	4.12	6.91	16.10	27.50	47.82	57.28	37.05	29.06
Average	32.28	21.03	7.77	6.99	6.87	6.49	17.94	33.20	49.92	66.76	90.35	51.31	32.57
10%ile	9.18	4.03	3.13	1.26	0.54	0.49	0.66	1.31	5.27	14.54	20.83	17.94	13.56
90%ile	65.52	48.38	16.48	6.89	20.18	18.10	54.70	95.55	137.25	141.19	189.21	111.57	53.91

< 0.5	0	0	0	0	3	7	3	4	2	0	0	0
0.5 - 3.0	1	0	6	33	41	23	17	9	1	0	0	0
3.0 -10.0	8	34	46	26	8	20	22	11	7	2	0	0
10.0 - 20.0	16	13	9	2	5	9	10	12	16	9	6	8
> 20.0	39	17	3	3	7	5	12	28	38	53	58	56

Table 1c: Simulated monthly flows for the Limited Future Development Scenario in m³/s to the Breede Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	0.00	7.73	2.84	1.12	0.49	13.20	3.46	0.00	44.70	7.43	17.04	23.26	10.11
1928	4.63	48.60	17.34	2.55	0.94	5.13	6.83	4.39	11.26	72.28	66.80	17.90	21.56
1929	6.48	4.01	7.73	4.56	31.14	18.52	4.15	2.67	2.05	4.13	31.88	51.83	14.10
1930	18.38	7.37	3.88	3.44	1.53	5.29	69.58	36.04	7.19	56.35	99.37	40.39	29.07
1931	59.40	17.57	34.57	11.72	32.25	4.30	0.87	7.74	17.32	28.55	17.87	137.10	30.77
1932	46.12	7.70	4.36	1.91	1.08	1.11	0.65	0.19	48.64	94.50	63.67	22.06	24.33
1933	6.49	9.70	4.32	5.07	3.69	3.97	1.12	0.00	2.43	16.18	37.42	37.91	10.69
1934	84.32	40.79	6.83	2.50	1.98	1.28	6.94	21.42	21.16	35.09	35.88	24.08	23.52
1935	6.89	11.53	4.88	2.62	0.99	0.48	0.16	0.80	2.36	16.13	37.88	38.48	10.27
1936	12.59	100.96	41.86	6.06	1.61	9.95	4.80	3.18	48.89	89.17	26.08	16.00	30.10
1937	5.83	7.11	9.31	6.54	0.96	6.73	14.18	24.22	9.13	16.83	24.99	27.47	12.77
1938	11.25	12.12	5.93	2.39	20.25	21.02	7.62	11.91	3.53	10.08	89.85	37.93	19.49
1939	5.50	3.84	2.81	0.61	26.00	12.05	14.18	4.06	20.34	16.87	10.43	12.51	10.77
1940	3.54	25.88	6.31	2.99	0.69	0.23	37.87	85.99	139.19	69.74	67.84	129.65	47.49
1941	47.70	14.74	4.83	6.31	1.79	0.84	0.54	36.64	186.10	31.76	42.26	12.05	32.13
1942	13.74	6.15	14.83	45.18	15.22	5.80	6.21	4.30	13.48	44.30	71.16	67.44	25.65
1943	19.90	47.67	12.77	3.09	0.68	2.39	1.99	36.31	108.28	34.60	75.08	70.60	34.45
1944	26.80	8.63	3.71	2.04	0.46	0.38	1.05	92.12	154.01	211.66	150.79	29.56	56.77
1945	87.66	30.17	4.27	2.63	0.75	32.71	13.36	2.53	3.30	6.21	14.80	55.29	21.14
1946	15.04	3.58	2.33	0.75	0.50	26.81	10.22	4.67	4.98	69.90	30.81	20.94	15.88
1947	13.23	8.32	4.04	2.39	0.79	8.47	6.29	10.97	9.59	42.23	14.13	62.78	15.27
1948	131.02	40.10	3.67	2.38	0.59	0.41	7.74	1.40	6.17	18.89	30.26	24.94	22.30
1949	19.51	138.73	35.72	2.78	1.13	0.41	18.18	0.32	0.29	69.57	15.16	34.68	28.04
1950	17.91	46.42	11.21	32.66	10.03	2.50	13.03	1.29	72.67	53.45	29.13	41.92	27.68
1951	16.89	10.68	3.19	2.00	1.04	0.63	0.64	20.72	12.02	39.79	127.29	107.82	28.56
1952	27.04	90.35	19.21	3.73	1.43	0.49	70.25	46.29	12.39	88.44	47.47	20.61	35.64
1953	21.36	18.00	5.64	2.45	0.56	0.97	12.76	132.24	74.44	221.04	222.71	65.40	64.80
1954	14.43	5.82	4.46	5.24	82.11	21.91	1.64	0.00	23.30	90.02	252.65	44.09	45.47
1955	39.69	12.00	3.82	2.80	0.76	3.97	2.04	16.43	52.61	56.32	68.50	17.47	23.03
1956	17.49	6.02	6.35	3.30	18.69	5.97	2.24	96.11	232.99	234.56	188.65	62.85	72.93
1957	93.33	18.60	4.34	2.75	1.92	6.61	3.87	117.34	54.13	10.34	52.32	20.11	32.14
1958	11.67	5.43	3.32	4.30	5.57	4.65	66.27	159.49	23.40	61.84	93.25	30.92	39.18
1959	55.46	13.74	3.96	3.16	0.91	2.17	1.92	12.26	44.16	13.28	10.26	9.57	14.24
1960	5.19	4.37	6.56	7.05	2.70	1.33	2.27	7.70	12.92	17.72	44.92	63.24	14.66
1961	18.33	6.05	3.18	2.56	2.45	9.96	9.35	0.51	156.82	59.17	428.20	119.45	68.00
1962	118.29	57.33	11.56	4.52	1.49	17.14	9.20	17.85	15.44	31.49	107.15	22.53	34.50
1963	12.29	9.75	5.69	5.45	6.32	15.78	6.87	0.08	73.92	43.14	77.62	28.10	23.75
1964	17.97	28.70	7.85	3.83	2.29	7.53	8.34	20.94	12.97	20.78	29.47	13.29	14.50
1965	39.42	28.73	8.34	5.12	1.57	1.30	1.32	1.28	13.86	50.81	94.17	48.70	24.55
1966	8.54	3.07	2.94	1.27	1.77	4.52	150.46	75.94	100.33	31.86	29.23	21.97	35.99
1967	22.87	9.38	4.32	2.92	0.54	0.63	4.33	39.75	54.38	71.53	67.43	17.30	24.61
1968	53.56	14.11	4.60	3.82	1.28	0.92	8.73	4.38	14.43	13.60	16.00	22.06	13.12
1969	27.92	3.98	2.35	1.60	3.68	1.21	0.00	0.00	32.85	36.00	72.98	31.29	17.82
1970	10.99	4.09	3.37	1.15	4.44	5.97	20.62	14.01	9.10	98.18	113.92	30.36	26.35
1971	5.85	17.98	6.42	2.51	3.64	2.24	5.41	11.86	14.95	12.05	31.52	21.99	11.37
1972	5.39	4.30	2.81	0.86	0.19	0.26	0.70	0.00	0.03	63.98	24.96	13.27	9.73
1973	8.34	3.78	5.04	2.41	19.99	7.77	0.81	20.99	39.82	17.21	569.44	105.95	66.80
1974	31.08	9.68	3.81	3.76	0.81	0.77	4.82	43.58	21.42	48.32	62.82	31.14	21.83
1975	14.82	5.96	3.62	1.84	1.89	5.95	9.34	5.86	158.22	85.50	33.95	18.43	28.78
1976	28.78	79.38	19.34	6.69	17.63	7.22	43.09	222.07	201.68	284.62	343.61	49.85	108.66
1977	16.88	11.93	7.50	4.24	0.96	0.82	9.99	7.53	4.89	10.64	42.66	32.22	12.52
1978	17.27	5.49	6.48	3.29	33.77	11.09	0.58	10.85	37.10	21.74	40.88	31.57	18.34
1979	33.79	5.94	3.59	5.14	1.55	0.61	4.60	5.84	13.16	11.73	18.05	13.69	9.81
1980	10.58	60.06	16.96	156.44	37.52	13.12	49.06	20.91	8.54	51.75	103.50	95.98	52.04
1981	18.55	6.99	6.73	4.87	1.13	5.43	165.75	61.16	23.15	24.71	26.61	34.74	31.65
1982	16.05	5.15	4.62	1.19	2.07	1.01	0.26	40.11	85.07	139.39	49.25	58.96	33.59
1983	22.66	8.10	4.58	2.16	1.49	20.02	3.84	122.48	24.27	70.53	27.54	114.55	35.19
1984	57.84	15.24	7.53	12.43	8.97	19.36	17.59	12.61	62.95	141.70	130.57	29.04	42.98
1985	48.19	39.05	9.23	4.71	1.79	2.98	8.58	9.56	19.45	53.58	297.63	105.87	50.05
1986	19.95	8.62	3.87	3.53	0.50	0.52	32.50	52.70	46.56	38.90	100.59	52.99	30.10
1987	13.39	3.04	4.95	1.59	0.52	1.71	16.30	15.58	32.37	24.88	35.61	60.21	17.51
1988	9.77	3.45	3.63	1.46	0.71	12.60	57.01	30.13	27.41	44.65	72.29	127.37	32.54
1989	67.93	38.63	5.55	3.15	3.40	2.04	80.01	43.46	65.82	105.60	46.32	13.38	39.61
1990	8.07	3.54	4.17	2.93	1.70	0.79	0.65	3.39	50.01	216.53	55.34	82.86	35.83
Median	17.70	9.69	4.86	3.04	1.59	4.13	6.85	12.08	23.22	43.72	48.36	31.89	27.02
Average	27.37	20.87	7.75	7.01	6.83	6.47	17.89	29.96	45.32	60.53	83.72	45.75	29.95
10%ile	5.84	3.89	3.18	1.33	0.55	0.50	0.65	0.23	3.94	11.82	17.29	14.38	11.71
90%ile	58.93	48.32	16.32	6.64	20.18	18.11	54.62	90.28	129.92	129.26	177.29	105.93	51.44

< 0.5	1	0	0	0	3	7	3	8	2	0	0	0
0.5 - 3.0	0	0	6	32	41	23	17	7	3	0	0	0
3.0 -10.0	14	34	47	27	8	20	23	13	10	3	0	1
10.0 - 20.0	25	13	8	2	5	9	9	10	13	14	9	11
> 20.0	24	17	3	3	7	5	12	26	36	47	55	52

Table 1d: Simulated monthly flows for the Moderate Future Development Scenario in m³/s to the Breede Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	0.00	3.33	1.92	0.87	0.49	13.14	3.46	0.00	31.81	5.96	16.31	22.15	8.29
1928	3.00	47.79	15.35	2.08	0.83	3.95	2.74	0.18	1.12	69.42	65.72	16.72	19.07
1929	5.49	3.40	7.14	3.24	26.95	15.07	3.52	2.19	2.05	2.22	23.25	42.56	11.42
1930	14.70	6.04	3.26	3.25	1.53	5.29	65.08	29.55	3.07	53.37	95.20	39.31	26.64
1931	53.96	16.11	32.92	10.63	18.51	2.07	0.45	0.00	12.65	27.80	17.12	135.98	27.35
1932	44.20	6.14	3.61	1.37	1.08	1.08	0.43	0.13	32.02	92.38	62.75	20.88	22.17
1933	3.13	8.68	3.96	4.78	3.94	3.74	0.90	0.00	0.00	6.98	33.32	35.40	8.73
1934	79.56	37.76	5.29	1.92	1.87	1.13	3.38	13.88	18.26	29.84	35.18	22.98	20.92
1935	5.22	8.45	4.19	1.49	0.99	0.48	0.03	0.75	0.46	7.87	29.70	37.37	8.08
1936	9.69	99.54	33.73	5.04	1.44	5.48	1.89	0.00	37.04	87.56	25.30	14.80	26.79
1937	4.77	6.44	8.95	4.39	0.83	6.42	9.70	10.67	3.70	15.83	24.24	26.36	10.19
1938	7.16	9.72	5.15	1.99	15.30	19.14	6.20	2.35	0.83	6.11	85.42	36.80	16.35
1939	3.52	2.61	2.06	0.44	25.96	12.05	10.52	3.46	11.03	15.57	9.65	11.38	9.02
1940	1.61	17.73	6.04	2.81	0.69	0.23	32.38	76.76	134.07	68.08	66.66	120.69	43.98
1941	42.67	12.29	4.48	5.85	1.83	0.84	0.58	26.39	174.36	31.15	41.17	10.85	29.37
1942	12.25	5.60	14.48	44.31	15.41	5.37	5.90	2.62	6.90	36.56	69.40	66.35	23.76
1943	16.46	44.09	12.30	2.68	0.63	2.37	0.94	25.14	102.63	34.03	73.47	69.48	32.02
1944	22.71	5.78	3.09	1.47	0.45	0.38	0.21	81.93	143.36	203.55	137.14	28.35	52.37
1945	85.97	29.14	3.91	2.26	0.84	32.94	11.92	0.88	1.03	1.66	8.01	53.14	19.31
1946	9.62	2.60	1.94	0.66	0.50	22.46	8.56	1.81	2.42	55.34	30.08	19.75	12.98
1947	10.32	7.46	3.77	2.27	0.79	3.20	3.95	0.44	5.81	37.54	13.37	60.62	12.46
1948	125.30	38.16	3.29	1.86	0.58	0.41	5.84	1.40	0.25	7.81	28.86	23.83	19.80
1949	15.23	135.22	29.72	2.30	1.11	0.41	12.67	0.32	0.03	61.54	14.33	32.80	25.47
1950	14.80	42.64	10.53	31.84	10.00	2.50	7.01	0.17	67.60	52.43	28.39	40.80	25.73
1951	13.55	7.76	2.77	1.59	1.00	0.63	0.25	9.81	8.85	38.15	124.97	105.61	26.25
1952	23.52	86.87	18.52	3.45	1.48	0.49	57.36	44.55	11.83	86.85	46.79	19.40	33.42
1953	20.06	15.54	5.22	1.90	0.55	0.81	6.85	118.33	72.78	213.03	220.94	64.27	61.69
1954	10.79	4.53	3.45	4.56	78.87	22.00	1.11	0.00	13.14	85.39	241.52	42.92	42.36
1955	33.52	9.31	3.31	2.22	0.91	4.17	1.93	10.98	43.36	54.77	62.84	16.29	20.30
1956	14.64	5.61	5.93	3.00	12.38	5.44	1.77	85.82	216.61	194.40	162.48	61.72	64.15
1957	84.14	16.86	3.94	2.24	0.73	6.71	3.80	108.71	49.65	9.33	50.81	18.93	29.65
1958	8.10	4.22	3.01	4.14	5.82	4.75	59.62	143.87	22.79	61.17	91.96	29.75	36.60
1959	50.55	12.64	3.64	2.93	0.91	2.11	0.84	1.25	37.04	12.63	9.46	7.66	11.80
1960	1.81	3.59	5.88	6.87	2.67	1.32	2.27	7.25	4.56	13.87	43.28	61.06	12.87
1961	14.94	5.23	2.59	1.89	2.10	9.96	7.85	0.51	136.24	58.35	420.15	118.28	64.84
1962	109.04	53.60	11.06	4.21	1.76	17.42	9.25	16.79	11.45	22.19	103.11	21.37	31.77
1963	10.70	7.52	4.83	5.24	3.33	15.67	5.84	0.08	61.52	42.35	76.27	26.93	21.69
1964	14.44	25.21	6.98	2.46	1.78	2.12	3.26	13.99	12.40	20.18	28.71	12.12	11.97
1965	31.87	24.92	7.26	4.93	1.48	0.70	0.70	1.28	4.33	49.26	93.16	47.49	22.28
1966	7.88	2.79	2.54	1.04	1.71	4.52	142.57	68.11	92.78	31.25	28.05	20.82	33.67
1967	18.90	7.00	3.37	1.52	0.53	0.63	0.61	27.47	52.77	69.95	66.24	15.97	22.08
1968	45.29	13.14	4.03	2.05	1.26	0.92	4.94	0.00	5.08	6.93	15.29	20.69	9.97
1969	21.36	1.90	1.65	1.41	3.68	1.21	0.00	0.00	19.22	34.33	71.21	30.15	15.51
1970	7.71	2.91	2.67	0.92	4.36	5.86	19.51	10.68	5.02	86.71	111.33	28.93	23.88
1971	4.77	17.33	6.15	2.33	3.60	2.24	4.78	4.89	9.87	8.84	29.49	20.69	9.58
1972	2.47	4.30	2.74	0.85	0.19	0.26	0.70	0.00	0.03	49.76	24.23	12.16	8.14
1973	4.27	3.34	3.45	1.97	19.97	7.77	0.81	18.89	28.62	15.77	562.46	104.83	64.34
1974	25.38	8.04	3.43	3.17	0.97	0.90	3.01	31.14	19.45	46.66	61.44	29.49	19.42
1975	9.48	4.84	3.31	1.73	1.95	5.87	8.33	3.59	136.04	83.84	33.17	16.57	25.73
1976	26.93	75.32	14.74	4.58	17.63	7.33	34.78	211.60	194.17	273.95	312.29	48.70	101.83
1977	13.20	10.33	6.36	3.81	1.16	0.89	7.84	0.60	2.13	9.89	37.68	31.11	10.42
1978	13.81	4.73	5.95	3.11	33.77	11.09	0.58	5.45	29.21	20.99	40.10	30.55	16.61
1979	25.36	5.24	3.30	4.30	1.54	0.61	0.56	0.00	3.26	10.97	17.37	12.18	7.06
1980	7.41	52.28	12.76	150.61	37.60	13.12	48.13	20.22	7.40	48.29	101.75	93.88	49.45
1981	16.88	5.49	6.32	3.96	1.21	5.56	158.29	56.07	16.04	23.03	25.85	33.54	29.35
1982	10.40	3.44	2.48	0.85	1.96	1.01	0.26	29.89	81.49	136.50	48.46	55.41	31.01
1983	22.85	7.60	3.97	1.85	1.48	18.73	3.08	101.83	23.60	69.41	26.79	104.13	32.11
1984	51.74	14.17	4.82	10.44	8.56	14.87	13.20	8.42	60.48	136.99	119.62	25.54	39.07
1985	49.06	36.62	8.84	4.39	1.99	2.43	4.78	0.17	16.01	51.93	283.60	100.65	46.71
1986	19.91	8.08	3.59	1.93	0.50	0.50	30.35	42.11	42.73	38.19	93.33	47.11	27.36
1987	10.72	2.67	3.54	1.25	0.51	1.63	11.41	3.22	27.41	24.30	33.80	59.10	14.96
1988	7.40	2.72	2.98	1.11	0.71	6.25	51.46	23.42	22.63	43.04	70.98	125.80	29.88
1989	63.72	36.01	5.23	2.75	3.31	2.04	64.13	41.90	64.26	103.85	45.55	12.19	37.08
1990	7.14	3.26	3.47	2.50	1.68	0.79	0.28	0.00	36.28	208.64	54.57	70.03	32.39
Median	14.54	7.90	4.00	2.39	1.54	2.85	4.36	5.17	18.74	40.27	47.63	30.83	24.68
Average	23.86	18.96	6.74	6.34	6.25	5.80	15.24	24.28	38.98	56.35	80.08	43.65	27.21
10%ile	3.74	3.02	2.62	1.06	0.53	0.49	0.44	0.00	1.06	7.83	16.55	12.97	9.70
90%ile	53.29	46.68	13.96	5.67	18.25	15.49	50.46	80.38	124.64	126.71	154.87	103.08	48.63

< 0.5	1	0	0	1	3	7	8	17	5	0	0	0
0.5 - 3.0	4	7	11	37	41	25	16	11	6	2	0	0
3.0 -10.0	17	31	42	21	9	19	23	8	12	9	3	1
10.0 - 20.0	19	10	8	2	6	10	6	7	11	6	6	14
> 20.0	23	16	3	3	5	3	11	21	30	47	55	49

Table 1e: Simulated monthly flows for the Bromberg Future Development Scenario in m³/s to the Breede Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	1.50	2.64	1.50	1.50	1.50	12.57	3.32	0.12	31.63	5.95	15.46	19.91	8.13
1928	2.58	47.00	14.17	1.50	0.87	3.39	2.45	0.66	0.83	69.33	62.02	13.57	18.20
1929	4.69	2.56	5.45	1.84	26.24	13.84	3.05	2.00	2.01	2.21	18.83	33.69	9.70
1930	9.31	4.31	1.57	1.80	1.50	4.72	50.26	23.68	2.11	40.11	85.89	34.44	21.64
1931	39.75	10.78	28.97	8.33	16.82	1.50	1.50	1.50	12.83	28.79	16.65	121.41	24.07
1932	39.02	4.85	2.01	1.50	1.50	1.50	1.50	1.50	31.40	86.66	56.35	16.39	20.35
1933	1.94	7.66	2.66	3.63	3.26	3.16	1.50	1.50	1.50	7.68	29.20	30.34	7.83
1934	75.07	35.39	3.54	1.50	1.50	1.16	2.44	10.57	15.69	26.69	32.34	20.70	18.88
1935	4.03	7.36	2.81	1.50	1.10	0.46	0.07	0.93	0.62	5.89	25.57	32.53	6.91
1936	7.32	82.64	27.24	2.93	1.50	4.92	1.83	1.50	37.56	84.73	21.74	12.35	23.85
1937	3.99	5.56	7.42	3.10	0.94	4.05	8.26	8.99	4.32	14.09	20.07	20.41	8.43
1938	3.25	8.25	3.59	1.50	12.43	17.39	5.55	1.39	0.85	6.04	77.08	31.31	14.05
1939	3.22	1.87	1.50	1.35	24.51	11.22	7.79	1.50	11.62	12.08	7.32	9.54	7.79
1940	1.50	13.25	4.05	1.50	0.68	0.19	27.53	74.47	127.76	61.18	58.63	111.25	40.17
1941	34.52	9.23	2.74	4.21	1.50	1.50	1.50	22.87	162.00	25.06	25.12	6.92	24.76
1942	8.04	4.12	12.21	36.41	12.90	4.31	5.24	1.50	7.41	37.43	65.76	62.15	21.46
1943	14.31	36.63	9.39	1.50	1.50	1.93	1.50	24.78	98.45	29.43	56.87	56.49	27.73
1944	19.48	4.56	1.65	1.50	1.50	1.50	1.50	71.86	130.29	193.36	137.05	26.66	49.24
1945	83.50	23.84	2.29	1.50	1.50	29.55	10.54	1.50	1.50	2.60	9.36	54.04	18.48
1946	9.49	1.82	1.50	1.50	1.50	17.83	7.09	1.50	2.56	52.85	25.83	16.70	11.68
1947	8.84	6.42	2.27	1.50	0.87	2.50	3.61	0.84	5.41	37.55	12.49	57.02	11.61
1948	99.95	29.51	1.81	1.50	1.50	1.50	4.56	1.50	1.50	8.53	28.72	22.24	16.90
1949	14.05	104.12	20.71	1.50	1.50	1.50	12.05	1.50	1.50	60.66	11.39	30.70	21.76
1950	12.25	33.22	7.15	25.00	7.84	1.91	6.62	1.50	63.86	46.91	25.13	28.43	21.65
1951	7.90	6.40	1.50	1.50	1.50	1.50	1.50	9.01	9.17	38.15	115.44	92.27	23.82
1952	17.16	63.36	11.90	1.73	1.50	1.50	52.80	43.27	12.39	83.87	42.90	16.53	29.07
1953	18.81	13.49	3.67	1.50	1.50	1.50	6.20	101.99	61.65	195.61	216.19	62.57	57.06
1954	7.42	3.49	2.03	3.31	61.37	16.02	1.50	1.50	13.49	78.61	239.51	41.30	39.13
1955	30.44	7.63	1.79	1.50	1.50	3.51	1.70	8.97	41.47	48.87	57.16	11.52	18.00
1956	12.51	4.60	4.42	1.54	11.71	4.27	1.50	71.80	195.22	194.57	162.54	60.37	60.42
1957	81.49	11.50	2.12	1.50	1.50	5.32	3.10	89.61	45.81	8.96	50.91	17.20	26.59
1958	6.69	3.19	1.67	2.99	5.06	4.02	51.18	135.53	17.28	54.93	92.06	28.11	33.56
1959	47.58	10.69	2.06	1.56	1.50	1.63	1.50	1.50	37.54	11.59	7.29	6.29	10.89
1960	1.75	2.89	4.67	5.47	1.87	1.50	1.87	5.75	5.06	12.82	40.03	53.81	11.46
1961	10.35	3.91	1.50	1.50	1.50	8.92	6.71	1.50	131.73	53.64	370.18	116.55	59.00
1962	106.29	49.09	6.17	2.38	1.50	16.83	8.94	16.32	12.02	23.07	100.72	19.17	30.21
1963	9.27	6.22	3.15	3.79	2.65	11.68	4.22	1.50	56.79	36.99	70.41	21.65	19.03
1964	12.07	21.90	5.00	1.50	1.50	1.50	2.73	12.84	13.03	16.45	24.23	8.79	10.13
1965	24.59	20.00	5.08	3.02	1.50	1.50	1.50	1.50	4.67	50.26	67.55	34.83	18.00
1966	5.19	2.07	1.50	1.50	1.50	3.95	122.42	56.24	86.06	25.94	25.37	19.33	29.25
1967	15.68	5.67	1.77	1.50	1.50	1.50	1.50	26.08	44.32	65.95	58.08	11.01	19.55
1968	42.58	8.15	2.63	1.50	1.50	1.50	3.47	1.50	4.75	5.16	15.75	17.80	8.86
1969	18.44	1.50	1.50	1.50	2.58	1.50	1.49	0.08	19.17	34.33	65.77	26.03	14.49
1970	5.15	2.25	1.50	1.04	3.79	5.34	18.84	10.06	5.03	73.88	94.12	23.78	20.40
1971	5.20	13.14	4.56	1.50	3.05	2.00	4.64	4.39	8.54	7.27	22.31	17.97	7.88
1972	2.29	3.02	1.50	1.50	1.50	0.21	0.88	0.12	0.00	49.60	24.23	12.13	8.08
1973	4.18	2.85	2.40	1.50	19.26	7.23	1.06	17.93	29.05	15.75	525.43	90.65	59.77
1974	21.33	5.80	2.06	1.74	1.50	1.50	2.79	31.18	19.68	42.49	57.58	17.98	17.14
1975	9.87	3.63	1.95	1.50	1.51	4.72	7.97	1.94	123.31	77.35	20.79	11.40	22.16
1976	14.69	69.92	11.93	2.89	16.42	6.41	29.55	198.22	190.64	274.19	312.23	47.09	97.85
1977	9.79	7.86	4.53	1.94	1.50	1.50	6.12	1.50	2.56	9.29	30.83	23.83	8.44
1978	6.55	2.93	4.36	1.57	27.54	8.61	1.50	3.19	29.80	21.71	32.96	25.76	13.87
1979	21.88	3.27	1.88	3.03	1.50	1.50	1.50	1.50	3.85	9.13	18.30	8.36	6.31
1980	5.19	50.92	10.07	127.61	27.36	10.34	43.32	17.37	4.76	45.31	91.68	81.53	42.95
1981	13.63	4.63	4.18	1.82	1.50	5.08	140.79	49.93	12.76	22.86	25.55	32.03	26.23
1982	9.15	2.76	1.50	1.50	1.55	1.50	1.50	28.50	81.99	121.85	39.79	48.00	28.30
1983	16.80	6.17	2.61	1.50	1.50	18.02	2.79	99.48	20.54	68.70	25.46	85.98	29.13
1984	41.98	10.41	3.04	8.25	6.60	13.48	12.31	6.98	61.04	117.95	119.29	23.84	35.43
1985	46.35	31.54	6.88	2.67	1.50	1.75	4.00	1.50	16.44	52.93	259.51	99.09	43.68
1986	16.78	6.43	2.12	1.50	1.50	1.50	26.98	40.53	43.23	39.07	81.15	34.27	24.59
1987	7.17	2.11	2.21	1.50	1.50	1.50	8.27	1.99	27.94	23.88	29.12	55.70	13.57
1988	4.17	2.27	1.73	1.50	1.50	3.84	34.08	19.34	14.28	37.94	68.29	109.10	24.84
1989	60.91	30.91	3.38	1.50	2.50	1.50	60.44	38.20	63.92	97.80	36.22	10.51	33.98
1990	4.26	2.80	2.08	1.63	1.50	1.50	1.50	1.50	35.58	183.36	47.18	68.44	29.28
Median	10.11	6.41	2.64	1.50	1.50	2.25	3.54	3.79	16.07	38.05	41.46	27.39	21.55
Average	20.39	15.61	4.82	4.99	5.58	5.20	13.40	22.21	36.90	52.78	73.58	38.46	24.49
10%ile	3.23	2.36	1.50	1.50	1.50	1.50	1.50	1.42	1.50	7.39	16.02	11.12	8.22
90%ile	47.21	43.89	11.35	4.09	16.70	13.73	40.55	71.84	115.85	111.90	154.89	89.25	43.46

< 0.5	0	0	0	0	0	3	1	3	1	0	0	0
0.5 - 3.0	6	14	35	51	47	30	27	28	11	2	0	0
3.0 -10.0	26	27	21	10	6	19	21	7	11	10	3	5
10.0 - 20.0	15	8	5	0	6	11	4	7	13	6	7	17
> 20.0	17	15	3	3	5	1	11	19	28	46	54	42

Table 1f: Simulated monthly flows for the Le Chasseur Future Development Scenario in m³/s to the Breede Estuary

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1927	1.50	2.12	1.78	1.50	1.50	13.12	3.46	0.13	1.50	3.09	7.03	12.00	4.06
1928	3.10	44.80	15.35	2.08	1.50	4.53	1.59	1.46	1.50	28.71	28.21	14.18	12.25
1929	4.86	2.43	6.31	3.00	25.51	14.75	3.52	2.30	2.05	2.22	23.41	22.00	9.36
1930	14.12	5.34	3.23	3.12	1.53	5.29	54.52	21.77	4.72	44.67	28.61	13.94	16.74
1931	40.63	13.06	32.35	10.60	3.61	2.02	1.50	1.50	1.50	6.41	7.84	123.33	20.36
1932	41.75	6.30	3.63	1.50	1.50	1.50	1.50	1.50	1.50	12.49	31.38	21.70	10.52
1933	2.88	7.92	3.48	4.10	3.66	3.56	1.50	1.50	1.50	8.71	24.23	16.49	6.63
1934	55.55	29.83	5.45	1.94	1.87	1.50	3.35	13.13	15.22	11.56	10.87	11.05	13.44
1935	4.95	8.72	4.23	1.51	1.50	1.50	1.50	1.11	1.50	7.01	12.42	18.46	5.37
1936	7.83	92.88	33.48	5.03	1.50	5.48	1.89	1.50	1.50	9.80	10.81	12.03	15.31
1937	3.57	5.36	8.05	3.49	1.50	6.59	7.89	2.50	3.74	9.90	12.92	14.11	6.63
1938	8.57	9.98	5.23	1.99	14.88	19.17	6.20	1.50	1.50	6.26	56.86	26.11	13.19
1939	3.27	2.63	2.06	1.50	25.96	12.05	7.90	3.08	2.43	9.73	8.11	9.97	7.39
1940	2.41	17.96	6.10	2.95	1.50	1.03	19.26	16.10	41.90	71.68	69.87	121.97	31.06
1941	37.57	9.22	3.73	5.12	1.70	1.50	1.50	10.85	115.42	34.31	44.30	11.68	23.07
1942	11.55	4.88	12.61	40.45	14.57	3.35	3.40	1.50	1.50	4.17	43.00	67.79	17.40
1943	11.06	38.59	11.36	2.40	1.50	2.36	1.50	18.81	26.04	37.17	76.96	70.59	24.86
1944	19.96	4.52	2.66	1.50	1.50	1.50	1.50	48.54	84.93	207.72	140.65	29.28	45.35
1945	81.46	25.11	3.22	1.68	1.50	32.11	11.37	1.50	1.50	3.82	4.66	4.45	14.36
1946	2.09	1.95	1.61	1.50	1.50	24.18	9.27	2.57	2.43	22.29	15.92	18.88	8.68
1947	10.62	6.88	3.49	2.12	1.50	3.20	3.95	1.50	1.50	4.54	7.17	10.49	4.75
1948	111.65	35.49	2.79	1.78	1.50	1.50	5.92	1.50	1.50	3.03	6.41	6.34	14.95
1949	3.60	118.32	31.02	2.30	1.50	1.50	1.60	1.50	1.50	11.24	12.26	7.76	16.17
1950	10.68	30.79	9.25	28.53	10.22	2.58	1.78	1.50	8.20	21.13	14.56	28.91	14.01
1951	12.00	3.09	2.38	1.50	1.50	1.50	1.50	1.50	1.50	2.43	85.33	106.85	18.42
1952	20.72	70.54	15.26	2.90	1.50	1.50	8.73	26.35	15.15	90.54	49.79	20.21	26.93
1953	19.29	13.40	4.69	1.78	1.50	1.50	3.47	54.20	46.44	217.03	224.45	65.20	54.41
1954	7.78	3.76	2.76	3.78	61.19	19.09	1.50	1.50	2.87	38.03	245.27	43.76	35.94
1955	28.25	4.76	2.70	1.50	1.50	3.81	1.70	10.79	13.59	17.55	66.04	17.13	14.11
1956	14.88	4.96	5.16	2.24	5.01	4.77	1.50	43.04	188.80	198.14	165.93	62.79	58.10
1957	78.79	13.88	3.30	1.65	1.50	6.44	3.48	100.56	48.68	10.45	39.32	18.73	27.23
1958	6.80	3.62	2.62	3.80	5.53	4.65	42.49	33.55	25.94	64.56	95.22	30.54	26.61
1959	45.84	11.08	3.15	2.40	1.50	2.11	1.50	1.50	3.51	9.26	9.70	8.92	8.37
1960	2.76	3.62	5.95	6.88	2.67	1.74	2.59	7.83	5.66	9.03	20.66	22.09	7.62
1961	11.76	4.39	2.56	1.74	2.10	9.96	7.71	1.50	10.13	21.77	424.48	119.03	51.43
1962	104.39	46.93	9.71	3.43	1.50	17.14	8.90	17.10	10.88	11.96	51.55	22.15	25.47
1963	9.48	5.63	3.99	4.67	2.73	15.67	5.84	1.50	32.10	21.30	45.24	27.93	14.67
1964	9.23	17.99	5.42	2.28	1.76	2.12	1.96	9.22	6.55	15.58	14.72	9.43	8.02
1965	36.24	25.71	7.26	5.03	1.50	1.50	1.50	1.50	1.50	3.88	81.75	42.26	17.47
1966	7.46	2.20	2.21	1.50	1.71	4.50	137.25	68.27	22.93	17.85	18.54	18.47	25.24
1967	12.19	5.65	3.37	1.50	1.50	1.50	1.50	1.74	23.71	14.51	33.75	16.83	9.81
1968	40.24	10.20	3.47	1.54	1.50	1.50	4.96	1.50	7.96	9.34	6.57	8.78	8.13
1969	5.33	1.92	1.65	1.50	3.68	1.50	1.50	1.50	1.50	2.35	23.68	13.56	4.97
1970	5.74	2.05	2.05	1.50	4.30	5.86	19.81	11.34	6.11	70.03	74.21	24.87	18.99
1971	3.95	16.39	5.77	2.16	3.60	2.24	5.04	4.37	6.88	9.11	23.50	14.93	8.16
1972	3.67	4.37	2.82	1.50	1.33	1.34	1.47	1.18	1.50	1.50	6.30	4.89	2.65
1973	1.79	2.54	2.85	1.80	20.04	7.79	1.50	20.35	12.29	4.74	435.65	105.73	51.42
1974	20.27	4.30	2.42	1.91	1.50	1.50	1.50	1.50	7.06	23.16	64.70	30.27	13.34
1975	4.65	3.99	2.86	1.50	1.82	5.87	8.48	3.98	52.26	87.27	36.19	17.44	18.86
1976	26.26	56.90	5.50	2.60	16.47	6.77	23.45	169.31	197.85	278.06	315.92	49.54	95.72
1977	10.36	8.54	5.08	2.67	1.50	1.50	5.81	1.50	1.50	9.45	22.86	18.20	7.41
1978	12.74	4.10	5.42	2.72	33.75	11.09	1.50	5.01	4.89	10.89	22.24	16.99	10.94
1979	9.47	4.40	2.91	3.81	1.54	1.50	1.50	1.50	1.50	6.71	6.49	12.38	4.48
1980	7.47	22.69	9.95	90.31	37.44	13.61	48.32	21.00	8.19	17.93	52.86	78.54	34.03
1981	14.06	3.30	5.70	3.14	1.50	5.43	142.05	51.11	13.41	16.64	11.81	34.15	25.19
1982	9.88	3.55	2.51	1.50	1.99	1.50	1.50	1.50	9.42	106.70	51.39	56.51	20.66
1983	21.72	6.75	3.46	1.50	1.50	4.92	2.00	35.85	26.90	72.84	29.71	105.77	26.08
1984	46.80	4.81	3.61	8.33	7.58	2.70	9.77	1.50	20.06	140.94	122.96	26.55	32.97
1985	45.56	33.76	7.68	3.66	1.50	1.87	1.50	1.50	1.50	1.50	285.36	101.70	40.59
1986	18.53	7.02	3.11	1.50	1.50	1.50	28.99	14.85	5.91	25.68	96.92	48.09	21.13
1987	8.28	2.01	2.79	1.50	1.50	1.63	8.94	1.96	3.47	7.45	15.72	46.51	8.48
1988	6.57	2.09	2.89	1.50	1.50	6.24	47.39	15.88	16.00	15.67	25.31	127.18	22.35
1989	58.58	32.07	4.67	2.16	2.93	2.04	43.01	24.00	29.62	107.57	48.44	12.94	30.67
1990	7.41	2.85	3.34	2.45	1.68	1.50	1.50	1.50	1.50	148.47	57.51	71.33	25.09
Median	10.65	5.97	3.55	2.16	1.50	2.64	3.43	2.13	6.01	13.50	30.55	21.85	16.46
Average	20.51	15.73	6.05	5.05	5.82	5.57	12.53	14.60	19.12	39.37	65.73	37.07	20.60
10%ile	3.15	2.27	2.40	1.50	1.50	1.50	1.50	1.50	1.50	3.30	7.37	9.59	6.63
90%ile	46.51	37.66	10.93	5.09	16.00	14.40	38.44	40.88	45.08	107.31	158.35	104.52	39.20

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
< 0.5	0	0	0	0	0	0	0	1	0	0	0	0
0.5 - 3.0	6	11	21	44	46	33	30	34	25	5	0	0
3.0 -10.0	24	30	36	16	8	20	22	6	15	21	10	8
10.0 - 20.0	15	8	4	1	4	9	3	9	8	13	11	22
> 20.0	19	15	3	3	6	2	9	14	16	25	43	34

Annexure C-4

Notes on changes in the flow regime due to future development

BREEDE RIVER BASIN STUDY

EFR : NOTES ON CHANGES IN THE FLOW REGIME DUE TO FUTURE DEVELOPMENT

19/6/01

V Jonker & H Beuster

1. Introduction

The potential impacts of future development options on the magnitude and occurrence of floods entering the Breede River estuary were assessed through a comparison of the present flow regime with flow regimes resulting from three future development scenarios (limited, moderate and high future water infrastructure development). The scenarios, and the effects that these levels of development may have on mean annual runoff to the estuary, are:

Table 1 Development Scenarios

Scenario	Infrastructure	Mean Annual Runoff (10^6 m^3/a)
Present Day	Present system	1034
Limited future	*Present system with:* Michells Pass diversion to Voelvlei Upper Molenaars pumped diversion to Berg	954
Moderate future	*Limited future with:* Ouplaas diversion to Brandvlei Raising of Buffeljags Dam	863
High future	In-channel storage at Le Chasseur	654

2. Present flow regime

2.1 Flood frequency analysis

In order to establish the occurrence and magnitude of floods that enter the estuary, a flood frequency analysis was carried out using maximum annual flow rates downstream of the confluence of the Breede and Buffeljags Rivers. Flow measurements at stations H7H006 (Breede at Swellendam), and H7H013 (Buffeljags downstream of Buffeljags Dam) were combined for the period 1968 to 2000 to provide an indication of return periods and magnitudes of flows entering the estuary. Figure 1, and Table 2 below show the results of this analysis.

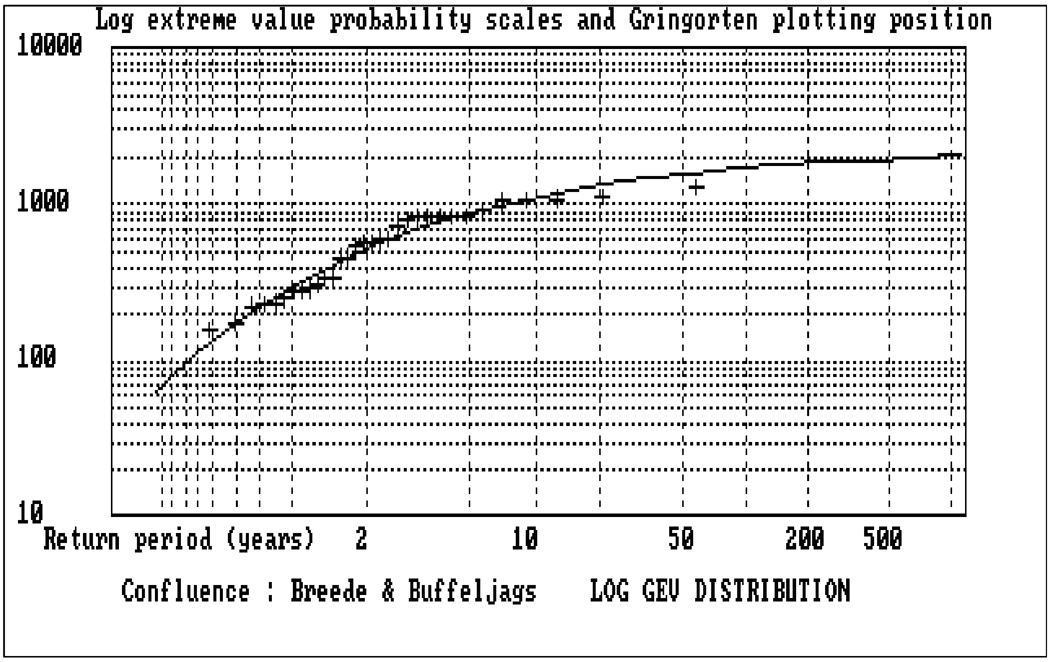

Figure 1 : Flood Frequency Analysis

Table 2 : Flood Frequency Analysis

Return period (years)	Peak discharge (m^3/s)
2	520
10	1 110
20	1 320
50	1 550

2.2 Flood volume analysis

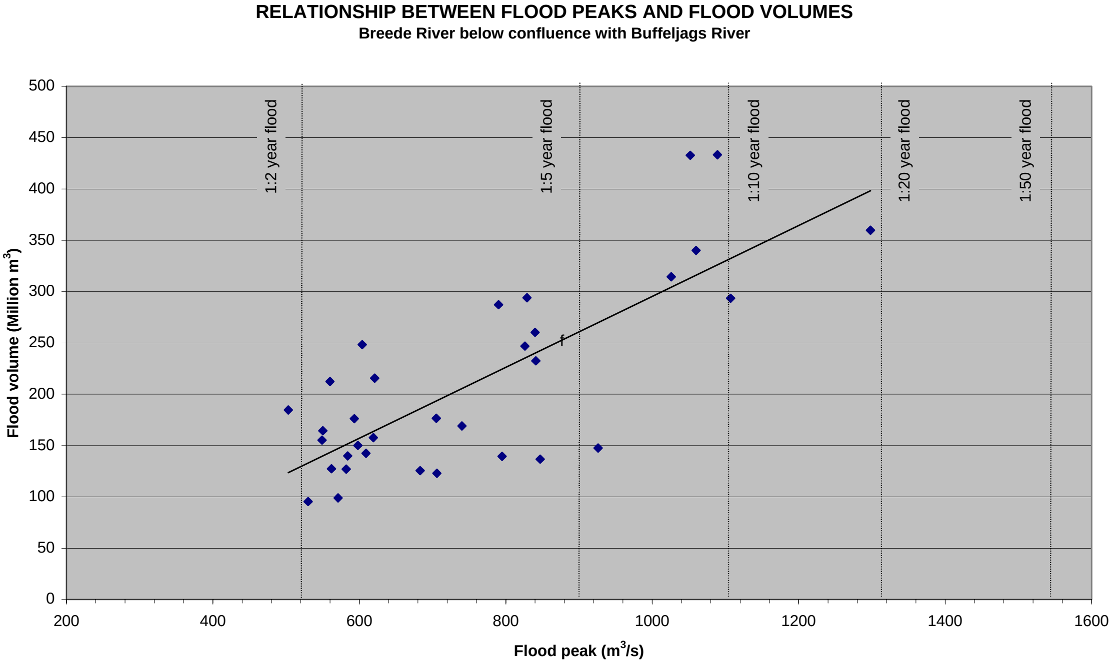

Figure 2 : Flood volumes

Flood volumes were derived by integrating average daily discharges of the annual maximum floods. Figure 2 above indicates that small floods (with return periods of about 1 in 2 years) have volumes of about 100 to 200 million m^3. Medium floods (approximately 1 in 5 year return period) have volumes of the order of 200 to 300 million m^3, while large floods (1 in 10 years +) have volumes in excess of 300 million m^3.

2.3 Flood hydrographs

Generalised characteristics of flood hydrographs are summarised in Table 3 below:

Flood size	Time to peak (days)	Duration of recession (days)
Small (+- 1 in 2 years)	< 2	10
Medium (+- 1 in 5 years)	3	10
Large (1 in 10 years +)	4	10 - 12

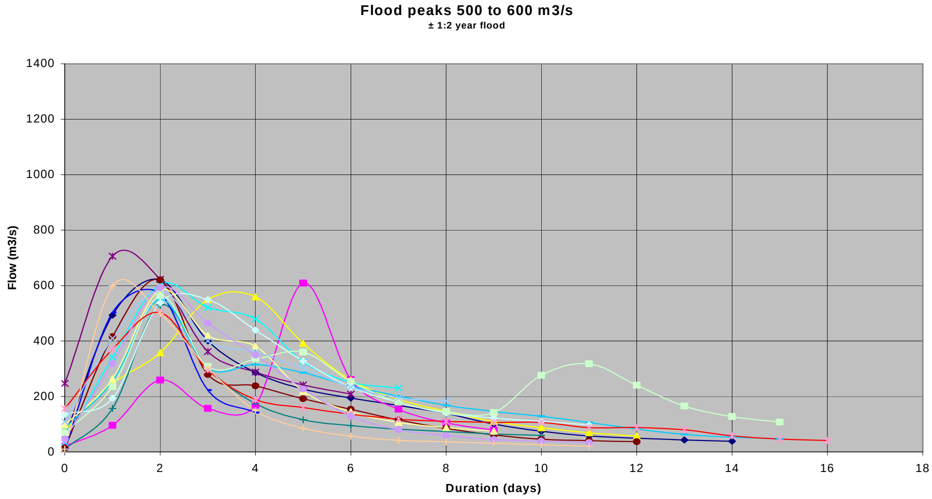

Figure 3(a) Hydrographs of small floods

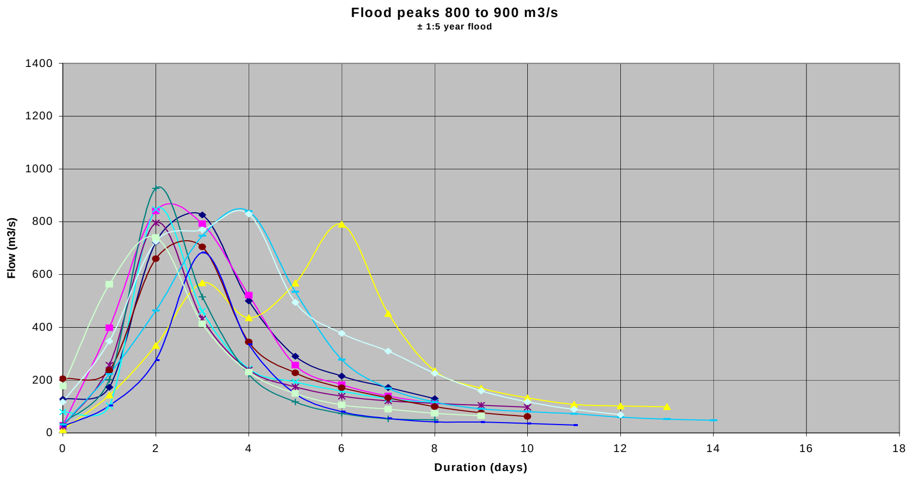

Figure 3(b) Hydrographs of medium floods

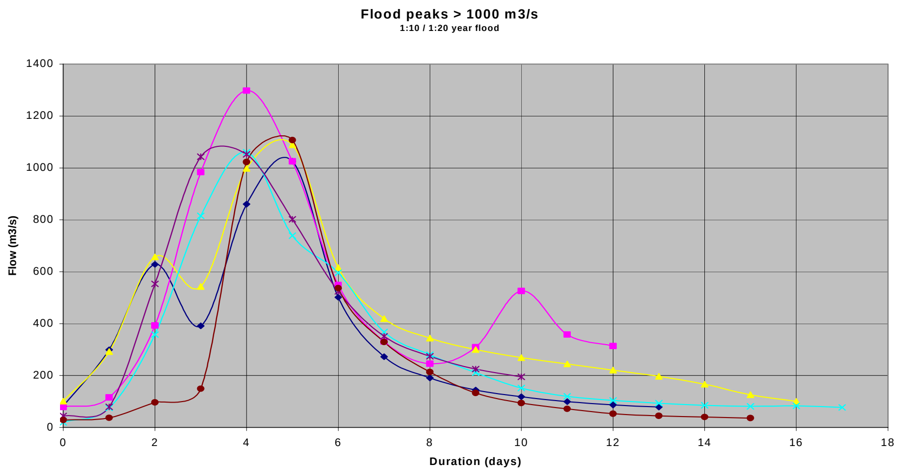

Figure 3(c) Hydrographs of large floods

3. Flow regimes associated with future development scenarios

3.1 Methodology

The impacts that the future development of water infrastructure may have on the magnitude and occurrence of floods entering the estuary, were assessed by carrying out simulations of the operation of the schemes listed in Section 1 above. Reservoir simulations were carried out at a daily time step, taking inflows, evaporation and abstractions into account to determine spillage from the schemes. A number of simplifying assumptions were made during this exercise:

- Nominal provisions for instream flow requirements were made by simulating the release of Desktop estimates of drought IFR requirements.

- Observed daily flow records at measuring stations in the vicinities of the potential schemes were used as "present day" inflows at the scheme sites. These flow records span a common period of 15 years (1983/84 to 1998/99). The cascading effect of the schemes on river flows were simulated by deducting the inflow sequence of an upstream site from the inflow sequence at a downstream site, and then adding back simulated spill and release sequences after allowing for appropriate lag times. This approach was also followed to determine inflows to the estuary.

By following the above approach, it was possible to estimate the reduction in annual maximum floods under the three development scenarios:

Flood return period (years)	Peak discharge (m^3/s) (1)			
	Present	Limited future	Moderate future	High future
2	523	518	489	437
10	1108	1097	1055	982
20	1317	1301	1257	1175
50	1553	1534	1485	1392

Notes : (1) Based on average daily flows. Actual peak discharges could be under estimated by up to 25%

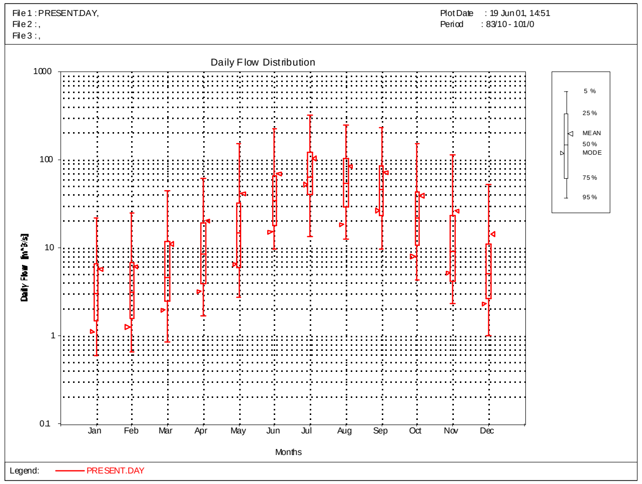

Figure 4(a) Daily flows : Present Day

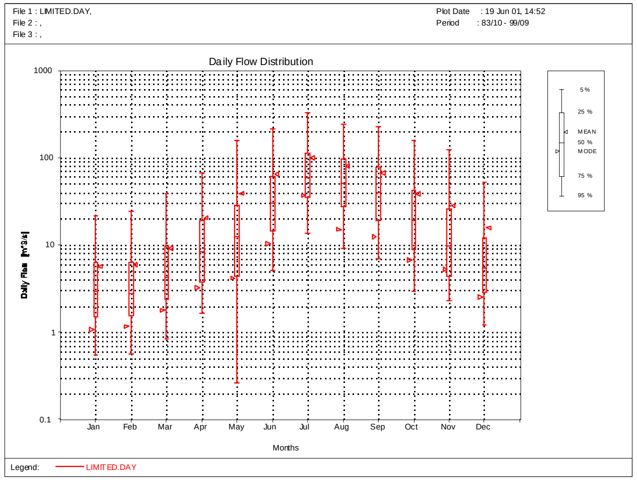

Figure 4(b) Daily flows : Limited Future

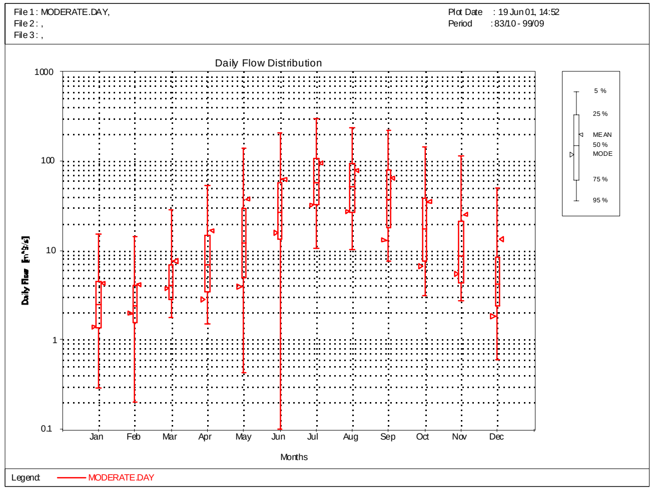

Figure 4(c) Daily flows : Moderate Future

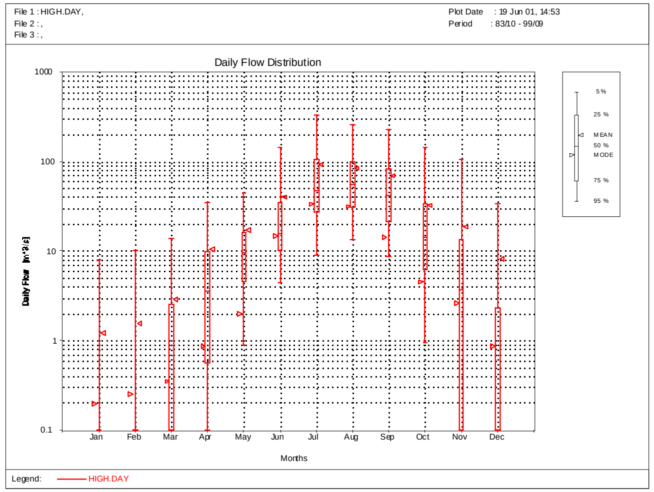

Figure 4(b) Daily flows : High Future

Figures 4(a) to 4(d) above show variations of daily flow for the present day and future development scenarios in the form of bar-and-whisker plots. Comparison of these indicate the following:

Limited future development: The two schemes associated with the limited development scenario (Michells Pass and Upper Molenaars diversions) are essentially run-of-river diversions of winter flows. Due to the fact that only the Michells Pass scheme relies on limited storage, high flows and very high flows (25% and 5% exceedance levels) are largely unaffected. As can be expected, winter low flows (75% and 95% exceedance levels) are reduced to some extent.

Moderate future development: The further implementation of the Ouplaas scheme in the Molenaars River, and the raising of Buffeljags Dam impact on inflows to the estuary in different ways: Winter low flows are reduced due to the regulation of winter floods in the Molenaars River and the additional storage created at Buffeljags Dam. Winter high flows remain largely unaffected due to the limited storage of the two schemes. The significant reduction of summer high flows is ascribed to the operation of the enlarged Buffeljags Dam.

High future development: Even after the provision of instream flow requirements, the implementation of Le Chasseur Dam on the main stem of the Breede River has the potential of severely reducing summer high and low inflows to the estuary. Substantial reductions of early to mid winter low and high flows are caused by the filling of available storage in Le Chasseur Dam. Flows during August and September are the least affected, and corresponds with the time of year when the dam would be full, or near to full. During a prolonged drought, a reduction of flows during this period can also be expected.

Appendix D

Specialist Report:

Microalgae

This report was compiled by:

G C Bate and J B Adams
Diatom and Environmental Management cc
Port Elizabeth

July 2001

Panoramic view of the Breede River Estuary

EXECUTIVE SUMMARY

- Using a formula derived for the Sundays and Gamtoos estuaries, the fresh water flow rate that would provide the maximum primary production from phytoplankton is about 11 m^3s^{-1}.

- Under natural conditions, the run-off simulations indicate that the annual average fresh water flow rate is much higher than 11 $m^3.s^{-1}$. This means that on an average annual basis the Breede Estuary behaved in a similar manner to a river mouth and a large proportion of phytoplankton biomass and minerals passed out through the mouth without accumulating within the estuary.

- The three field sampling sessions reported here were all undertaken under relatively high fresh water flow rates. This was indicated by the low salinity values through out the estuary.

- The phytoplankton biomass measurements showed comparatively low values that are consistent with a high fresh water flow rate, low residence time and a poorly developed phytoplankton river-estuary interface zone (REI).

- The estimates of phytomicrobenthos biomass also indicated low values by comparison with data from other estuaries. The conclusion is that the water flowing into the estuary is not eutrophic. This is because benthic biomass is influenced by the mineral element content of the water column.

- Phytomicrobenthos species richness was variable, with some sites having a very rich flora and with others having about average numbers of species.

- The dominant diatom species identified reflect the relatively fresh nature of the water throughout the estuary on all sampling dates. However, some brak and marine species found midway and near the head of the estuary indicate periodic saline intrusions that would likely be important in creating temporary estuarine conditions.

- Predictions about the potential changes to the estuary indicate that the “limited” and “moderate” development scenarios would leave the estuary largely unchanged from the present on an annual basis and on an average seasonal basis. The Bromberg and LeChasseur development scenarios would result in the estuary being classifiable more as a river mouth during average winters but optimally productive during an average summer.

- The Breede Estuary functioned as a river mouth under natural flow conditions, supplying important materials to the nearshore marine environment. The periodic normal summer and summer drought low flow periods would have resulted in a marine influence penetrating far into the interior. This would have resulted in a large faunal recruitment into the estuary that would have greatly benefited the marine fishery resources of the area.

- Reductions in fresh water flow into the Breede Estuary should only be approved in the full understanding that the cumulative effect in this area together with other areas around the South African coast might cause marine fishery stocks to be permanently, and possibly irretrievably altered.

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INTRODUCTION

Microalgae are single cell photosynthetic plants that are the major primary producers in most water bodies. This is certainly the case in South African estuaries where it is possible that > 80% of all the organic matter synthesised within an estuary is by microalgae. Despite the huge part played by microalgae, they have been some of the least studied components of the biota. Fortunately, the lack of information on microalgae has been appreciated recently and work has begun in a number of estuaries.

Microalgae are suspended in the water column (phytoplankton), on the bottom of the estuary (phytomicrobenthos), on stones (epilithon), in the sediment surface (epipelon) and attached to submerged vegetation (epiphyton). There are a great many different types of microalgae but one group has been fairly well studied and are used as a tracer for the others on the basis that all the different types will respond to water quality in a similar, if not identical manner, i.e. there will be a higher biomass if more useable mineral elements are present in the water column. The group used as a tracer are diatoms. These organisms are some of the most abundant microalgae in estuarine systems and probably account for the greatest proportion of the food produced in an estuary. They are relatively easy to work with and are used throughout the world as indicators of habitat and especially the mineral nutrient status of estuaries.

Microalgae take up minerals from the water column and therefore play an important role in reducing eutrophication as river water passes through an estuary before entering the sea. Fresh water and sea water interact and the mixing zone is an area of increased biological activity and biomass, as well as an area where many specialised habitats form and are utilised by fauna that are important to both marine and freshwater ecosystems.

Much more information is required before the knowledge base on microalgae can be used as a definitive indicator of ecological health in estuaries. Each study provides greater insight as data from previous studies are accumulated. Suffice it to say that these organisms are where all the biological processes begin.

MATERIALS AND METHODS

Sites

The estuary was sampled on three separate occasions; March 2000, August 2000 and March 2001. The first two visits were part of this project while the third was part of a Water Research Commission funded project (K5/1107 – Diatoms as indicators of Water Quality in Rivers and Estuaries). The sites, five positioned from the mouth to the freshwater area on each occasion, are shown in Figure 1.

Figure 1. The Breede Estuary runs from about Malgas (S34° 17' 59" E 20° 35'00" - upper limit of tidal influence) to Witsand/Infanta (S34 ° 24' 32" E 20 ° 50' 55" - mouth). It is situated on the south coast of South Africa and empties into St. Sebastian Bay. Individual sampling sites are indicated by a 'push pin' while sites close together are indicated by a cluster of squares.

Sediment collection

Sediment was collected from each intertidal and subtidal site using a narrow tube (10mm ID), long enough to allow samples to be taken from sub-tidal areas at depths of ca. 1-2 m at mid-tide. The samples of sediment were incubated and slides prepared that allowed qualitative and quantitative evaluations to be made of the diatom flora. The data accumulated were assessed using data collected from other South African estuaries and rivers.

Sediment samples were measured for chlorophyll-a in order to assess the relative microalgal biomass between sites within the estuary and between the Breede Estuary and other estuaries.

RESULTS

Diatom species

Table 1. Epipelic diatoms found in the Breede Estuary over three sampling sessions (March 2000, August 2000 and March 2001) together with information on their dominance (D = dominant; s = sub-dominant but comprising > than 10% of the cell counts) and whether they were from intertidal or subtidal habitats at sites 1-5. An x indicates whether the species have previously been reported from fresh, brak or marine water.

Genus	Species	Code name	Dom/Sub	Fresh	Brak	Marine	Site	Site	Ref
Achnanthes	delicatula	ACHNDELI	D	x			Int	2	Sims
Amphora	angusta	AMPHANGU	s			x	Int	3	Sims
Amphora	coffaeaformis	AMPHCOFF	D		x	x	Int	2	Sims
Amphora	cymbamphora	AMPHCYMB	D		x		Sub	2	Archibald
Amphora	subacutiuscula	AMPHSUBA	s	x			Int	3/4	Archibald
Amphora	sublaevis	AMPHSUBL	D	?	?	?	Int/Sub	1/3/4	No ref.
Aneumastus	tusculus	ANEUTUSC	s	x	x		Int	2	Sims
Bacillaria	paradoxa	BACIPARA	D		x		Sub	4/5	Sims
Berkeleya	micans	BERKMICA	s			x	Int	3	SIMS
Cocconeis	engelbrechtii	COCCENGE	s	x			Int	5	Archibald
Cocconeis	placentula	COCCPLAC	s	x			Sub	4	Sims
Diploneis	elliptica	DIPLELLI	s	x	x		Int/Sub	2/4	Sims
Donkinia	species 1	DONKsp01	s			x	Sub	3	Sims
Fragilaria	elliptica	FRAGELLI	D	x			Sub/River	4/5/R	Archibald
Gyrosigma	scalproides	GYROSCAL	D			x	Int	5	Sims/Patrick
Navicula	gregaria	NAVIGREG	D	x	x	x	Int/Sub	1/2/3	Sims
Navicula	tenelloides	NAVITENE	D	x			Int/Sub	1/2/4	Sims
Navicula	viridula var. rost	NAVIVIro	D	x			Int	5	Sims
Nitzschia	palea	NITZPALE	D	x			Int	3	Sims
Nitzschia	pellucida	NITZPELL	s			x	Sub	5	Sims
Nitzschia	scalpelloides	NITZSCAL	s	x	x		Int	3	K&LB
Nitzschia	sigma	NITZSIGM	s		x	x	Int	5	Sims
Opephora	marina	OPEPMARI	D			x	Int	1	Sims
Parlibellus	species 1	PARLsp01	s			x	Int	2	Sims
Proschkina	sp01	PROSsp01	D			x	Int	1	Round
Tryblionella	calida	TRYBCALI	s	x			Int	5	Sims

The data in Table 1 show that at site 1 (mouth) the dominant species were AMPHSUBL, NAVIGREG, NAVITENE, OPEPMARI and PROSsp01. No literature reference was available to indicate the salinity tolerance of AMPHSUBL but NAVIGREG is found in salinity from fresh to marine. It also occurs where there has been disturbance and is considered a colonising species. NAVITENE is a fresh water species (F) while OPEPMARI and PROSsp01 are both representatives of marine genera (M).

At site 2 the dominant species were ACHNDELI (F), AMPHCOFF (B,M), AMPHCYMB (B), NAVIGREG (F,B,M) and NAVITENE (F,B,M). At site 3 the dominant species were AMPHSUBL(?), NAVIGREG(F,B,M) and NITZPALE (F). At site 4 the dominant species were AMPHSUBL (?), BACIPARA (B), FRAGELLI (F) and NAVITELLI (F) while at site 5 the dominant species were BACIPARA (B), FRAGELLI (F) (Archibald, 1983; Sims, 1996). The diversity of phytomicrobenthic species is shown in Table 2.

Table 2. The number of species found at each site on the different sampling dates. (GP = Groenpunt site – near site 1; Int = intertidal site; Sub = subtidal site; NS = not sampled; SE= slide empty; += more than).

	March 2000	**Aug 2000**	**Mar 2001**	**Mean**
Site	**No. taxa**	**No. taxa**	**No. taxa**	**No. taxa**
GP Int	30	NS	NS	
1 int	38	SE	70+	
2 int	33	24	30	
3 int	SE	8	36	
4 int	24	20	27	
5 int	19	32	17	
Mean	**29**	**21**	**28**	**26**
GP Sub	30	NS	NS	
1 sub	24	36	70+	
2 sub	40	SE	44	
3 sub	SE	22	36	
4 sub	19	19	28	
5 sub	30	13	43	
Mean	**29**	**23**	**38**	**30**

The data in Table 2 indicate that site 1 near the mouth had the greatest number of species. The count of 70+ is unusually high. Subtidal species numbers were slightly higher than intertidal sites while the number was highest during March 2001 and lowest during August 2000.

Some of the species found during this study have been collected from other sites where the water quality had been analysed. The available data are presented in Table 3.

Water column salinity values

Salinity values for the water column are shown in Table 3

Table 3. Water column salinity values (ppt) during the sampling sessions in March and August 2000 and March 2001. Intertidal data represent surface water values while subtidal data represent bottom water values.

Date	March 2000		August 2000		March 2001	
Site	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal
River	0	0	0	0	0	0
5	0	0	2	3	0	1
4	0	0	4	7	7	7
3	0	0	3	11	15	16
2	16	28	4	1	24	25
Mouth	20	32	5	6	28	29

The data in Table 3 show that the salinity values for March 2000 were similar to those for March 2001. On the latter date the water flow was probably similar to that in March 2000 with the greater penetration of salinity in March 2001 likely the effect of tidal state. The fresh water flow in August 2000 appears to have been higher than during both March sampling sessions because the salinity values near the mouth were lower.

Chlorophyll content of the sediment

The chlorophyll-a content of the sediment was measured on two occasions (March and August 2000). The samples were collected from the intertidal and subtidal regions. They were collected from four sites that covered the area included within sites 1 and 2 of the benthic diatom samples. These sites represented the more saline section of the estuary and excluded the region that would normally be the summer REI region. The reason for this was the high water flow March 2000. The August samples were taken from the same sites in order to compare the results.

The data from the samples shows that the mean chlorophyll concentrations were low (0.04 – 1.47 mg chlorophyll-a m-^{2}). By comparison, mean chlorophyll-a concentrations in the Gamtoos estuary were 0.59 – 3.58 mg.m^{-2}). The March chlorophyll values were higher than in August and they were also higher close to the mouth and decreased upstream. Intertidal and subtidal chlorophyll values were not significantly different.

DISCUSSION

Diatom distribution in the estuary

At 16 sites over three seasons, only 13 diatom taxa were dominant while 12 taxa were present as subdominants. This implies that the work involved in identifying these organisms is not too onerous, especially now that a large database of South African riverine and estuarine taxa is available within a single source. In these analyses, only the dominant taxa have been considered. A subdominant is defined for these purposes as any taxon that has a frequency of more than 10% but is not dominant. As the percentage dominance of a single taxon increases at a site, the probability of another taxon being counted as a subdominant decreases. However, the number of subdominants may be important in determining the nature of a site.

NAVIGREG is a species that is considered to be a recent coloniser, probably of disturbed sites in fresh, brak and marine sites; hence the name (*Navicula gregaria*). This species was dominant near the mouth in March 2000, site 3 in August 2000 and at site 3 in April 2001. The question that arises is what the causal factor might be for the disturbance at these times. It might be human or it might be the low salinity values recorded at times when the fresh water flow was high, or possibly local scouring was the cause. NAVITENE is a fresh water species that occurred as a close subdominant to NAVIGREG at intertidal site 1 and as a co-dominant at the subtidal site 1 in March 2000. It seems more probable from this evidence that the presence of NAVIGREG was the result of recolonisation following a period of fresh water flow near the mouth rather than the result of physical disturbance.

As might be expected, the taxa present as dominants towards the head of the estuary were largely fresh water species. However, at subtidal sites 4 and 5 during the August 2000 sample session, BACIPARA (a brak species) was dominant. This coincides quite well with the salinity data, which was higher than at the other times for those sites, at 7 and 3 ppt respectively.

In a project currently underway at the University of Port Elizabeth on diatoms as indicators of fresh water, some species found during the study reported here were also found. In a year-long study of the Swartkops River where samples were taken on a monthly basis, the water quality was good (low nutrient status) near the source of the river. It gradually deteriorated and became of poor quality near the head of the estuary after passing through Uitenhage and Despatch. The water quality could be graded into 5 classes from Class 1 (good) to 5 (poor). From the UPE data it is possible to draw some tentative conclusions regarding the mineral nutrient status of the water flowing into the Breede Estuary. NAVIGREG, NAVITELO have usually been found in Class1 water. NITZPALE, on the other hand was found in water where NH_4^+, F^+ and NO_3^- was Class 3 and where PO_4^- was Class 2. NAVITENE has been found in good quality black water in the Palmiet and Bot rivers. TRYBCALI, a co-dominant at intertidal site 5 in March 2000, appears to indicate fresh water but with a high conductivity. The conclusions to be drawn from these data are that the fresh water passing into the Breede Estuary is generally of good quality.

Diatom species diversity

The species diversity appeared to be relatively normal with some sites having a high diversity. In the light of available information, no further interpretation can be made from the number of taxa found at each site.

Water column salinity values

In March 2000, fresh water penetrated all the way to site 2 in both the inter- and subtidal sites. This indicates a high fresh water flow rate. During the sampling, the water between sites 1 and 2 was very rough. This supports the contention that there was a high flow of fresh water pushing against a flood tide The salinity was high in the subtidal at site 4 indicating that the tide might have been newly turned to flood tide. The vertical salinity gradient at site 2 also suggests a high fresh water flow rate.

In March 2001, the tide appears to have been high because salinity was 7 ppt as far up as site 4. In all likelihood, the flow of fresh water was not very high because the water was generally well mixed.

In August 2000, there appears to have been a high fresh water flow rate into the estuary, possibly on a low neap tide. This is indicated because salinity within the estuary was low throughout.

Sediment chlorophyll-a values

All the sediments sampled were muddy and the low sediment chlorophyll-a levels indicate a low mineral nutrient content in the water column. Data from previous studies indicated that benthic chlorophyll-a was closely linked to the eutrophic status of the water flowing in the estuary rather than to the mineral status of the sediment.

At each of the sampling sessions, the fresh water flow rate was more like a high winter flow. The August 2000 session was undertaken to determine the situation under winter high flow conditions. In the event, this status was never found during the sampling sessions undertaken.

Fresh water flow required to give maximum primary productivity

The volume of the estuary was calculated to be 40.6 x 10^6 m^3 (van Niekerk, Pers. Com).

From the calculations of Adams and Bate (2000), the fresh water flow in the Breede estuary that would provide the maximum phytoplankton primary production is $11 m^3.s^{-1}$. The data of Taljaard *et al.* (2001 - this study) shows that the natural annual average flow is 56.6 $m^3.s^{-1}$, with an average summer flow (April – August) of 23.5 $m^3.s^{-1}$ and an average winter flow of 89.6 $m^3.s^{-1}$. Under natural average conditions, these flow rates would make the Breede functionally a river mouth (from the phytoplankton perspective) rather than an estuary in that minerals entering the estuary from the river would not remain in it for a sufficiently long time for the population to divide maximally. In the Sundays and Gamtoos Estuaries this time taken for river water to move through the estuary was called "the residence time" and was equivalent to three spring tidal cycles.
The flow rates under natural, present and after 'development' at different levels is shown in Table 4. These data show quite clearly that the Breede behaved, from the phytoplankton perspective, as a river mouth for much of the time in its natural state. For short periods in summer it would have functioned as an estuary *sensu stricto*.

Taljaard *et al.* (2001 - this study), have shown by simulation that river water entering the Breede estuary would have been "resident" for more than 42 days (three spring tidal cycles), even at river flow rates in excess of 20 $m^3.s^{-1}$. From a physical perspective, this should make the "residence" time optimal for phytoplankton biomass. Unfortunately, similar simulations have not been performed for the Sundays and Gamtoos estuaries. Data from those estuaries showed that if the numerical value of the river flow rate was 1/42nd of the volume of the estuary, then phytoplankton biomass was highest. Hence, the problems in the case of the Breede Estuary may be one of interpretation. The measured chlorophyll-a values and the microphytobenthic species composition all indicate fresh water flows in excess of the optimum. With the limited database from which to make evaluations of this nature, the confidence of these statements is low. However, it would be less correct to make biological evaluations on physical simulations than it is to make biological extrapolations from measured data in different estuaries.

A problem exists in the case of interpretations of the data from the Breede Estuary. The available information has been collected from the Sundays and Gamtoos Estuaries. While these are relatively big estuaries they seem to be micro-tidal (or meso-tidal) by comparison with the Breede Estuary. The great penetration of sea water into the Breede and the relatively well mixed nature of the water (surface and lower salinity values quite similar at different points up the estuary) may make it necessary to reassess the REI as it relates to phytoplankton. We know that phytoplankton grow in response to mineral enrichment that arises from river imports and from the interaction between sea water and fresh water. However, it is possible that in the Sundays and Gamtoos estuaries the physical attributes of mixing between fresh and sea water may have resulted in a clearly defined zone arising. This may not be the case in the Breede Estuary.

The interpretation of this information as it relates to the value of fresh water flow rates in the Breede Estuary is complex. What can be stated with high confidence is that at low fresh water flow rates elevated phytoplankton biomass will exist within the estuary even though it may be dispersed due to tidal mixing. At some high(er) flow rate, the time available for phytoplankton to grow will be too small within the estuary and they will divide and grow out at sea. The higher productivity will then be at sea and not within the estuary.

The best available information for the critical flow rate that results in the maximal REI for phytoplankton ($REI_{pp)}$ is provided from the Gamtoos data, i.e.

$$Flow_{opt}\ (m^3.s^{-1}) = \frac{8.7 \text{ x estuary volume}(m^3)}{\text{the number of seconds in a year (s)}}$$

Where 8.7 is the number of three spring tidal cycles in a year.

The data in Table 4 allow us to link these foregoing considerations to the Breede flow simulations

Table 4. Simulated average flow rates into the Breede Estuary under natural conditions, present conditions and four 'development' scenarios. (after Taljaard *et al.* 2001 – this study) (RM = river mouth). (11 $m^3.s^{-1}$ is the calculated optimum flow for the Breede Estuary).

State	Annual flow ($m^3.s^{-1}$)	Winter flow ($m^3.s^{-1}$)	Summer flow ($m^3.s^{-1}$)	Estuarine condition Annual	Winter	Summer
Natural	56.6	89.6	23.54	RM	RM	RM
Present	32.6	51.6	13.6	RM	RM	Good
Limited Dev.	30.0	47.2	12.7	RM	RM	Good
Moderate Dev.	27.2	43.1	11.3	RM	RM	Good
Bromberg	24.5	39.6	9.4	RM	RM	Good
LeChasseur	20.6	31.4	9.8	RM	RM	Good

The impression should not be given that because the flow rate was too high under natural conditions for the Breede to be considered a true estuary, that there is no environmental impact as the flow rate is attenuated. With very high fresh water flow, the estuary, or the important high productivity portion (REI_{pp}), would be out at sea. The important consideration is that even under present conditions the beneficial impact of the Breede River on the nearshore fishery has been reduced to about 58% of what it was.

The 10%ile data for natural conditions indicates that there would have been occasional high salinity penetrations up the estuary. On those occasions, recruitment of estuary dependent fishes would likely have been extremely high because there are a great many areas where juveniles would find refugia. For the foregoing reasons, the impact of water flow reductions through the Breede Estuary is likely to be far greater than the simple quantitative reduction in water flow.

The TDS values reported by Taljaard *et al.* (2001 – Table 5) show that the maximum was 0.860 $g.l^{-1}$. Comparison of those data with the Swartkops River Water Quality Classes shows that the Breede River at Swellendam has water that would mostly fall into Class 1, but with some periods falling into Class 2. Humans generally consider 'good' water to be of a quality that is good for human consumption, i.e. the lower the TDS the better. Under natural conditions, the TDS of the Breede River is likely to have had 'poor' quality water in the sense that the mineral nutrient loading would have been very high as a result of the residence in the rivers of hippotamus, crocodiles and the daily visits by birds, elephant and large herds of antelope.

Hence, the elimination of natural fauna by humans has likely had a major effect in reducing primary productivity in the REI region of all South African estuaries. In the case of the Breede, the major beneficiaries of recycled nutrients in the nearshore would have been the marine fishery. This has likely already been greatly reduced and any amount of development that results in further fresh water flow modification will exacerbate the impact. When seen in the context of the Breede Estuary in isolation, the reduction of fresh water to the nearshore might be seen as the least of many possibe evils, however, the cumulative effect of successive river flow reduction can only have a detrimental effect on marine resources and therefore food supplies to South Africans, to say nothing of adversely affecting the availability of jobs.

Table 5. Biotic health scores allocated for microalgae under the flow conditions prevailing for each of the scenarios.

BIOTIC HEALTH SCORES FOR Microalgae						
SCENARIO →	**PRES**	Ltd	Mod	Brom	Le Cha	Confidence
Attribute	Scores represent 100% - deviation					
Species richness	90	90	90	90	90	60
Abundance	90	90	80	80	80	40
Community composition	90	90	70	70	70	40
Biotic health score	90	90	70	70	70	

In Table 5, the health score under the present conditions is considered to be 90% for all attributes. Species richness is unlikely to be affected to any great extent under any of the scenarios and the 90% score allows for some degree of error in the anticipated effect. The scores under the Limited scenario indicate that there is unlikely to be any change between the Present and Limited scenarios. Under the Moderate, Bromberg and Le Chasseur scenarios there is unlikely to be a change in species richness. However, the value of 80% for Abundance under Moderate, Bromberg and Le Chasseur reflects a deviation of 20% from Natural – this being a likely increase in microalgal biomass as a result of the greater "residence time" of freshwater within the estuary. Similarly, Community composition scores drop because of an anticipated change in dominance of phytomicrobenthic species towards brak rather than a fresh water species. The overall productivity within the estuary is likely to increase as the extent of water abstraction increases, but the increase will be at the expense of productivity in the marine environment.

The effect of over fishing Cod on the Grand Banks of Newfoundland has recently been reported. On the Grand Banks, a ban on fishing was imposed in 1992. Despite this, the Cod fishery has not recovered (New Scientist NO. 2275, 27 January 2001, Pg 16). The latest scientific opinion on this matter is that some stocks (of fish and animals) are sustained by virtue of there being a certain minimum number of individuals. Cumulative effects arise insidiously because they cannot be observed and because our scientific knowledge is incomplete. It is therefore extremely important that indirect effects be carefully considered before decisions are taken that may adversely affect human quality of life in areas apparently remote from the site of concern.

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APPENDIX E

Specialist Report:
Macrophytes

This report was compiled by:

JB Adams and TG Bornman

Department of Botany
University of Port Elizabeth
PO Box 1600
Port Elizabeth, 6000
btajba@upe.ac.za

July 2001

SUMMARY

* This report provides input on the macrophyte component of the Breede Estuary for the Intermediate reserve determination by the Department of Water Affairs and Forestry.

* During field surveys the distribution of macrophytes up the length of the estuary was documented, and the area covered by the different plant community types assessed. The largest salt marsh at Green Point was sampled along two transects to determine zonation and sediment characteristics.

* There were 23 dominant macrophytes species and six of the nine possible plant community types (phytoplankton, intertidal benthic microalgae, submerged macrophytes, intertidal salt marsh, supratidal salt marsh and reeds and sedges).

* Submerged macrophyte species were distributed along a salinity gradient with the seagrass *Zostera capensis* in the lower reaches and *Potamogeton pectinatus* in the upper reaches where salinity was low. The largest salt marsh occurred at Green Point with less extensive brackish marshes in small coves and tributary sites along the estuary. Intertidal species occurred along the first 100m thereafter *Sarcocornia pillansii* and *Disphyma crassifolia* (supratidal spp.) were dominant to 500m inland. Large reed beds characterize the upper reaches of the estuary and begin approximately 10km from the mouth.

* The botanical importance rating system (Colloty *et al*. 2000) was used to determine the botanical importance score of the Breede Estuary. The score was 350 and the estuary has the fifth highest score of all estuaries in South Africa.

* The area covered by the different plant community types was measured from the oldest available aerial photograph (1942) and compared with recent information (1989 aerial photograph and field survey). The total area covered by macrophytes has decreased by 10.5% between 1942 and 2000. This was due to a small loss of salt marsh and a larger decrease in the area covered by the submerged macrophyte *Zostera capensis*.

* The most important changes that have occurred from the reference to the present state is the reduction in freshwater input and increase in saline intrusion. As a result of this there would have been some reed die-back and loss of pondweed habitat (area less than 10 ppt). Reed die-back would occur if they were exposed to salinity greater than 20 ppt for longer than 3 months. Die-back would only occur if the roots and rhizomes of the plants were located in salinity greater than 20 ppt.

*The limited future development scenario would result in little change to the macrophytes. Changes would occur for the moderate, Bromberg and Le Chasseur scenarios. As the salinity increases further upstream reed die-back could be expected and there would be a loss in pondweed habitat. Community composition of the small brackish marshes in the lower reaches of the estuary would change as brackish species would be replaced by salt tolerant species. The seagrass *Zostera capensis* would extend into the middle reaches of the estuary and replace the brackish species i.e. *Potamogeton pectinatus*.

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1. INTRODUCTION

The Department of Water Affairs and Forestry are considering further developments of the water resources of the Breede River catchment. Investigations on the influence of river inflow on the environmental aspects of the Breede Estuary were commissioned. This was later converted to an intermediate reserve study. This report presents the results of the specialist study on the botanical characteristics of the estuary. This included the salt marshes, reeds, sedges and submerged macrophytes.

Terms of reference for specialists were;

1. Identify key macrophyte species and their importance.

1. Identify the key abiotic factors that influence the macrophytes.
2. Define the present status of the macrophytes.
3. Predict the reference condition of the macrophytes.
4. Predict the effect of each of the 4 future development scenarios on the macrophytes.

6. Complete the Intermediate RDM specialist templates.

The estuary was visited on 17-20 March 2000 and 10-12 August 2000. Field work consisted of macrophyte surveys and studies on the distribution, biomass and controlling environmental factors for phytoplankton and benthic microalgae. A component of the study was capacity building and 2 Honours students completed their projects on the Breede Estuary. Post doctoral fellow, Dr Helen Astill also used the estuary as one of her research sites. The following reports were completed;

Dayimani, V. 2000. Botanical characteristics of the Breede Estuary. Unpublished Honours Project. Department of Botany, University of Port Elizabeth. 31 pp.

Coetzee, V. 2000. Environmental parameters influencing microphytobenthos communities in the Gamtoos and Breede Estuaries. Unpublished Honours Project. Department of Botany, University of Port Elizabeth. 55 pp.

Astill, H.L., V. Coetzee, & J.B. Adams. 2001. The influence of sediment characteristics and nutrients on microphytobenthos biomass in two permanently open estuaries. Accepted for publication in Estuarine, Coastal and Shelf Science after revision.

2. MATERIALS AND METHODS

2.1 Identification of key macrophyte species

When the estuary was visited macrophyte species were identified and the area covered by the different plant community types (e.g. salt marsh, submerged macrophytes) was checked. The area (ha) covered by the different plant community types was measured from aerial photographs. These data were used to calculate the botanical importance of the estuary.

2.2 Application of the botanical importance rating system

A botanical importance rating system has been developed to summarize the botanical importance of an estuary (Coetzee *et al.* 1997; Colloty *et al.* 2000). Botanical importance was calculated as follows (Figure 1):

Botanical importance = Functional importance + Species richness + Community richness + Sum of habitat rarity scores of each plant community type present.

Functional importance was based on the area and number of different plant community types and their contribution in the form of energy input (i.e. primary productivity). The functional importance formula includes all estuarine plant community types namely; salt marsh, reeds and sedges, benthic microalgae (found in the intertidal sand and mudflats) and phytoplankton (water surface area on slack low tide). Average primary productivity values were calculated from available South African literature (Colloty *et al*. 2000).

Species richness was the number of plant species identified for a specific estuary and **community richness** was the number of plant community types.

For **plant community type rarity** a weight was assigned to the six least common community types found in South Africa. For example if that community type only occurs once, it receives a score of one. If a community type is found in 35 estuaries it receives a weight of 1/35. The weights of each community type found in each estuary are then summed to obtain a final score. To obtain a plant community type rarity score the sum of weights was then applied to the ranges shown in Table 1.

Table 1: Rarity weights and the respective community rarity scores.

Sum of weights	Plant community type rarity score
0-0.017	20
0.018-0.027	40
0.028-0.04	60
0.041-0.049	80
0.05-0.067	95
0.068-0.133	100

2.3 Identification of key abiotic factors that influence the macrophytes

Water column salinity and macrophyte distribution were documented during the field surveys. Different macrophyte species are generally distributed along a salinity gradient. The largest salt marsh at Green Point was sampled along two transects to determine zonation and sediment characterisitics (moisture, conductivity, pH, redox potential and organic content).

2.4 Reference condition and present status

Change over time from the reference condition to the present state was determined by calculating the functional importance of an estuary in its past and present state. The area covered by the different plant community types was measured from the oldest available aerial photograph (1942) and compared with recent information (1989 aerial photograph and field survey). These photographs were obtained from the Department of Surveys and Mapping (Mowbray, Cape Town). The baseline map was traced from four 1981 orthophotomaps (scale of 1:10 000) and digitised. Different plant community types were digitised as different polygons. The aerial photographs were scanned and the digitized map was overlayed on the scanned pictures and corresponding areas were compared. The query builder (in Arc View) was used to calculate the area change over the period covered.

The difference in functional importance scores was calculated as a percentage and this was subtracted from 100 and expressed as deviation from the reference condition or the habitat integrity score. If there is no change then estuaries are given a score of 100, if there is a change the percentage change is applied to the ranges shown in Table 2. Changes in scores over time, positive or negative are regarded as a deviation from the reference condition.

Table 2: The habitat integrity scores applied to the ranges for percentage deviation from reference scores.

Percentage deviation from reference	Habitat integrity score
0	100
0.5-7.6	60
7.7-14	40
15-30	20
31-90	10

3. RESULTS AND DISCUSSION

3.1 Key macrophyte species and the influence of abiotic factors

There were 23 dominant macrophyte species in the Breede Estuary. These species and the associated plant community types are shown in Table 3. The Breede Estuary had six of the nine possible plant community types (phytoplankton, intertidal benthic microalgae, submerged macrophytes, intertidal salt marsh, supratidal salt marsh and reeds and sedges). Macroalgae, mangroves and swamp forest were absent. The latter two plant community types only occur along the east coast in mostly subtropical areas.

Submerged macrophytes

The seagrass *Zostera capensis* was found in the lower reaches of the estuary probably because of the high winter flows reducing salinity in the middle-upper reaches. *Potamogeton pectinatus* occurred in the upper reaches, this plant grows best at a salinity less than 10 ppt, whereas *Zostera* grows best at a salinity greater than 20 ppt. *Zostera* beds are important as they provide sheltered food rich habitats for many estuarine invertebrates and juvenile fish. *Eicchornia crassipes* (water hyacinth) was present in the upper freshwater reaches of the estuary during the survey in 2000. Hyacinth is an indicator of eutrophic conditions. It is a floating macrophyte that gets flushed into estuaries during floods but does not survive, as it cannot tolerate salinity greater than 5 ppt.

Zostera beds are easily disturbed by bait digging and trampling. Once the root and rhizome system have been disturbed the plants may take years to recover. The plants are also sensitive to increases in turbidity as a result of boating activities that stir up bottom sediments and reduce light available for photosynthesis.

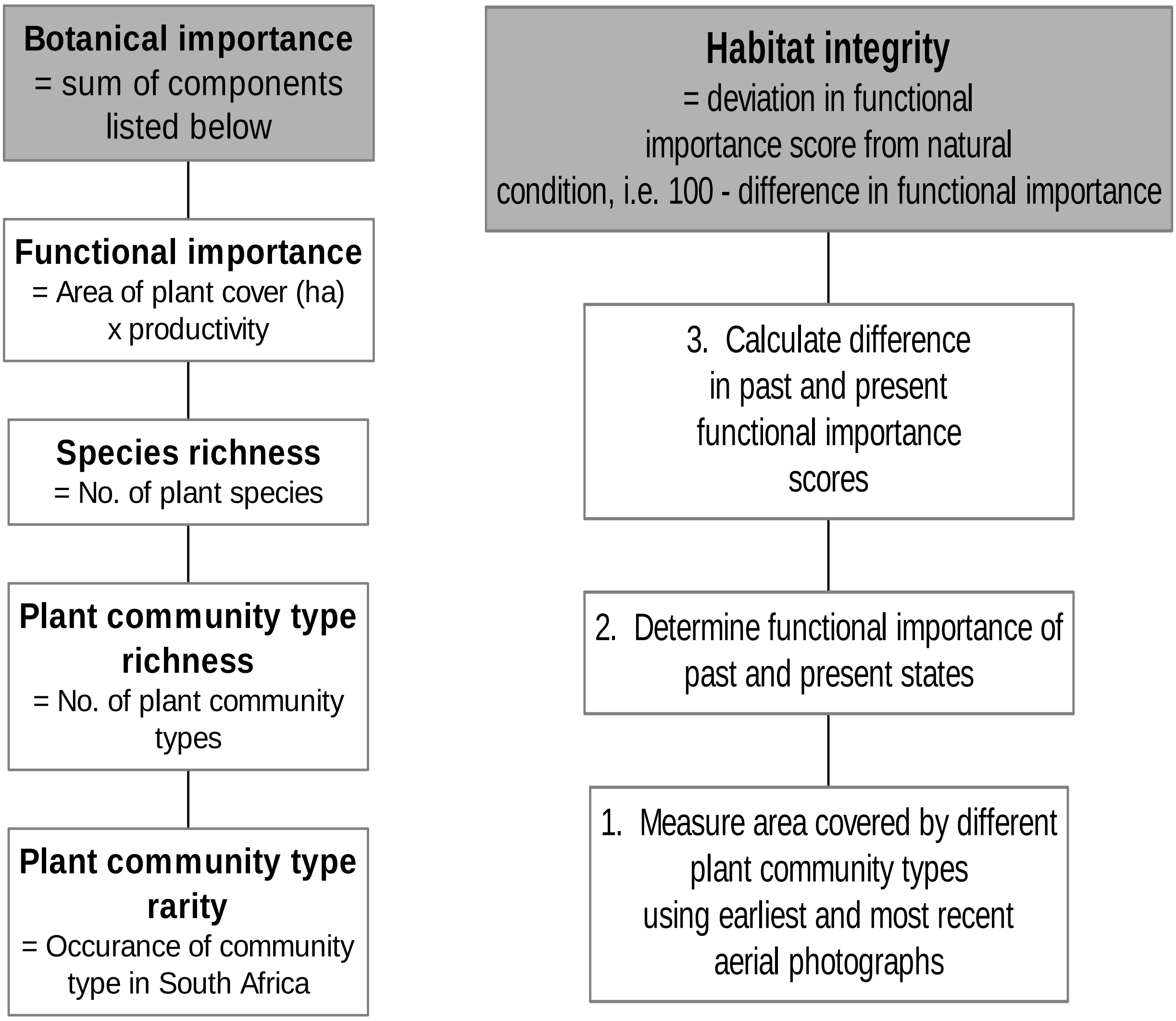

Figure 1: Flow chart depicting the components of the botanical importance rating and habitat integrity index.

Salt marsh

The largest salt marsh occurred at Green Point with less extensive marshes in small coves and tributary sites along the estuary. *Juncus kraussii* and *Cotula coronopifolia* were dominant at these small marshes. These species are indicative of brackish conditions.

Vegetation and physico-chemical data were collected along two transects at Green Point. The species found in the intertidal and supratidal salt marsh corresponded with those found by O'Callaghan. The kite-diagrams in Figure 2 and 3 below represent the percentage cover for the most dominant (> 5% average cover per site) salt marsh species found during the March 2000 survey. The floodplain was dominated by *Sarcocornia pillansii* and *Disphyma crassifolia* whereas the intertidal areas are made up out of several dominant species, i.e. *Cotula coronopifolia*, *Triglochin sp.* (both *T. striata* and *T. bulbosa*), *Chenolea diffusa* and *Sarcocornia perennis* (Table 5). The transects started just above the *Zostera capensis* zone and as a result this species is not included in the figures. The intertidal species were restricted to the first 100m of the transect and were low enough to receive water through tidal action.

There was little sign of salt accumulation in the marsh. According to anecdotal evidence the marsh is never inundated by floods, but has been inundated by seawater when there are storms at sea. The salt marsh was characterized by high soil moisture and low soil conductivity. Water, salinity and particle size are the most important controlling factors determining the distribution and percentage cover of vegetation in salt marshes. The low soil conductivity (20mV average) and high moisture content (9% average) of the Green Point marsh is conducive to growth and is evident in the high vegetation cover, especially of *S. pillansii*, compared to other estuaries such as the Olifants Estuary on the West Coast and the Swartkops Estuary near Port Elizabeth. Particle size analysis indicated a higher percentage silt in the first 100 m compared to a higher percentage clay further along the transect. This compares well with other marshes, where the intertidal area and areas of the supratidal marsh that are frequently inundated have a higher silt content in the sediment.

Transect 2 had a higher soil pH and lower soil redox potential than Transect 1. This was probably due to the higher elevation of Transect 1. It is less prone to inundation and subsequent decrease in available oxygen in the soil. Distance from the river edge was negatively correlated to the percentage soil moisture, i.e. the greater the distance from the river, the less moisture in the soil. Conductivity was positively correlated to depth, i.e. the amount of soluble ions increased with depth, indicating a saline water table.

Table 3: Electrical conductivity (mS) of the soil at 100m, 200m and 300m along both transects at three different depths (0-0.1m, 0.1-0.2m and 1.0-1.1m).

Trs. no. & distance	Depth		
	0-0.1m	0.1-0.2m	1m-1.1m
1 100m	6.7	0.3	32.8
200m	24.2	19.4	31.7
300m	27.4	13.3	21.6
2 100m	32.9	15.2	45.4
200m	13.2	0.1	31.3
300m	18.51	11.04	17.28

Table 4: Soil redox potential and pH of transects 1 and 2 at 100m, 200m and 300m and at the three different depths (0-0.1m, 0.1-0.2m and 1.0-1.1m).

Trs. No. and distance	Redox potential (mV)			pH		
	Depth			Depth		
	0-0.1m	0.1-0.2m	1m-1.1m	0-0.1m	0.1-0.2m	1m-1.1m
1 100m	293	318	399	6.7	8.9	8.3
200m	253	214	239	7.8	8.9	8.3
300m	321	355	253	5.5	5.2	7.8
2 100m	264	287	203	7.7	7.8	7.2
200m	248	282	297	7.6	7.4	7.3
300m	269	251	254	7.6	7.6	7.9

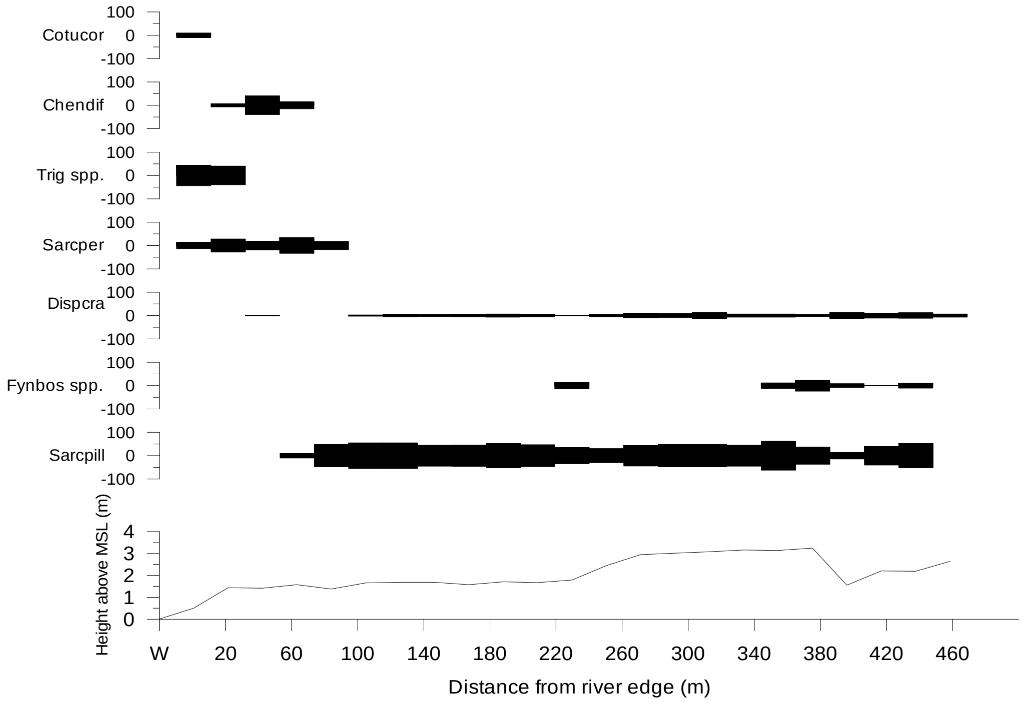

Figure 2. Kite-diagram of the percentage cover of dominant species along Transect 1 (Cotucor = *Cotula coronopifolia*; Chendif = *Chenolea diffusa*; Trig spp. = *Triglochin* spp.; Sarcper = *Sarcocornia perennis*; Dispcra = *Disphyma crasifolia*; Sarcpil = *Sarcocornia pillansii*).

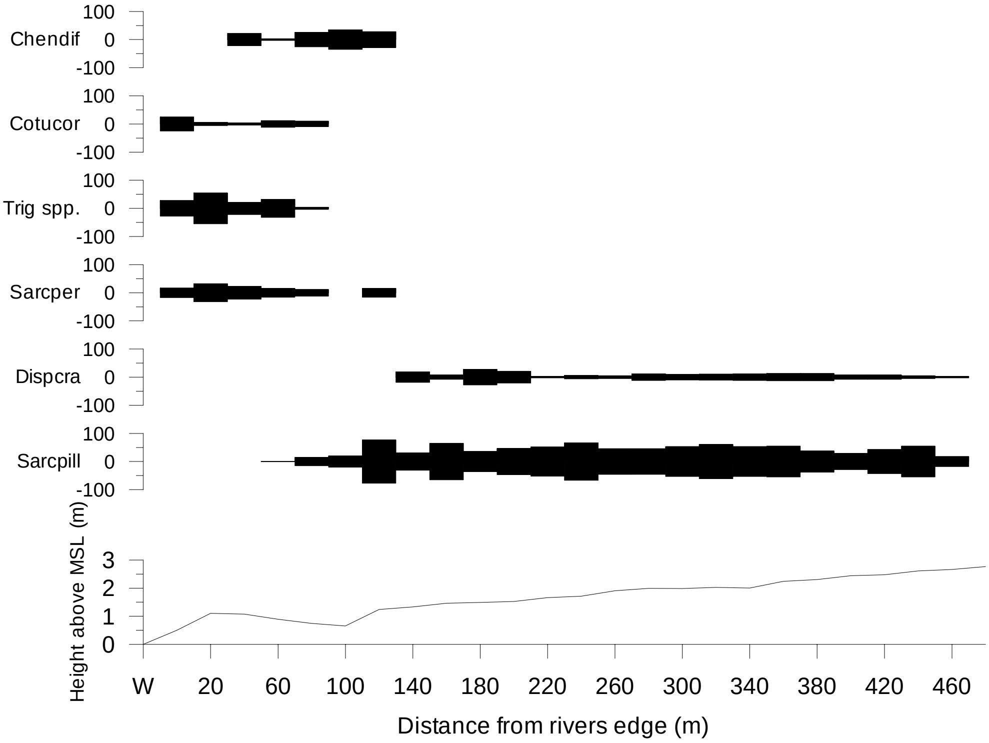

Figure 3. Kite-diagram of the percentage cover of dominant species along Transect 2 (Cotucor = *Cotula coronopifolia*; Chendif = *Chenolea diffusa*; Trig spp. = *Triglochin* spp.; Sarcper = *Sarcocornia perennis*; Dispcra = *Disphyma crasifolia*; Sarcpil = *Sarcocornia pillansii*).

An open mouth is important as this maintains the intertidal salt marsh community. Salt marsh plants are distributed away from the water's edge along an inundation gradient. Distinct zones of intertidal and supratidal plants were found. Tidal exchange is important for maintaining nutrient exchange between the marsh and the estuary.

Reeds and sedges

Large reed beds characterize the upper reaches of the estuary and begin approximately 12 km from the mouth at the position where the power lines cross the river. This area could not be mapped from the available photographs as only photographs of the lower reaches of the estuary were available. These plants can survive tidal inundation with saline water if their roots and rhizomes are located in freshwater (Adams and Bate 1999). They are therefore good indicators of sites of freshwater seepage. High nutrient loads to the estuary would promote the growth and expansion of *Phragmites australis* (reeds). A reduction in the frequency of floods and the accumulation of sediments in the upper estuary would also result in encroachment into the main estuary channel.

Table 5: List of plant species found in the Breede Estuary.

Species	Family	Plant community type
Apium graveolens		Supratidal salt marsh
Chenolea diffusa Thunb.	Chenopodiaceae	Intertidal salt marsh
Cotula coronopifolia Thunb.	Asteraceae	Intertidal salt marsh
Cyperus textiles	Cyperaceae	Reeds and sedges
Disphyma crassifolium (L.) L. Bol.	Mesembryanthemaceae	Supratidal salt marsh
Juncus kraussii Hochst	Juncaceae	Reeds and sedges
Limonium scabrum Thunb.	Plumbaginaceae	Salt marsh
Phragmites australis (Cav.) Steud.	Poaceae	Reeds and sedges
Potamogeton pectinatus L.		Submerged macrophyte
Plantago carnosa Forssk.	Plantaginaceae	Supratidal salt marsh
Salsola sp		Supratidal salt marsh
Samolus sp	Primulaceae	Supratidal salt marsh
Sarcocornia decumbens (Tolken) A.J. Scott	Chenopodiaceae	Intertidal salt marsh
Sarcocornia pillansii (Moss) A.J. Scott	Chenopodiaceae	Supratidal salt marsh
Sarcocornia perennis (Mill) A.J. Scott	Chenopodiaceae	Intertidal salt marsh
Sarcocornia natalensis (Bunge ex Ung.-Sternb.) A.J.	Chenopodiaceae	Intertidal salt marsh
Scott		Salt marsh
Schoenoplectus scirpoides		Reeds and sedges
Spartina maritime (Curtis) Fernald	Poaceae	Intertidal salt marsh
Sporobolus virginicus (L.) Kunth.	Poaceae	Reeds and sedges
Triglochin bulbosa L.	Juncaginaceae	Salt marsh
Triglochin striata Ruiz. & Pav.	Juncaginaceae	Salt marsh
Typha capensis (Rhorb.) N.E. Br.	Typhaceae	Reeds and sedges
Zostera capensis Setch.	Zosteraceae	Submerged macrophyte

3.2 Botanical importance

The botanical importance score for the Breede Estuary was 350. Table 6 shows this score by comparison with other South African estuaries. The Breede Estuary has the fifth highest botanical importance score of all estuaries in South Africa. It shares this position with the Swartkops, Mlalazi and Berg estuaries. These are all permanently open estuaries with high species richness that have large areas covered by estuarine plants.

Table 6: The botanical importance scores of some South African estuaries. The component scores of functional importance, species richness, community richness and habitat rarity are shown. The Breede Estuary is indicated in bold

Estuary	Functional importance	Species richness	Community richness	Habitat rarity	Botanical Importance
St Lucia	100	100	100	100	400
Mngazana	85	100	100	100	385
Knysna	85	100	80	95	360
Keiskamma	85	100	80	95	360
Breede	**75**	**100**	**80**	**95**	**350**
Swartkops	75	100	80	95	350
Mlalazi	75	75	100	100	350
Berg (Groot)	85	90	80	95	350
Olifants	85	100	80	80	345
Great Fish	75	95	60	80	310
Groot Brak	65	80	60	80	285
Kabeljous	65	80	40	80	265

3.3 Reference condition and present status

Table 7 indicates that there has been a decrease in the area covered by the salt marsh. However this may be due to mapping error but could also be as a result of erosion. Submerged macrophytes were not visible on the 1989 aerial photograph. This may be due to flooding and removal of the *Zostera* beds. A decrease in the distribution and biomass of *Zostera capensis* in other South African estuaries has been related to large floods that uproot the plants and remove them from the estuary (Adams and Talbot 1992, Talbot *et al*. 1990). .

Carter (1983) and de Villiers (1988) related the loss of *Zostera* beds to marine sedimentation and smothering. De Villiers (1988) documented the decline of *Zostera* cover between 1942 and 1987 (Table 7). Our field surveys in 2000 showed that these beds have increased in cover to approximately 6 ha. Strong tidal flows in the mouth area and the redistribution of sediments are probably responsible for the dynamics of the *Zostera* beds.

Table 7: Changes in *Zostera* cover on the flood tide delta in the Breede River Estuary over the period 1942-1987 (De Villiers 1988).

Aerial photograph Year Day/ Month	*Zostera* cover (ha)
1942 -	22.8
1954 3/04	19.9
1967 8/05	15.5
1974 26/05	8.8
1981 9/04	4.8
1987 23/02	2.5

From 1942 to 2000 the area covered by the different plant community types has decreased. The functional importance score was reduced from 227830.81 to 203883.25. This was expressed as a 10.5 % deviation from the natural condition and the estuary thus obtained a habitat integrity score of 40.

The salt marsh at Green Point is in a good condition. The marsh has high soil moisture content and low soil salinity compared to other marshes. This is probably due to the high winter rainfall of the area. As a result of this the marsh is characterized by high species richness (22 species) for such a small area.

Direct human influence on the salt marsh is restricted to a couple of trails through the supratidal area. The farmer whose property borders onto the salt marsh allows his sheep to graze here during the drier times of the year. The influence of grazing on the salt marsh is evident in the low growth form of *S. pillansii*. The activities that will most impact on the salt marsh is the pumping of prawns and worms and the beaching of boats on the *Zostera* beds and mud flats. The marsh showed signs of erosion, possibly as a result of the heavy boating activity in this region.

Table 8: The area covered by different plant community types(ha), functional importance scores and percentage change over time.

Habitat	1942	1981	1989	2000
Sand (intertidal benthic microalgae)	146.81	135.3	135.68	136
Intertidal marsh	22.5	19.45	16.99	20.5
Supratidal marsh	32.15	30.5	21.03	29.55
Submerged macrophytes	25.67	5.09	0	6
Water (phytoplankton)	835	835	835	835
Reeds and sedges	-	-	4.8	4.8
Functional importance score	227830.81	195696.34	187466.69	203883.25
% Change		14.1	17.7	10.5

Table 9: Past and present functional importance and habitat integrity scores of selected estuaries compared with the Breede Estuary.

Estuary	Past functional importance scores	Present functional importance score	Habitat integrity score
Mngazana	329685	312604	99
Mntafufu	38134	29116	76
Mnyameni	20248	14815	73
Swartkops	280357	182666	65
Mlalazi	224042	128816	57
Mtentwana	4253	1815	42
Nhlabane	120585	13666	11
Breede	**227830.81**	**203883.25**	**89.5**

3.4 Effect of future development scenarios on the macrophytes

The most important changes that have occurred from the reference to the present state is the reduction in freshwater input and increase in saline intrusion. As a result of this there would have been reed die-back, loss of pondweed habitat and a change in the community composition of the brackish marshes. Reed die-back would not occur if there was a fresh / brackish groundwater source as these plants can survive tidal inundation with saline water if their roots and rhizomes are located in brack water (< 20 ppt, Adams and Bate 1999). Pondweed (*Potamogeton pectinatus)* grows best in brackish water (< 10 ppt). As salinity moves further upstream saline species such as the seagrass *Zostera capensis* would replace brackish species such as pondweed. The small salt marshes of the Breede Estuary are characterised by brackish species i.e. *Juncus kraussii* and *Cotula coronopifolia*. Under saline conditions more salt tolerant plants may replace them.

There has also been a reduction in the highest average monthly flows. As a consequence of this the flushing of sediments by floods may have been reduced. Accumulation of sediment would encourage growth of reeds into the main estuary channel. Agricultural activities have resulted in elevated nitrate concentrations in the river and estuary in the winter months. Water hyacinth, an indicator of eutrophication, was found in the upper reaches of the estuary. The increase in nutrients may have stimulated reed growth

The salt marsh at Green Point should be little affected by future development scenarios. The low soil salinity and high soil moisture indicates that precipitation is an important source of freshwater. The water table is brackish and the overlying sediment has lower soil conductivity than the sediments under the water table, indicating that the plants are probably not drawing water up from the water table.

A reduction in the frequency of floods has resulted in the expansion of *Zostera* beds in some estuaries (e.g. Kromme and Kariega estuaries). This response is unlikely in the Breede Estuary as the tidal flows are probably more important in redistributing sediments in the lower, mouth reaches of the estuary and this would influence the distribution and abundance of these plants.

3.4.1 Salinity tolerance of common reed (*Phragmites australis*)

Observations from a number of South African estuaries have shown that *Phragmites* forms dense beds in the upper brackish (<15 ppt salinity) reaches of estuaries. In estuaries where *P. australis* was tidally inundated with seawater (35 ppt) the plants always appeared to occur at sites of freshwater seepage. Laboratory studies indicated that as early as the 2nd day after plants were exposed to saline water (20 ppt) they showed signs of stress (i.e. decrease in fluorescence). After the second week of receiving 20 ppt salinity stem elongation was significantly reduced compared to plants treated with freshwater (Adams and Bate 1999). Lethal salinity levels for *P.australis* are considered to be > 30 ppt. Slow die-back of *P.australis* was recorded at > 46 ppt in Lake St Lucia.

From laboratory studies Benfield (1994) found the minimum concentration of NaCl that was lethal to *P. australis* seedilings was 21.3 $\pm$ 1.7 ppt. The LC50 (that level of the environmental entitiy beyond which 50% of the population cannot live for an indefinite time) for NaCl was at 16.7 ppt.

From these data the rule used for *Phragmites* response to increased salinity in the Breede Estuary was that after 3 months at 20 ppt the plants would die-back.

Table 10: Estuarine Health Index scores for macrophytes for the different run-off scenarios.

	Present	Limited	Moderate	Bromberg	Le Chasseur
% Natural MAR	57.9	53.4	48.3	43.3	36.4
Species richness	100	100	90	90	90
Abundance	80	80	77	75	70
Community composition	100	100	85	85	85

3.4.2 Present conditions

The biggest change in the freshwater flow to the estuary has occurred from natural to present conditions. The estuary now receives only 57.9 % of the natural MAR (Table 10). As a result of this saline water has moved further upstream. Under reference conditions 20 ppt salinity would have only occurred 12 km from the mouth for a couple of tidal cycles, now salinity in this region is 20 ppt for 4-5 months of the year (Table 11). From 12-26 km up the length of the estuary salinity between 20-30 ppt can occur during a low flow period (Table 12). The reeds occur from approximately 12 km upstream from the mouth and would have been affected by this increase in salinity. *Phragmites* grows optimally at a salinity less than 15 ppt . A decrease in growth and abundance would occur during low flow periods and therefore an abundance score of 80 is assigned for the calculation of the Estuarine Health Index score (Table 10). Although the salinity is outside the optimal range of tolerance for 4-5 months of the year, the reeds are found in this area, they are probably maintained by the lower salinity for the majority of the year. The role of groundwater in sustaining the reeds also needs investigation. Species richness and community composition would not have changed significantly between the reference and present condition. Although conditions have become more saline the estuary is still freshwater dominated (State 1) for 5 months of the year (Table 13).

Pondweed (*Potamogeton pectinatus*) grows optimally at salinity less than 10 ppt. Under reference conditions this zone would have stretched from 22 km upstream. Under present conditions this zone now starts at 37 km (Table 12) so overall 15 km of potential habitat for this species has been lost.

3.4.3 Limited future development scenario

The species richness, abundance and community composition scores remain the same as for the present condition (Table 10). Salinity at 12 km upstream from the mouth would occur for 4-5 months of the year, similar to that of the present state (Table 11).

3.4.4 Moderate future development scenario

Compared to the present and limited development scenario a further 3 km of habitat for pondweed would be lost. The zone where salinity was less than 10 ppt would now occur from 40 km upstream of the mouth (Table 12). Species richness was thus assigned a score of 90. The seagrass *Zostera capensis* would extend into the middle reaches of the estuary and thus brackish species would be replaced by saline species.

An abundance score of 77 was assigned as pondweed habitat (area less than 10 ppt) would be reduced by a further 3 km (Table 12) and reeds would be exposed to salinity greater than 20 ppt for an extra month. Reeds would probably dieback during the low flow summer months and because the duration of exposure to suboptimal salinity is longer they will take longer to grow back. Available habitat for invertebrates and fish would be lost as well as the detritus food source.

Community composition would change as the small salt marshes characterised by brackish species i.e. *Juncus kraussii* and *Cotula coronopifolia* would be replaced by saline marshes with more salt tolerant species. These marshes occur in the lower reaches of the estuary. This area would receive less freshwater as State 1 (freshwater dominated state) would only occur for 3 months of the year (Table 13). Freshwater is important in flushing out accumulated salts in marshes.

3.4.5 Bromberg future development scenario

Abundance score would decrease due to a further loss of pondweed habitat and effect of saline water on the reed beds. Salinity of 30 ppt would occur for 2 months 12 km upstream from the mouth. Unless the roots and rhizomes of the reeds where located in fresh / brackish water they would die-back. The species richness and community composition scores would remain the same as for the moderate development scenario.

3.4.6 Le Chasseur future development scenario

An abundance score of 70 was assigned. At 12 km upstream from the mouth salinity would remain at 20 ppt for 7 months of the year and 30 ppt for 3 months of the year (Table 11). This would result in reed die-back as for most of the year salinity would remain in the sub-optimal tolerance range. Some re-growth could occur for the remaining 2 months of the year but this is unlikely as this would be winter that is not the growing season for the plants. The suboptimal salinity conditions (i.e. 20-30 ppt) would extend from the mouth to 30 km upstream, above the 30 km reach reeds would still grow but potentially reeds could be lost for a 16 km reach along the estuary (i.e. 14-30 km, Table 12).

Table 11: Duration of salinity penetration 12 km upstream from the mouth reached during the low flow period (< 10 m^3/s) for the median simulated flows in the Breede Estuary (Taljaard *et al*. 2001).

Scenario	**Median flows (months)**
Reference : 20 ppt	Move past with tidal cycle
Present: 20 ppt	4-5 months
Limited : 20 ppt	4-5 months
Moderate : 20 ppt	5 months
Bromberg : 20 ppt 30 ppt	5-6 months 2 months
Le Chasseur : 20 ppt 30 ppt	7 months 3 months

Table 12: Distance (km) of maximum saline penetration reached during a low flow period (<10 $m^3 s^{-1}$) for the median flows in the Breede Estuary. Total distance for each salinity range shown in brackets.

Scenario	**20-30 ppt**	**10-20 ppt**	**< 10 ppt**
Reference	9-14 (5)	14-22 (8)	22-50 (38)
Present	12-26 (14)	26-37 (11)	37-50 (13)
Limited	12-26 (14)	26-37 (11)	37-50 (13)
Moderate	13-28 (15)	28-40 (12)	40-50 (10)
Bromberg	14-31 (17)	31-44 (13)	44-50 (6)
Le Chasseur	14-30 (16)	30-42 (12)	42-50 (8)

Table 13: Duration of states (months) for the different run-off scenarios (Taljaard *et al*. 2001).

Scenario	**State 1**	**State 2**	**State 3**	**State 4**	**State 5**
Flow ($m^3 s^{-1}$)	> 20	10-20	3-10	0.5-3	<0.5
Salinity (ppt) at 10km after 4 months	2-26	8-30	24-33	24-35	31-35
Reference conditions	7	2	3	None	None
Present conditions	5	1	4	2	Occurs
Limited future development	4	2	4	2	Occurs
Moderate future development	3	2	4	3	Occurs
Bromberg future development	3	2	3	4	Less
Le Chasseur future development	2	2	3	5	None

3.5 Future monitoring requirements

The confidence of the reserve determination for the macrophytes can be improved by establishing the extent to which the reeds are dependent on groundwater input. If the reeds are dependent on groundwater then the salinity of the water column can increase to greater than 20 ppt without affecting reed growth.

Aerial photographs are needed to determine change in habitat. From aerial photographs the area covered by the different macrophytes can be calculated and changes in response to the reserve noted. For example a loss of reeds or change in marshes can be measured.

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APPENDIX F

Specialist Report:

Invertebrates

This report was compiled by:

Prof Tris Wooldridge

Dept of Zoology Department
University of Port Elizabeth, Port Elizabeth, 6000

July 2001

Executive summary

- The composition and distribution of invertebrates in the Breede River estuary was investigated in March and September, 2000. Both sampling occasions coincided with relatively high river flows. These data compliment previous information, although earlier information was not of a quantitative nature.

- Sediment particle size analysis indicated that in subtidal channels, sediment was mainly composed of fine to medium sands (125 – 500 microns). Relatively coarse sand occurred on the intertidal banks near the mouth, while fine muds dominated upstream of Groen Punt.

- Zooplankton and the hyperbenthos (22 species) were poorly represented (numerical abundance) in the estuary, probably because of strong tidal currents and the flushing effect this has on populations.

- Benthic invertebrates recorded in grab samples numbered 38. Taxa were largely represented by polychaetes, tanaeids, isopods and amphipods. Tanaeids were particularly abundant in the middle reaches.

- The intertidal community (31 species) was dominated by polychaete worms and burrowing crustaceans. Abundance of the mudprawn *Upogebia africana* was very high at stations where it occurred.

- Statistical analysis indicated that communities sampled along the estuary showed a high degree of dissimilarity between sites.

- The river prawn *Palaemon capensis* was abundant in the brackish water zone where fringing macrophytes (*Phragmites australis*) occurred. Reeds and sedges appear to be major contributors to the estuarine foodweb through the supply of large quantities of detrius. River prawns are closely associated with reed beds and trapped mats of water hyacinth. Although very difficult to quantify, observed densities of river prawn suggest that they occupy a key role in the estuarine foodweb.

- Under the reference condition, density of some intertidal species such as the sandprawn *Callianassa kraussi* and *Upogebia africana* was probably more variable over time compared to the present scenario. This would be due to greater river dominance.

- The invertebrate fauna in the estuary is not likely to change significantly under the Limited Development scenario. However, under the Moderate Development scheme, biomass of the dominant intertidal fauna is likely to increase, while biomass of river prawns will probably decrease.

- Fluctuations in invertebrate community structure likely to be more variable under the Bromberg and Le Chasseur development scenarios. In addition, changes in the structure of the estuarine foodweb is likely to occur.

Introduction

The Breede River on the warm temperate south coast has a catchment area of over 12500 km^2 and drains part of the winter mountainous rainfall region. The drainage basin has an estimated Mean Annual Runoff (MAR) of 1893 x 10^6 m^3 (Carter 1983). Relatively high rainfall in the mountains leads to strong river flows in winter, although occasional pulses of increased river flow are experienced during summer. The coastal plain has a very low gradient and the river is tidal for about 50 km, although saltwater intrusion is highly variable within and between years. During dry summers, estuarine salinity conditions extend as far as Malgas, 40 km from the coast. Normally, 'appreciable salinity conditions' extend about 16 km upstream in summer, although in winter the whole estuary may become fresh throughout the water column (Day 1981).

Brief description of the estuary

The Breede River estuary opens to the sea at St Sebastian Bay near Cape Infanta. Estuarine banks are steep and largely composed of shales. Intertidal areas are mostly narrow, although near the mouth extensive sandbanks up to 1 km wide occur on the western side. Intertidal sediments change to mud near Groen Punt and sometimes extend uninterrupted for hundreds of metres along the shoreline in the lower third of the estuary.

Maximum width at high tide near the mouth exceeds 1 km, decreasing to about 500-700 m at the 12 km chainage. At Malgas, the estuary is approximately 150 m wide. Water depth is highly variable, ranging between 17.6 and 2 metres in channel areas (quoted in Carter 1983). Average depth is above 4 m (Taljaard *et al*, this report series), although the middle and uppermost reaches tend to be shallower compared to the lower estuary.

Invertebrates of the Breede River estuary

Biologists from the University of Cape Town undertook several visits to the estuary between 1950 and 1980, summarized in Day (1981). These surveys indicated a relatively rich benthic fauna, although data also include species from hard substrata. The sandbanks at the mouth were regarded as 'rather poor', since no sandprawns (*Callianassa kraussi*) were found, and pencil bait (*Solen capensis*) and bloodworm (*Arenicola loveni*) occurred only in patches. The mudprawn *Upogebia africana* was abundant with densities up to 400 m^{-2}. Eelgrass patches (*Zostera capensis*) yielded an abundance of shrimp (*Palaemon perengueyi*), amphipods (*Melita zeylanica*) and small crabs (*Hymenosoma orbiculare*). Other crab species found at higher tidal levels included *Paratylodiplax edwardsii* and *Sesarma catenata*. Carter (1983) documented more recent surveys and indicated that about 149 invertebrate species were recorded in the estuary. Carter's list of species also includes organisms found on hard substrata.

Two additional invertebrate surveys to the estuary were undertaken in summer (18-23 March) and winter (13-15 August) of the year 2000. The main purpose of the two visits was to:

- quantify the dominant species of invertebrates (previous information was largely non-quantitative) present in soft sediments and in the hyperbenthos (organisms living in the water layer close to the substrate), and
- to determine distribution patterns along the horizontal salinity gradient in the estuary.

The two surveys were designed to gather information during the low and high rainfall months, but both visits coincided with periods of high rainfall when low salinity values extended far downstream in the estuary.

Methods of sampling

On each sampling trip, benthic invertebrates were collected using a Van Veen grab (210 cm^2 in area, sampling to 10 cm depth). Three replicate samples (each replicate was the composite of three grabs) were taken at Stations G1-G5, at the Power Line and at Groen Punt (Fig.1). Grab samples were passed through a 0.5 mm mesh screen and animals collected were stored and preserved in small bottles for later analysis in the laboratory.

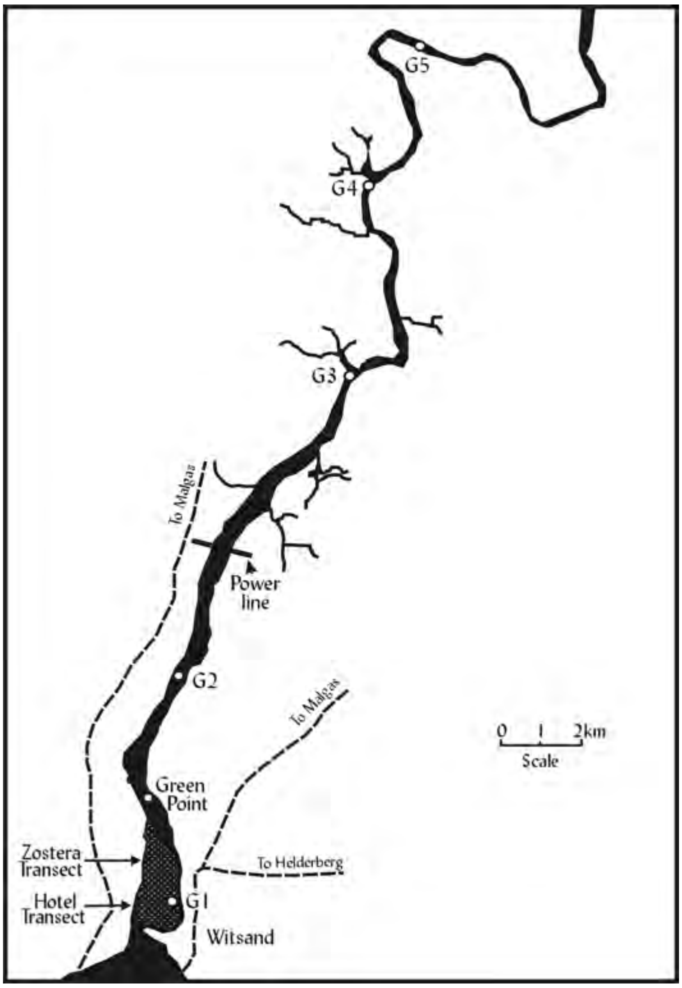

Fig.1. Map of the Breede River Estuary showing position of the sampling sites. See text for explanation of codes.

Intertidal invertebrates were sampled across four transects. Two transects were located on the sandbank in the lower estuary, the first transect (H) positioned directly opposite G1 and the second (Z) a short distance upstream where patches of *Zostera capensis* occurred. The third intertidal transect (G) was located across the mudbank at Groen Punt (Green Point) and the fourth (T) across the mudbank opposite G2 on the western side. Samples were collected at the lower, mid and high tide levels of spring tide along each transect. At each level, three replicate 0.25 m^2 quadrates were dug to a depth of 30 cm and the excavated material sieved through a 0.50 mm mesh bag. Organisms retained by the mesh were stored and preserved in small bottles for later analysis. Large burrowing invertebrates were not effectively sampled using the above method. Instead, burrow counts (five replicates) were done at all sites for species such as blood worm (*Arenicola loveni*), sandprawn (*Callianassa kraussi*), mudprawn (*Upogebia africana*), marsh crabs (*Paratylodiplax edwardsii* and *Sesarma catenata*), bubble crabs (*Dotilla fenestrata*) and pencil bait (*Solen* spp).

Hyperbenthic samples were collected at all five stations (G1-G5) using a bottom sled. The rectangular mouth frame supported on skids measured 74 cm x 64 cm. A calibrated flowmetre mounted in the opening quantified water volume passing through the 1 mm mesh net attached to the frame. An average of 16.9 m^3 of water was sampled at each station. Vertical salinity and temperature profiles in the water column were measured at each station shortly before tows commenced. In addition, sediment samples were collected for particle size analysis

Additional samples (for freshwater shrimp *Palaemon capensis*) were collected using a hand net among reeds (*Phragmites australis*) and patches of water hyacinth (*Eichornia crassipes*) along the banks in the upper half of the estuary.

In the laboratory, samples were analysed to species level where possible and the data analysed using appropriate multivariate statistics found in the statistical package, PRIMER V.3.1b (Plymouth Routines in Multivariate Ecological Research). If multivariate techniques were not appropriate, other packages using MS Excel or Statistica for Windows were used.

Sediment analysis and salinity distribution

Sand grain analysis for four stations is shown in Table 1. Data were collected in March 2000 and reflect the sandy nature of the sediment, with most sites having a large proportion of fine to medium sand (retained by sievs of 125 – 250 microns). Most sites had a very small proportion of muds (<63 microns). Some deposition of fines occurred Site G3, located on an inner bend of the estuary.

Organic material in the sediment was low, with all sites registering <2% organic content. Calcium carbonate ($CaCO_3$) values registered <3%, except for Site G1 where $CaCO_3$ content was 36.5%.

Table 1. Sediment analysis at four subtidal sites in the Breede estuary. Values given as percentiles. Refer to Fig 1 for location of stations.

Particle size (microns	Site G1	Power line	Site G3	Site G4
2000	0.2	-	-	-
1000	1.3	-	0.6	-
500	13.2	3.5	11.9	7.2
250	62.3	90.6	27.0	16.9
125	20.4	4.7	50.7	75.1
63	1.6	0.1	9.4	0.2

Salinity values recorded on the two sampling occasions reflected river dominance that extended far downstream. On 18 March, surface and bottom salinity registered 10 and 12 ppt (parts per thousand) respectively at the Power Line site. Water depth was 4 m and readings were taken close to high water (16h30) around spring tides. Salinity at Groen Punt was 20 ppt at the surface and 32 ppt at the bottom (depth 7 m). At 0.5 m below the surface salinity had increased to 22 ppt.

On the 13 August, surface salinity at the Power line site was 5 ppt, while bottom salinity was 7 ppt (09h45). Water depth was 2.5 m. Readings were taken on an outgoing tide, 45 minutes before low slack water in the estuary. Low tide at sea occurred at 09h12.

Invertebrates of the Breede River estuary

Benthic and hyperbenthic fauna

A total of 38 species were recorded in grab samples (Table 1). Among polychaetes, *Desdomona ornata* (maximum abundance 900 m^{-2}) and *Prionospio sexoculata* (maximum abundance 374 m^{-2}) were numerically dominant. It was not possible to identify all worms to species level, mainly due to the occurrence of particularly small animals. The amphipod *Grandidierella* sp. (maximum abundance 642 m^{-2}), the isopod *Cyathura aestuaria* (maximum abundance 1222 m^{-2}) and the tanaid *Apseudes digitalis* (maximum abundance 13565 m^{-2}) were particularly abundant in the middle estuary (G3), while the mysid *Gastrosaccus brevifissura* was common at the Power Line site (maximum abundance 166 m^{-2}). Small mudprawns (*Upogebia africana*) were collected at muddy sites (maximum abundance at Groen Punt 24 m^{-2}), while the bivalve mollusc *Sanguinolaria capensis* attained a maximum of 766 m^{-2} at G1. Cluster analysis and the MDS ordination plot of the benthic invertebrates in the estuary indicated two main groups – a community associated with the upper freshwater dominated zone (G3, G4, G5) and the mid to lower sites having higher salinity values (G1, Groen Punt and G2 (Fig.2). The Power Line site did not fit into either of these groupings, possibly because of low species number at this site. Twenty-seven species were retained after excluding all those with less than 1% of total abundance. These species were then used in SIMPER analysis that indicated a dissimilarity of 80.52% between the two major groups.

Table 2. Species list of invertebrates collected in subtidal grab samples. Position of stations indicated in Fig. 1. Numbers represent abundance m^2.

	G1	Groenpunt	G2	Power line	G3	G4	G5
Polychaeta							
Capitella capetella	2.6	0.0	0.0	0.0	0.0	0.0	0.0
Ceratonereis keiskamma	0.0	0.0	0.0	15.8	123.7	154.0	5.3
Desdomona ornata	165.9	79.0	10.5	0.0	900.5	3.9	0.0
Eteone siphodonta	55.3	10.5	0.0	0.0	0.0	0.0	0.0
Eteone sp	0.0	7.9	0.0	0.0	0.0	0.0	0.0
Exogene normalis	2.6	0.0	0.0	0.0	0.0	0.0	0.0
Glycera tridactyla	5.3	86.9	21.1	0.0	0.0	0.0	0.0
Glycine sp	2.6	0.0	0.0	0.0	0.0	0.0	0.0
Nephtys hombergi	15.8	0.0	0.0	0.0	0.0	0.0	0.0
Nereid sp.	0.0	0.0	0.0	0.0	2.6	0.0	0.0
Phylo sp	2.6	0.0	0.0	0.0	0.0	0.0	0.0
Prionospio sexoculata	302.8	373.9	0.0	15.8	0.0	0.0	0.0
Prionospio sp	0.0	10.5	0.0	0.0	0.0	0.0	0.0
Scololepis squamata	71.1	0.0	0.0	0.0	0.0	0.0	0.0
Thelepus sp.	7.9	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified Polychaeta	560.8	431.8	15.8	0.0	0.0	59.2	31.6
Mysidacea							
Gastrosaccus brevifissura	0.0	0.0	60.6	165.9	0.0	0.0	0.0
Mesopodopsis wooldridgei	0.0	0.0	13.2	0.0	0.0	0.0	0.0
Cumacea							
Cumacean sp	0.0	2.6	0.0	0.0	0.0	0.0	0.0
Iphinoe truncata	34.2	26.3	10.5	0.0	0.0	0.0	0.0
Tanaidacea							
Apseudes digitalis	0.0	0.0	2.6	0.0	13565.0	0.0	0.0
Isopoda							
Cyathura aestuaria	0.0	0.0	5.3	0.0	1221.7	11.8	0.0
Amphipoda							
Grandidierella lignorum	0.0	7.9	7.9	0.0	189.6	3.9	5.3
Grandidierella sp	0.0	0.0	18.4	0.0	642.4	7.9	0.0
Decapoda							
Upogebia africana	5.3	23.7	18.4	0.0	0.0	0.0	0.0
Anomura							
Diogenes brevirostris	50.0	0.0	0.0	0.0	0.0	0.0	0.0
Brachyura							
Hymenosoma orbiculare	0.0	7.9	2.6	0.0	5.3	0.0	0.0
Mollusca							
Bivalve (red squares)	0.0	0.0	0.0	0.0	0.0	7.9	0.0
Corbicula africana	0.0	0.0	0.0	0.0	0.0	0.0	84.3
Levinsenia oculata	2.6	0.0	0.0	0.0	0.0	0.0	0.0
Modiolus capensis	0.0	0.0	0.0	0.0	0.0	11.8	0.0
Nassarius kraussianus	63.2	19.7	0.0	0.0	0.0	0.0	0.0
Natica tecta	0.0	10.5	5.3	0.0	0.0	0.0	0.0
Sanguinolaria capensis	766.2	126.4	15.8	0.0	0.0	0.0	0.0
Solen cylindraceus	0.0	7.9	2.6	0.0	0.0	0.0	0.0
Venerupis corrugatus	0.0	5.3	2.6	0.0	0.0	0.0	0.0
Echinodermata							
Echinocardium cordatum	0.0	2.6	0.0	0.0	0.0	0.0	0.0
Insecta							
Chironomid larvae	0.0	0.0	0.0	0.0	5.3	0.0	5.3

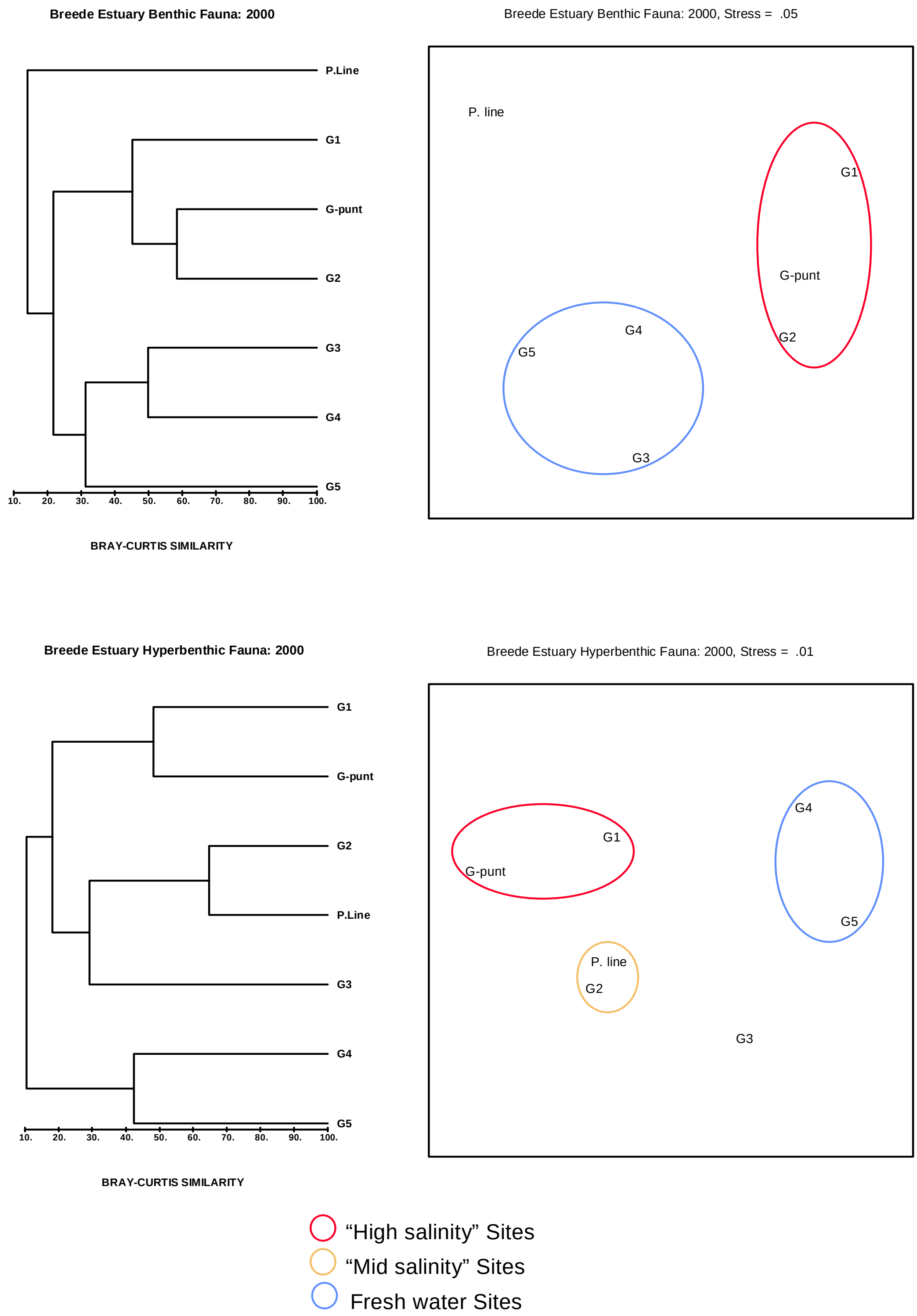

Fig. 2. Cluster analysis and MDS ordination plot for the benthos (upper figure) and for the hyperbenthos (lower figure).

Table 3. Hyperbenthic fauna collected in the Breede estuary. Numbers represent abundance m^{-3}.

	G1	Groen Punt	G2	Power Line	G3	G4	G5
Copepoda							
Acartia natalensis	0.0	0.0	15.3	109.8	0.0	0.0	0.0
Pseudodiaptomus hessei	0.0	0.0	91.7	114.4	88.1	0.0	0.0
Mysidacea							
Gastrosaccus brevifissura	0.1	0.0	0.2	6.3	0.0	0.0	0.0
Mesopodopsis wooldridgei	0.4	2.4	0.2	0.0	0.0	0.0	0.0
Rhopalophthalmus terranatalis	0.1	3.9	0.7	4.5	0.0	0.0	0.0
Cumacea							
Cumacean sp.	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Iphinoe truncata	0.1	0.0	0.0	0.3	0.0	0.0	0.0
Tanaidacea							
Apseudes digitalis	0.0	0.0	0.0	0.0	26.1	0.0	0.0
Tanaid sp	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda							
Corallana africana	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda							
Corophium triaenonyx	0.0	0.0	0.0	0.0	0.2	1.9	0.0
Grandidierella lignorum	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Grandidierella sp	0.0	0.0	0.0	0.0	1.6	0.0	0.2
Hyperiid sp	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Decapoda							
Decapod larvae	1.6	0.0	0.0	2.3	0.0	0.1	0.0
Murura sp	0.0	0.0	0.0	0.0	7.3	0.0	0.0
Palaemon capensis	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Brachyura							
Hymenosoma orbiculare	0.0	0.0	2.5	0.0	0.2	0.0	0.0
Hymenosoma zoea	0.0	0.0	2.5	0.0	0.0	0.0	0.0
Mollusca							
Ribbed mussel	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Pisces							
Heteromycteris capensis	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Solea bleekeri	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The hyperbenthic fauna (Table 3) was represented by 22 species, none of which were abundant. Cluster analysis (Fig. 2, lower figure) indicated three main groupings – a marine associated fauna (Zone A) recorded at G1 and Groen Punt, a mid-estuarine component (Zone B) at the Power Line and G2, and a freshwater associated fauna (Zone C) at G4 and G5. Site G3 did not group with any of the other sites. SIMPER analysis showed dissimilarity between the hyperbenthic faunal groups as follows:

Zone A & Zone B: 79.84%

Zone C & Zone A: 92.38%

Zone C & Zone B: 90.27%

The high values of dissimilarity between the zones indicate that many species present in these zones are specific to the zones in which they are found.

Intertidal fauna

Thirty-one species of intertidal macrofauna were recorded opposite the hotel (H) and *Zostera* areas (Z) (see Fig.1). Larger organisms such as sandprawn (*Callianassa kraussi*), mudprawn (*Upogebia africana*) and bloodworm (*Arenicola loveni*) were not sampled effectively along these transects (deep burrowing organisms) and only juveniles were retained in samples. Polychaetes were common at all localities, particularly around low and mid- water levels. The small worm, *Prionospio sexoculata* was particularly abundant at the uppermost site (T). Small crustaceans were also well represented numerically, while *C. kraussi* occurred along the hotel site and *U. africana* at muddy sites further up the estuary. The latter two species were most abundant along the low tide level.

Crabs such as *Dotilla fenestrata* was fairly common at the high tide level along the *Zostera* transect while *Paratylodiplax edwardsii* occurred around midtide at the muddy sites.

Cluster and MDS analyses (Fig. 3) showed that sandy sites (along transects H and Z) grouped separately from the two muddy sites (G and T). The main species identified in SIMPER analysis are shown in Table 5, while Table 6 indicates the percentage dissimilarity between sites.

Table 4. Species list of invertebrates collected at the intertidal sites. Position of stations indicated in Fig. 1. Numbers represent abundance m^2. **H** refers to the hotel transect and **Z** to the *Zostera* transect (see Fig.1). Site **G** is located at Groen Punt and Site **T** is located opposite G2**. L, M** and **H** refer to Low, Mid and High water levels respectively.

	HL	HM	HH	ZL	ZM	ZH	GL	GM	GH	TL	TM	TH
Polychaeta												
Arenicala loveni	15.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceratonereis keiskamma	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Desdomona ornata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
Glycera tridactyla	110.0	13.3	10.0	20.0	40.0	0.0	10.0	5.0	5.0	0.0	0.0	0.0
Nephtys hombergi	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nereid sp	0.0	3.3	0.0	3.3	50.0	30.0	1200.0	145.0	0.0	0.0	130.0	15.0
Phylo sp	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prionospio sexoculata	0.0	0.0	0.0	23.3	120.0	0.0	0.0	30.0	0.0	103060.0	0.0	0.0
Scolelepis squamata	0.0	10.0	0.0	16.7	23.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified polychaeta	15.0	0.0	65.0	66.7	600.0	6.7	0.0	195.0	600.0	530.0	96.7	0.0
Mysidacea												
Gastrosaccus brevifissura	0.0	16.7	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	3.3	0.0
Mesopodopsis wooldridgei	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cumacea												
Cumacean sp.2	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Iphinoe truncata	110.0	86.7	40.0	20.0	3.3	0.0	0.0	5.0	0.0	0.0	0.0	0.0
Tanaidacea												
Apseudes digitalis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	700.0	1405.0	6630.0	2280.0	510.0
Isopoda												
Cyathura aestuaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	70.0	1035.0	20.0	60.0
Eurydice longicornis	0.0	43.3	0.0	0.0	13.3	6.7	0.0	0.0	0.0	0.0	0.0	0.0
Sphaeromid juv	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Amphipoda												
Grandidierella lignorum	0.0	0.0	0.0	0.0	0.0	0.0	960.0	235.0	150.0	940.0	413.3	10.0
Decapoda												
Alpheus crassimanus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0
Callianassa kraussi	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upogebia africana	0.0	0.0	0.0	0.0	0.0	0.0	470.0	125.0	75.0	505.0	370.0	100.0
Brachyura												
Dotilla fenestrata	0.0	0.0	0.0	0.0	0.0	46.7	0.0	0.0	0.0	0.0	0.0	0.0
Hymenosoma orbiculare	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	6.7	0.0
Paratylodiplax edwardsii	0.0	0.0	0.0	0.0	3.3	0.0	5.0	20.0	0.0	0.0	56.7	0.0
Thaumastoplax spiralis	0.0	0.0	0.0	0.0	0.0	0.0	5.0	5.0	0.0	0.0	0.0	0.0
Mollusca												
Donax serra	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Littorinids	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Macoma litoralis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0
Orange bivalve	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sanguinolaria capensis	30.0	16.7	0.0	83.3	70.0	3.3	0.0	65.0	0.0	0.0	0.0	0.0

Table 5. Principal species identified along each transect in the Intertidal zone, with percentage abundance shown in brackets.

Hotel transect (H)	*Iphinoe truncata* (40%), *Glycera trydactyla* (27) and unknown polychaetes (13)
Zostera transect (Z)	Unknown polychaetes (24), *Sanguinolaria capensis* (22) and a Nereid sp (21)
Groen Punt (G)	*Grandidierella lignorum* (28), *Upogebia africana* (23), *Apseudes digitalis* (12) and *Glycera tridactyla* (11)
G2 (T)	*Apseudes digitalis* (35), *Upogebia africana* (23), *Grandidierella lignorum* (16) and *Cyathura aestuaria* (15)

Table 6. Simper analysis showing the dissimilarity between the four intertidal faunal groups.

Hotel & Zostera	62%
Groen Punt & Hotel	80%
Groen Punt & Zostera	73%
G2 & Hotel	93%
G2 & Zostera	84%
G2 & Groen Punt	44%

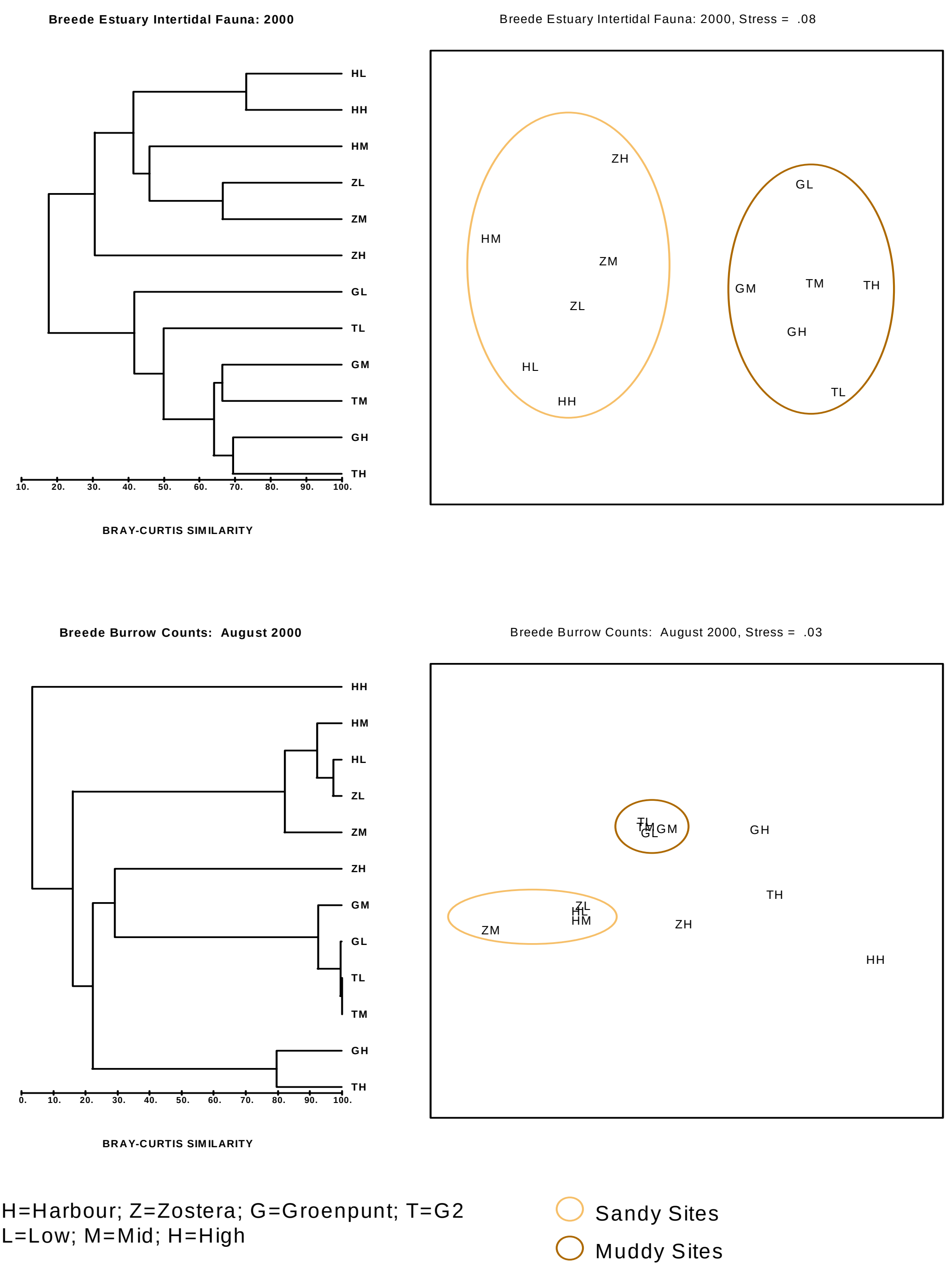

Fig. 3. Cluster analysis and MDS ordination plot for the intertidal benthos (upper figure) and for the burrow counts of larger intertidal species (lower figure).

Abundance of the larger burrowing organisms (e.g. *Solen* spp., *Arenicola lovenii*, *Callianassa kraussi, Upogebia africana*) or relatively motile organisms (*Dotilla fenestrata, Paratylodiplax edwardsii*) was quantified through burrow counts at the three interetidal levels (Table 7). In the case of *Upogebia africana*, abundance values are extremely high, probably due to a high proportion of juveniles.

Table 7. Abundance (numbers m^2) of larger burrowing invertebrates at three intertidal levels and at four sites in the Breede estuary. Call – *Callianassa kraussi*, *Solen* – *Solen* spp., *Arenicola* – *Arenicola lovenii*, *Dotilla* – *Dotilla fenestrata*, Up – *Upogebia africana*, *Sesarma* – *Sesarma catenata*, Para – *Paratylodiplax edwardsii*, Para/Up – mixed zone. Data from five replicate counts in each case. L, M and H refer to Low, Mid and High spring tide levels respectively. Station positions indicated in Fig.1.

Species/ Site	Call	Solen	Arenicola	Dotilla	Up	Sesarma	Para	Para/Up
Hotel L	18	2	2	0	0	0	0	0
Hotel M	20	5	5	0	0	0	0	0
Hotel H	0	0	0	50	0	0	0	0
Zostera L	14	1	1	0	0	0	0	0
Zostera M	31	4	0	0	0	0	0	0
Zostera H	0	0	2	0	0	0	0	0
Groen L	0	0	10	0	634	0	0	0
Groen M	0	0	12	0	787	2	0	0
Greon H	0	0	6	0	0	17	0	662
G2 L	0	0	9	0	612	0	0	0
G2 M	0	0	10	0	721	0	0	0
G2 H	0	0	2	22	0	1	0	169

Callianassa kraussii was the dominant species present at the low and midwater levels at the Hotel and Zostera sites. Numbers however, were relatively low. At low and midwater muddy sites, *Upogebia africana* was extremely abundant. The crab *Paratylodiplax edwardsii* occurred at the high water level, but burrows were difficult o distinguish from those of mudprawns. A second crab species *Sesarma catenata* occurred at mid and high water levels at Groen Punt. This transect abuts an extensive saltmarsh on the eastern shore. Cluster analysis (Fig.3, lower section) again distinguished a sandy and muddy shore component, with the high tide levels at each site excluded from the pattern.

Key factors influencing invertebrate distribution and abundance in the Breede River estuary

Water column salinity, sediment particle size and current velocity were identified as important abiotic factors influencing distribution of the biota in the estuary. Zooplankton was not considered an important biotic component in earlier surveys (reported in Carter et al. 1983) and the same conclusion was drawn following the two surveys undertaken in 2000 (present report). This is probably due to strong currents and a relatively low residence time of the water mass in the system. This conclusion also appears true for the hyperbenthos. Although plankton and hyperbenthic population densities probably increase during dry years (reduced flushing effects), it is unlikely that they become major links in energy transfer between trophic levels under present day conditions. Thus, the presence of the REI zone (where integrated salinity values are <10 ppt) with reference to the zooplankton is probably less important in the Breede in comparison to many other tidal estuaries. This is because of the channel-like nature of the estuary and strong currents that flush plankton from the estuary.

By contrast, major pathways in the estuarine foodweb are linked to benthic and intertidal organisms. Within each community, substrate type and salinity distribution are probably main determinants of community structure. Because of strong currents (irrespective of nutrient supply) phytoplankton is poorly represented in the Breede (Bate, this report series). This begs the question 'what is the main primary producer supporting the rich biotic community in the estuary'? Although no direct evidence is available, many bottom samples collected above the Power Line (particularly on the inner bends of the estuary) contained a high proportion of decaying organic debri. This material appeared to have originated from the fringing reed beds. Consequently, detritus originating from the fringing macrophytes is probably a key component supporting higher trophic levels in the estuary.

Additional non-quantitative sampling along the margins of the estuary suggested that the river prawn *Palaemon capensis* occurred in very large numbers among the fringing macrophytes (particularly *Phragmites australis*). Because of the strong association of prawns and reeds, it was not possible to directly quantify prawn abundance and only a broad assessment of their status was possible. *Palaemon* also occurred in abundance among mats of water hyacinth *Eickornia crassipes* trapped along the bank. Given their apparent abundance, river prawns are probably a key prey species for juvenile predatory fish such as the dusky cob *Argyrosomus japonicus*. A second species of river prawn, *Macrobrachium* sp. has also been recorded from the Breede estuary. The species has not been identified (a specimen was sent to the South African Museum by S. Lamberth). The typical lifestyle of other *Macrobrachium* species and *Palaemon capensis* incorporates an estuarine phase during the life cycle. Prawns move from river environments at the end of winter to the estuarine brackish water zones where breeding takes place. At the end of summer, prawns again migrate upstream. There is therefore direct inter-dependence between the river and estuary for some of the macrofauna, but these conclusions are tentative (very little published information is available) and further work is required.

Reference condition and present status

Hydrological data (Taljaard et al, this report series) indicate that catchment runoff to the estuary over the past 75 years been reduced by about 42%. Thus, the Breede River estuary was significantly more freshwater dominated under natural conditions compared to the present state. Because of river dominance much of the time (leading to low salinity values over most of the estuary), intertidal organisms such as *Upogebia africana* (mudprawn), Callianassa *kraussi* (sandprawn) and *Arenicola loveni* (bloodworm) were probably restricted to the lowest reaches of the estuary, but only if suitable substrate was present. Day *et al.* (1981) did not record sandprawn in their surveys of the estuary, while bloodworm and pencil bate occurred only in patches. Breeding in *Callianassa kraussi* is constrained by river dominance, since the species requires a salinity of about 20 ppt or higher for larvae to develop successfully.

The long-term effects of low salinity water (<10 ppt) on the reproductive success and survival of *Upogebia africana* is not well understood, but past freshwater dominance probably resulted in a smaller estuarine population (distribution along the estuary) compared to present conditions. Winter (pers. com.) has suggested that mudprawns require similar salinity conditions to sandprawn in order to breed successfully.

Thus, decreased river dominance between natural and present day conditions probably led to an increase in estuarine populations of intertidal organisms in the Breede estuary. By contrast, river prawns may have extended further downstream because of existing conditions in the past.

Effect of future development scenarios on invertebrates in the Breede River estuary

The Limited and Moderate Future Development scenarios will further decrease runoff by about 5 and 10% respectively. However, under normal rainfall conditions, salinity distribution in the estuary is not likely to change significantly compared to present day. Under drought conditions, greater intrusion of marine water upstream could lead to dieback of the fringing macrophytes (*Phragmites australis*) under the Moderate Development scenario. Drought conditions (as experienced by the estuary) could persist for longer than at present (State 4 – typical river flow rates varying between 0.5 and 3 m^3/s will persist for about 3.5 months compared to about 2 months per year at present). This will possibly lead to a reduction in habitat available to *Palemon capensis* on average over a period of years. The distribution of mud- and sandprawn is likely to extend further upstream under the Moderate scenario, provided suitable habitat is available. Zooplankton is likely to be little affected.

Similar responses experienced by the estuarine invertebrates are predicted for the Bromberg and Le Chasseur Developments, particularly in drought periods when river flows between 0.5 and 3 m^3/s will persist for about eight months during a dry year. Considerable dieback of reeds is likely to occur during these periods. The brackish water zone will be reduced considerably, decreasing the biomass of *Phragmites australis* and its contribution to the detritus pool. Ultimately the food web structure is likely to change significantly (reduced detritus from reedbeds and reduced habitat available to river prawns). By contrast, the zooplanktonic and hyperbenthic community is likely to increase because of increased residence time of the estuarine water, despite the relatively small REI zone. The net result will be a food web with a different structure compared to the present day scenario.

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APPENDIX G

Specialist Report:
Fish

This report was compiled by:

Steve Lamberth

July 2001

INTRODUCTION & BACKGROUND

Numerous developments entailing varying levels of water abstraction are being considered by the Department of Water Affairs and Forestry for the water resources of the Breede River system. These include the provisioning of irrigation for agriculture and the possible transfer of water to metropolitan areas. The feasibility of these developments and their impacts on flows and ultimately the river and estuarine ecosystems are being investigated under various components of the Breede River Basin Study. This report forms the fish component of an Intermediate RDM study on the Breede River Estuary co-ordinated by the CSIR.

The RDM methodology is driven by a scenario based approach. Runoff scenarios for the natural and present day conditions are used to define the present ecological status of the estuary and to determine the ecological reserve category (ERC). These runoff scenarios, together with a series of future runoff scenarios are then evaluated to derive the Reserve and Resource Quality Objectives for the estuary under consideration.

For the Breede River Estuary, the following future runoff scenarios were to be evaluated in addition to the natural (reference) and present runoff scenarios:

- Limited development scenario (46 % reduction of natural MAR)
- Moderate development scenario (52 % reduction of natural MAR)
- Bromberg scenarion - major development (57 % reduction of natural MAR)
- Le Chasseur scenario - major development (64 % reduction of natural MAR)

Terms of reference for the fish study were:

- To synthesize new and existing information on, and to provide a description of, the species composition, abundance and distribution of the fish fauna of the Breede River Estuary. In doing so, key fish species important in terms of the estuary, were to be identified
- To define the present status of the fish community and establish the relative importance of the estuary to different species or groups of species and to discuss the value of the estuary relative to other South African estuaries.
- To predict the reference condition of the fish community using the above information and that available for the other biotic and abiotic components.
- To predict the response of the fish community to the reduction in freshwater inflows presented by each of the four future scenarios in terms of the biotic and abiotic changes that may occur

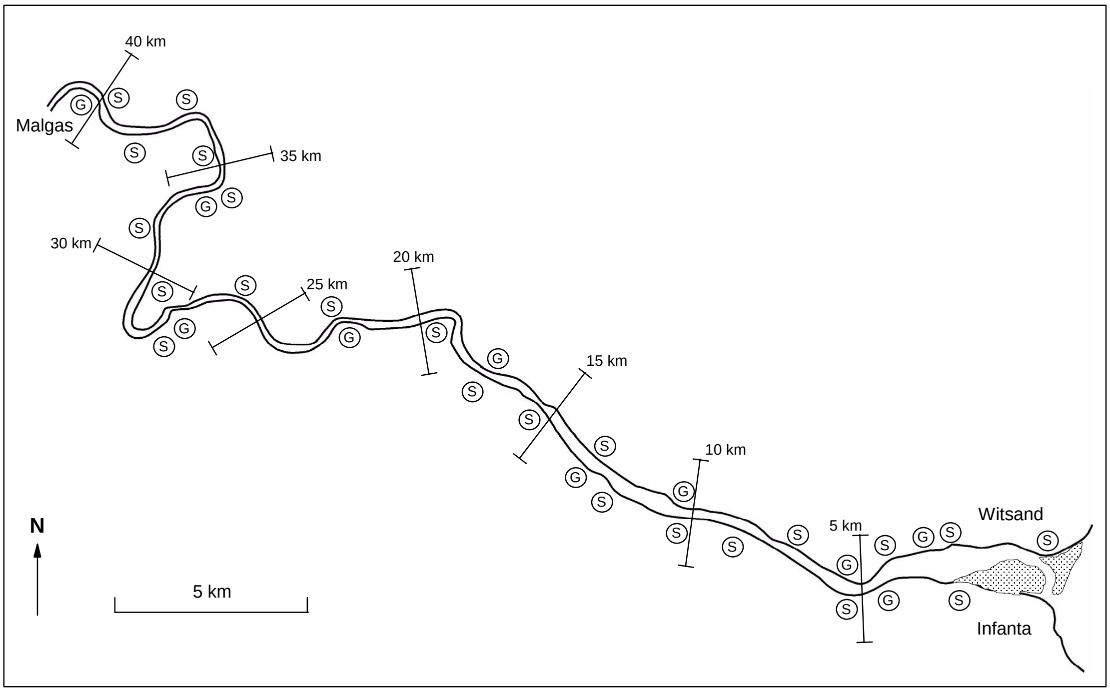

Fig. 1. Map of the Breede River Estuary showing seine (S) and gillnet (G) sampling sites

STUDY AREA

The Breede River is 322 km long from its source near Ceres to where it enters the Indian Ocean in Sebastian Bay draining a catchment of approximately 12 600 km^2. The Breede Estuary is approximately 50 km long from the mouth at Witsands to the extent of the tidal influence 10 km upstream of Malgas and has a total surface area of 455 ha (Fig 1.) Three large and numerous smaller dams within the catchment have seen to it that the mean annual runoff (MAR) reaching the estuary under natural conditions has been reduced by 42 % to the present day 1 034 % 10^6 m^3. (Taljaard *et al* 2001) Although the estuary falls within the winter/bimodal rainfall transition zone, most of the catchment falls within the winter rainfall area and flows are strongly seasonal with high flows and floods during the winter months.

The Breede is a permanently open estuary with a mean depth of 4.6 m but there are some holes of up to 17 m depth in the middle and upper reaches. In the last two km, an extensive sand-spit running from the northern bank diverts the main channel across to the southern bank where it enters the sea against a wave cut terrace (Carter 1983). The estuary is highly responsive to freshwater inflows and high flows of 20-95 m^3s^{-1} are able to completely flush and reset the system during a tidal cycle (Taljaard *et al.* 2001). In turn, the estuary ranges from well mixed during spring highs to stratified during spring lows and neaps and the REI zone may shift 8-10 km between tides.

METHODS AND STUDY APPROACH

Quantitative data on the fish of the Breede River Estuary was obtained from a summer and winter seine and gillnet survey in February and August 2000 as well as from a bimonthly seine and gillnet fishery simulation survey conducted from September 1997 to October 1999. The 2000 survey entailed sampling every 1-2 km from the mouth to Malgas approximately 40 km upstream whereas the 1997-1999 sampling was confined to the lower 5 km of the estuary (Fig. 1).

Additional information was obtained from a limited number of angler catch cards completed during this period, from unpublished data supplied by Alan Whitfield of the J.L.B. Smith Institute and from the published literature.

Gillnets used were 70 m in length with mesh sizes ranging from 44-178 mm. During the 2000 trip they were deployed for approximately one hour at each site whereas during the 1997-1999 sampling they were set and checked on an hourly basis until sufficient fish were caught. Most of the fish caught were cut from the net to prevent injury, identified, measured and released. A few selected species were tagged. Night sampling was avoided due to boat traffic, the possibility of net theft and the difficulty in preventing high mortalities through large catches.

The seine net used was 30 m long, 2m deep with a mesh size of 10 mm and hauling ropes of 50 m. Depending on the size of the catch, all fish or a sub-sample, were identified, measured and, if alive, released. Temperature, Salinity (portable refractometer) and water clarity (sechii disc) were measured at each site.

THE FISH OF THE BREEDE RIVER ESTUARY

Importance of the estuary to fish

The benefits provided by estuaries to fish are well documented and include high productivity, low predation, low salinities and refuge from adverse conditions in the marine environment such as low temperature or oxygen levels, all factors which contribute to more rapid growth and/or reduced mortalities (Potter *et al*. 1990). As a result, many South African fish species are either partially or entirely dependent on estuaries to complete all or part of their lifecycle (Wallace *et al*. 1984). The life history characteristics of most of South Africa's estuarine fish are known. This allows the fish recorded from the Breede Estuary to be classified into the five major categories of estuarine-dependence suggested by Whitfield (1994) (Table 1).

A total of 59 fish species from 30 families have been recorded from the Breede River Estuary (Day 1981, Ratte 1982, Harrison 1999, Carter 1983, Coetzee & Pool 1990, Hutchings & Lamberth 1999, Lamberth unpublished data and this study) (Table 2). Twenty-three (39 %) of these are entirely dependent on estuaries to complete their lifecycle. Ten of these breed in estuaries and include the estuarine round-herring *Gilchristella aestuaria*, kappie blennie *Omobranchus woodii*, Cape halfbeak *Hyporhamphus capensis* and Cape silverside *Atherina breviceps*. Nine, including dusky kob *Argyrosomus japonicus*, white steenbras *Lithognathus lithognathus*, leervis *Lichia amia* and spotted grunter *Pomadasys commersonnii* are dependent on estuaries as nursery areas for at least their first year of life. A further four, namely the obligate catadromous African mottled eel *Anguilla bengalensis*, Madagascan mottled eel *A. marmorata* and longfin eel *A. mossambica* and the facultative catadromous freshwater mullet *Myxus capensis* require estuaries as transit routes between the marine and freshwater environment. Another 13 (22 %) species e.g. harder *Liza richardsonii*, groovy mullet *Liza dumerilii*, elf *Pomatomus saltatrix* and spotted halfbeak *Hemiramphus far* are at least partially dependent on estuaries. In all, 61 % of the fish species recorded from the Breede Estuary can be regarded as either partially or completely dependent on estuaries for their survival. Most (36 %) of the remaining species were marine species e.g. geelbek *Atractoscion aequidens*, bullray *Myliobatis aquila*, piggy *Pomadasys olivaceum* and musselcracker *Sparodon durbanesis*, which occur in, but are not dependent on estuaries and two, carp *Cyprinus carpio* and smallmouth bass *Micropterus dolomieu* were alien euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance.

Table 1. The five major categories of fishes which utilize South African estuaries (After Whitfield 1994)

Categories	Description of categories
I	Estuarine species which breed in southern African estuaries. Further divided into: Ia. Resident species which have not been recorded spawning in the marine or freshwater environment Ib. Resident species which also have marine or freshwater breeding populations.
II	Euryhaline marine species which usually breed at sea with the juveniles showing varying degrees of dependence on southern African estuaries. Further divided into: IIa. Juveniles dependent on estuaries as nursery areas. IIb. Juveniles occur mainly in estuaries but are also found at sea. IIc. Juveniles occur in estuaries but are usually more abundant at sea
III	Marine species which occur in estuaries in small numbers but are not dependent on these systems
IV	Euryhaline freshwater species, whose penetration into estuaries is determined by salinity tolerance. Includes some species which may breed in both freshwater and estuarine systems.
V	Catadromous species which use estuaries as transit routes between the marine and freshwater environments. 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

Species that breed in estuaries and/or estuarine residents comprise 17 % of the Breede Estuary fish fauna as compared to 26-27 % for the Berg and Olifants estuaries on the West Coast and between 4-18 % for estuaries on the southwest (Cape Agulhas to Cape Point), east and KwaZulu-Natal coasts (Bennett 1994, Lamberth & Whitfield 1997). Although lower than the 25 % recorded for all south-coast estuaries, previous work on the Breede Estuary showed that estuarine residents comprised 27 % of the total species recorded (Harrison 1999). Entirely estuarine dependent species comprise 39 % of the Breede Estuary fish fauna which is low compared to 54 % for all south-coast estuaries but high compared to 26, 25, 22 and 9 % for west, southwest, east and KwaZulu-Natal coasts respectively (Bennett 1994, Lamberth & Whitfield 1997, Harrison 1999). However, entirely estuarine dependent fish comprised 56 % of the species recorded in the Breede Estuary by Harrison (1999). The latter study was a standard comparison across all estuaries on the south coast in which entirely estuarine species comprised 56-78 % of the fish fauna. Partially estuarine dependent species comprise 22 % of the Breede fish fauna, which is lower than the 29-40 % for the west coast but similar to the 27-18 % for southwest, east and KwaZulu-Natal coast estuaries (Bennett 1994, Lamberth & Whitfield 1997).

Table 2. A list of all species recorded in the Breede River Estuary during this study (2 000) and a 1997-1999 seine & gillnet survey and angler catch-cards (a), by Day 1981 (b), by Ratte 1982 (c), by Harrison 1999 (d), by the Estuarine & Coastal Research Unit CSIR (e) and by Coetzee & Pool 1990 (f). The species are classified into five major categories of estuarine-dependence as suggested by Whitfield 1994, Table 1.

Family name	Species name	Common name	Dependence category	Recorded By
Osteichthyes				
Anguillidae	*Anguilla mossambica*	Longfin eel	Va	a
	Anguilla bengalensis	African mottled eel	Va	a
	Anguilla marmorata	Madagascar mottled eel	Va	a
Ariidae	*Galeichthyes feliceps*	Barbel	IIb	a,b,c,d,f
Atherinidae	*Atherina breviceps*	Cape silverside	Ib	a,c,d
Blenniidae	*Omobranchus banditus*	Bandit blenny	III	b
	Omobranchus woodi	Kappie blenny	Ia	a
Carangidae	*Lichia amia*	Leervis	IIa	a,b,c,d,f
	Seriola lalandi	Yellowtail	III	b
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	IV	a,b
Clinidae	*Clinus superciliosus*	Super klipvis	Ib	a,b
Clupeidae	*Gilchristella aestuaria*	Estuarine round herring	Ia	a,b,c,d
Cyprinidae	*Cyprinus carpio*	Carp	IV	a,b,f
Dichistiidae	*Dichistius capensis*	Galjoen	III	b
Elopidae	*Elops machnata*	Ladyfish	IIa	a,b,d,f
Gobiidae	*Caffrogobius multifasciatus*	Prison goby	Ib	a,b,d,e
	Caffrogobius natalensis	Baldy	Ib	a,b,d
	Caffrogobius nudiceps	Barehead goby	Ib	a,b,c,d
	Psammogobius knysnaensis	Knysna sandgoby	Ib	a,b,e
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa	a,b,c,d,f
	Pomadasys olivaceum	Piggy	III	a,b,de
Hemiramphidae	*Hemiramphus far*	Spotted halfbeak	IIc	a,c
	Hyporhamphus capensis	Cape halfbeak	Ia	a
Monodactylidae	*Monodactylus argenteus*	Natal moony	IIb	b
	Monodactylus falciformis	Cape moony	IIa	a,b,c,d,e,f
Mugilidae	*Liza dumerilii*	Groovy mullet	IIb	a,c,d,f
	Liza macrolepis	Largescale mullet	IIa	e
	Liza richardsonii	Harder	IIc	a,b,c,d,e,f
	Liza tricuspidens	Striped mullet	IIb	a,c,d
	Mugil cephalus	Flathead mullet	IIa	a,b,c,d,e,f
	Myxus capensis	Freshwater mullet	Vb	a,b,f
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc	a,b,c,,e,f
Rachycentridae	*Rachycentron canadum*	Prodigal son	III	a
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	IIa	a,b,c,d,e,f
	Atractoscion aequidens	Geelbek	III	a,c
	Otolithes ruber	Snapper kob	III	b
	Umbrina spp.	Belman	III	b
Siganidae	*Siganus sutor*	Whitespotted rabbitfish	III	e
Soleidae	*Heteromycterus capensis*	Cape sole	IIb	a,b,d,e
	Solea bleekeri	Blackhand sole	IIb	a,b,c,d,e

Continued

Table 2. Continued

Family name	Species name	Common name	Dependence category	Recorded by
Sparidae	*Diplodus cervinus*	Wildeperd	III	a,b
	Diplodus sargus	Dassie	IIc	a,b
	Lithognathus lithognathus	White steenbras	IIa	a,b,c,d,e,f
	Lithognathus mormyrus	Sand steenbras	III	a
	Rhabdosargus globiceps	White stumpnose	IIc	a,b,e
	Rhabdosargus holubi	Cape Stumpnose	IIa	a,d,f
	Sarpa salpa	Strepie	IIc	a,b,c,e
	Sparodon durbanensis	White musselcracker	III	a
	Spondyliosoma emarginatum	Steentjie	III	a
Stromateoidae	*Stromateus fiatola*	Blue butterfish	III	f
Syngnathidae	*Syngnathus acus*	Pipefish	Ib	a,b,d
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III	a,b
	Chelondon patoca	Milkspotted blaasop	III	e
Triglidae	*Chelidonichthys capensis*	Cape gurnard	III	b
Chondrichthyes				
Carcharhinidae	*Carcharhinus leucus*	Zambezi shark	IIc	b
Dasyatidae	*Dasyatis chrysonota*	Blue stingray	III	a
	Gymnura natalensis	Butterfly ray	III	a
Myliobatidae	*Myliobatis aquila*	Bullray	III	a
	Pteromylaeus bovinus	Duckbill ray	III	a
Rhinobatidae	*Rhinobatos annulatus*	Lesser guitarfish	III	a

Non estuarine dependent marine species comprise a relatively high proportion (36 %) of the fish species recorded, but most e.g. galjoen *Dichistius capensis*, prodigal son *Rachycentron canadum* and geelbek *Atractoscion aequidens* can be construed as rare vagrants which seldom enter estuaries, their occurrence largely a result of the permanently open nature and strong marine influence at the mouth of the estuary.

Based on their distributional ranges given by Smith and Heemstra (1986), 25 (42 %) of the fish recorded in the Breede River Estuary are southern African endemics. In terms of the fish importance score outlined in the RDM methodology, the Breede Estuary has a biodiversity and overall importance score of 90 % which places it within the top quintile of all estuaries in South Africa (Turpie *et al*. in prep). The Breede is one of five permanently open out of a total of eight estuaries along the south coast from Cape Agulhas to Mossel Bay (Harrison 1999). It is the largest of the eight and accounts for 43 % of the total estuarine area within this region (Turpie *et al*. in prep.). Its importance lies in its size and its situation in a region of high endemicity close to the warm temperate, cool temperate transition zone the latter which has only six permanently or semi permanently open estuaries in the entire stretch of coastline between the Gariep River and Cape Agulhas (Harrison 1999).

Table 3. Species composition and abundance (catch per haul) in bimonthly seine net samples from the Breede Estuary during 1997-2000. Shading indicates months in which new recruits were recorded.

	Number per haul												Total catch	% Occurrence
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Liza richardsonii	14.0	34.4	35.0	-	38.8	-	15.6	30.4	37.1	161.0	60.0	-	2 627	69
Caffrogobius spp.	15.3	21.1	62.3	-	3.2	-	9.2	46.7	5.6	86.0	184.0	-	2 382	68
Atherina breviceps	103.3			-	225.0	-	60.2					-	1 961	4
Gilchristella aestuaria		7.6		-	5.5	-		9.4	1.1	63.0	5.0	-	536	37
Rhabdosargus holubi	39.0	9.3	2.3	-	14.3	-	0.6	11.2	0.9	44.0	28.0	-	808	38
Heteromycterus capensis	6.3	0.7	5.8	-	5.2	-	10.6	1.2	4.4	6.0		-	213	26
Liza dumerilii		1.5		-		-		6.0			8.0	-	198	15
Psammogobius knysnaensis	1.3	0.7	1.8	-	2.0	-	2.6	2.2	4.6			-	147	26
Solea bleekeri	1.0	4.0	1.8	-	0.2	-	2.6	0.3	0.9	1.0	6.0	-	140	35
Syngnathus acus		0.3	1.3	-	0.5	-	0.6	1.6	0.1	2.0	2.0	-	65	17
Rhabdosargus globiceps	0.3	0.1	1.5	-	2.0	-	2.0	0.2			22.0	-	57	21
Diplodus sargus	0.3	1.9	1.8	-	0.2	-						-	55	10
Galeichthyes feliceps		1.8	1.3	-	0.5	-						-	52	6
Pomadasys olivaceum		1.5	0.5	-	0.2	-		0.4				-	50	9
Lithognathus lithognathus	7.0	0.4	0.3	-		-		0.1	0.6	1.0	2.0	-	41	14
Mugil cephalus		0.5		-		-		0.7	0.4			-	31	8
Argyrosomus japonicus		0.7		-	1.0	-						-	22	5
Omobranchus woodi	4.0	0.1		-		-				2.0		-	15	4
Monodactylus falciformis		0.4		-		-						-	14	8
Amblyrhynchotes honckenii		0.1		-	0.5	-	0.8	0.1				-	11	8
Hyporhamphus capensis		0.2		-		-		0.1	0.6			-	11	6
Pomatomus saltatrix	0.3	0.2		-	0.3	-	0.2	0.1			1.0	-	11	9
Lichia amia		0.4		-		-						-	9	6
Lithognathus mormyrus	1.0			-	0.7	-						-	7	5
Spondyliosoma emarginatum		0.2		-		-			0.1			-	5	3
Myxus capensis		0.1		-		-		0.1				-	4	3
Pomadasys commersonnii		0.1		-	0.5	-						-	4	3
Clinus superciliosus		0.1		-		-						-	3	1
Myliobatis aquila	0.7	0.1		-		-						-	3	3
Total per haul	194	88	115	-	301	-	105	111	57	366	318	-	9 492	
Number of species	14	27	12	-	18	-	11	18	12	9	10	-	29	

Distribution and abundance

Gillnet sampling is usually targeted at the adults and sub-adults of the larger fish species whereas seine-nets are aimed at catching juveniles and the smaller fish species. A total of 10 995 fish representing 34 species from 20 families were caught during seine and gillnet sampling from September 1997 to August 2000.

Seventy-eight seine hauls yielded 9 492 fish or 122 fish.haul^{-1} (Table 3). *Liza richardsonii* (28 %), *Caffrogobius* spp. (25 %) and *Atherina breviceps* (21 %) dominated, providing 74 % of the total catch. A further six species, *Rhabdosargus holubi (9 %), Gilchristella aestuaria (6 %), Heteromycterus capensis (2 %), Liza* dumerilii (2 %), *Psammogobius knysnaensis* (1.5 %) and *Solea bleekeri* (1.5 %) together contributed 22 % towards the remainder of the catch.

Table 4. Species composition and abundance (catch per set-hour) in bimonthly gillnet samples from the Breede Estuary during 1997-2000.

	Number per set-hour												Total catch	% Occurrence
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Liza richardsonii	11.5	4.5	33.8	-	29.9	-	11.5	20.6	12.8	41.2	20.0	-	938	64
Liza dumerilii	0.3	6.0	2.5	-	27.6	-	5.6	1.4		1.6		-	319	33
Pomadasys commersonnii		0.1	0.4	-	1.7	-	4.3	0.6		1.6	0.7	-	63	33
Liza tricuspidens	0.3	0.1	0.3	-	0.6	-	3.3	1.8	0.8	1.6		-	45	21
Lichia amia	1.2	1.8	0.6	-		-			0.8	0.1	1.3	-	32	24
Rhabdosargus holubi		0.8	1.0	-	2.6	-		0.1		0.4	0.3	-	26	21
Argyrosomus japonicus	0.3	0.3		-	1.3	-				0.1	1.7	-	18	12
Mugil cephalus		0.4		-	0.3	-		0.5				-	13	9
Myliobatis aquila	0.5		0.4	-		-	1.0					-	10	10
Galeichthys feliceps				-	1.5	-						-	9	3
Lithognathus lithognathus				-	0.7	-		0.2			0.3	-	7	7
Sarpa salpa			0.5	-		-			0.8			-	5	3
Pomatomus saltatrix				-	0.2	-				1.2		-	4	3
Diplodus sargus			0.2	-	0.5	-						-	4	5
Myxus capensis		0.2		-		-		0.1				-	3	3
Diplodus cervinus	0.3			-	0.1	-						-	2	3
Pteromyleus bovinus	0.2			-		-					0.3	-	2	3
Monodactylus falciformis		0.1		-		-						-	1	2
Dasyatis chrysonota			0.2	-		-						-	1	2
Amblyrhynchotes honckenii				-		-		0.1				-	1	2
Total per set-hour	14	14	40	-	67	-	26	25	15	48	25	-	1 503	
Number of species	8	10	10	-	12	-	5	9	4	8	7	-	20	

Liza richardsonii and *Caffrogobius* spp. occurred in 68-69 % of the hauls whereas *A. breviceps* comprised a few large catches in 4 % of the hauls. *Caffrogobius* spp. were not identified to species level in the field but roughly comprise 75, 16 and 9 % *C. multifasciatus*, *C. nudiceps* and *C. natalensis* respectively (Harrison 1999).

Gillnet sampling caught a total of 1 503 fish at an average catch rate of 32 fish.set-hour^{-1} (Table 4). Catches were dominated by *Liza richardsonii* (62 %) and to a lesser extent *Liza dumerilii* (21 %) which together with *Pomadasy commersonnii* (4 %), *Liza tricuspidens* (3 %), *Lichia amia* (2 %) and *Rhabdosargus holubi* (2 %), provided 94 % of the total catch. *Liza richardsonii* appeared in 64 % whereas *L. dumerilii* and *P. commersonnii* each occurred in 33 % of the sets.

Seasonality

Catches were not strongly seasonal (Tables 3 & 4). The highest (366 fish.haul^{-1}) and lowest (57 fish.haul^{-1}) seine catches were in the spring months of October and September respectively (Table 3). The greatest number of species caught was in February (27) and the lowest in October (9). The number of new recruits recorded was highest in the summer months of January-March with seven species and lowest in the winter months of July-August with three species (Table 3). Gillnet catches were just as erratic with the highest *cpue* (67 fish.set-hr^{-1}) and lowest cpue (14 fish.set-hr^{-1}) being recorded in May and January-February respectively (Table 4). In turn, the number of species caught was highest in May (12) and lowest in September (4).

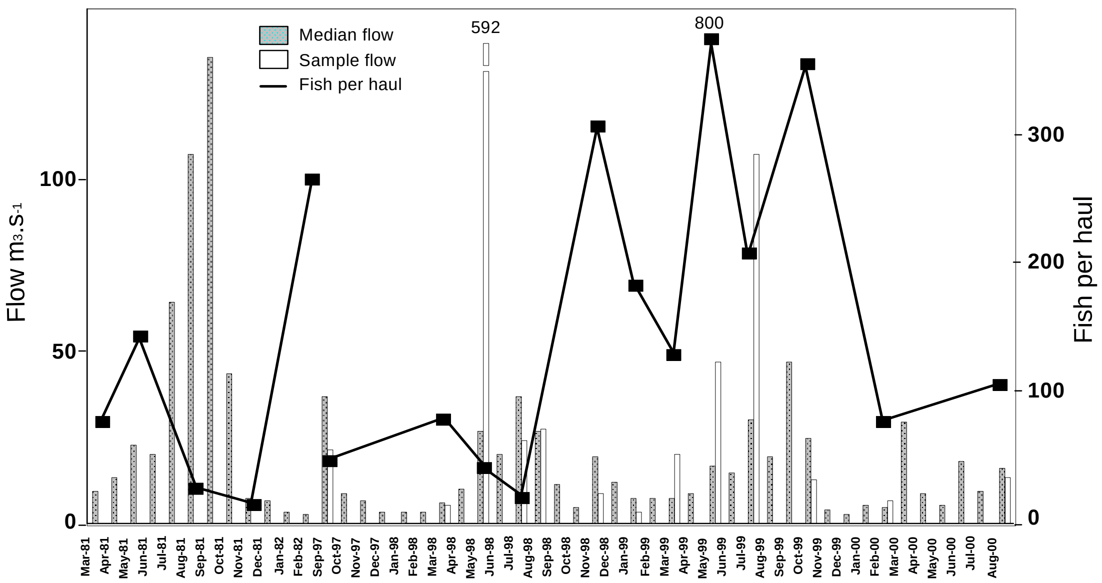

Fig 2. Median monthly flow, flows at time of sampling and catch per seine haul on the Breede Estuary during 1981-1982 and 1997-2000. (1981-1982 after Whitfield unpublished data)

Averaging seine catches over the seasons yields the highest catches in spring (Sep-Nov) and autumn (Mar-May) at 247 and 208 fish.haul^{-1} respectively. Gillnet catches are similar with the greatest *cpue* being in autumn (54 fish.set-hour^{-1}) and spring (29 fish.set-hour^{-1}).

The reasons for the high spring and autumn *cpue* values are difficult to ascertain. False Bay commercial beach-seine catches showed a similar pattern that was attributed to the shoaling of *Liza richardsonii* and other species prior to migration into or out of the surf-zone during the spring and autumn months and not to an overall change in abundance (Lamberth *et al*. 1994). However, even though many species may leave the Breede Estuary during the winter months its unlikely that pre-migration shoaling is the cause for the higher *cpue* values. What may be true is that the higher *cpue* does not reflect a change in the total number of fish in the estuary but more a distributional change in response to flow or other variables that concentrate fish in certain areas and increase catchability.

A subjective look at monthly seine catches during 1981-1982 and 1997-2000 reveals that on the whole *cpue* was either highest or lowest during months of higher median flow and / or when flow at time of sampling was higher than median flow (Figure 2). For example, May 1999 had the highest *cpue* (800 fish.haul^{-1}) coupled with a sampling flow of 50 m^3.s^{-1} whereas May 1998 had relatively low *cpue* (40 fish.haul^{-1}) during a flood of 592 m^3.s^{-1}. Not shown in Figure 2 is that large adults of species such as kob *Argyrosomus japonicus* and spotted grunter *Pomadasys commersonnii* only occurred in seine samples in these months, all in the shallows close to the shore and perhaps in response to high flow in the main channel. A tentative guess at fish response to high flow is that during spates (e.g. May 1998, 1999) they move into the shallows to escape the strong flow in the main channel whereas after prolonged periods of high flow (e.g. July-October 1981) they either migrate or are swept out of the system. However, there was no significant correlation between flow and catches, and the relationship, if real, could only be substantiated by intensive sampling on a seasonal basis.

On the whole, seasonal fluctuations in catches in the Breede Estuary are not as pronounced as for estuaries on the west and southwest coast (Bennett 1989, Bennett 1994, Lamberth & Whitfield 1997). The most likely reasons are the high variability coupled with the responsive nature of the system and the situation of the lower Breede within the winter /

bimodal rainfall transition zone. The intermingling of the rainfall zones results in multiple cues over short time periods and ultimately accounts for the relatively high diversity low abundance nature of the fish fauna compared to estuaries further to the west.

Along stream distribution

Surface salinities did not differ much between the summer (February 2000) and winter (August 2000) sampling period (Figure 3). During winter, salinity from the mouth to 2 km upstream was 35 ppt. as opposed to being 30 ppt at 0.5 km in summer. In both seasons the 20 ppt and 10 ppt marks occurred at approximately 6 km and 10 km respectively. In summer, salinity dropped to 0 ppt at 20 km as opposed to 28 km from the mouth in winter (Figure 3). This is directly opposite to normal seasonal patterns where the extent of saline intrusion shrinks or expands in response to high or low flows in winter and summer respectively. Water clarity at the mouth ranged from approximately 500 cm in winter to 200 cm in summer. In both seasons, water clarity dropped to below 100 cm at approximately 5 km from the mouth. In winter, water clarity increased after 20 km from the mouth whereas in summer it remained less than 100 cm throughout. Average water temperature in summer was 24.4 ºC ranging from 21-27 ºC as opposed to 15.6 ºC in winter ranging from 14-17 ºC (Figure 3). In both seasons, temperatures increased gradually from the mouth to the middle reaches followed by a slight decrease from 20-40 km upstream.

Upstream distribution of the species caught during the summer and winter survey was largely a reflection of the estuarine-dependence category to which they belong. *Gilchristella aestuaria*, a category Ib species which breeds only in estuaries (also freshwater populations) was largely confined to the REI zone and showed a shift from 25-40 km upstream during summer to 5-15 km during winter (Figure 4 a). Species that have marine and estuarine breeding populations i.e. *Syngnathus acus*, *Psammogobius knysnaensis* and *Clinus superciliosus* were largely confined to the lower reaches of the estuary in salinities of 20-35 ppt. The exception in this group was *Caffrogobius,* which ranged throughout the estuary during both seasons but with the bulk of the population showing a distinct downstream shift from 10-20 km to 0-10 km from the mouth during winter (Figure 4a).

Category IIa species which are entirely dependent on estuaries as a juvenile habitat showed various responses between summer and winter. *Rhabdosargus holubi* and *Lithognathus lithognathus* showed a downstream shift of approximately 10 km during winter (Figure 4a). *Argyrosomus japonicus* and *Lichia amia* were spread throughout the estuary during summer but disappeared from catches during winter, probably a reflection of their overall low abundance rather than their absence from the system *Mugil cephalus* and *Monodactylus falciformis* were mostly found further than 20 km from the mouth in salinities less than 0 ppt. Both these species venture far into freshwater and have been found up to 100 km upstream near Swellendam (Lamberth 2001). *Pomadasys commersonnii* displays an interesting seasonal response to higher flow (not that evident from sampling), in that most of the population appears to move upstream during the winter months to 20-40 km from the mouth (Figure 4c). This is borne out by angler catches being higher in this stretch of the estuary and almost zero in the lower reaches during winter.

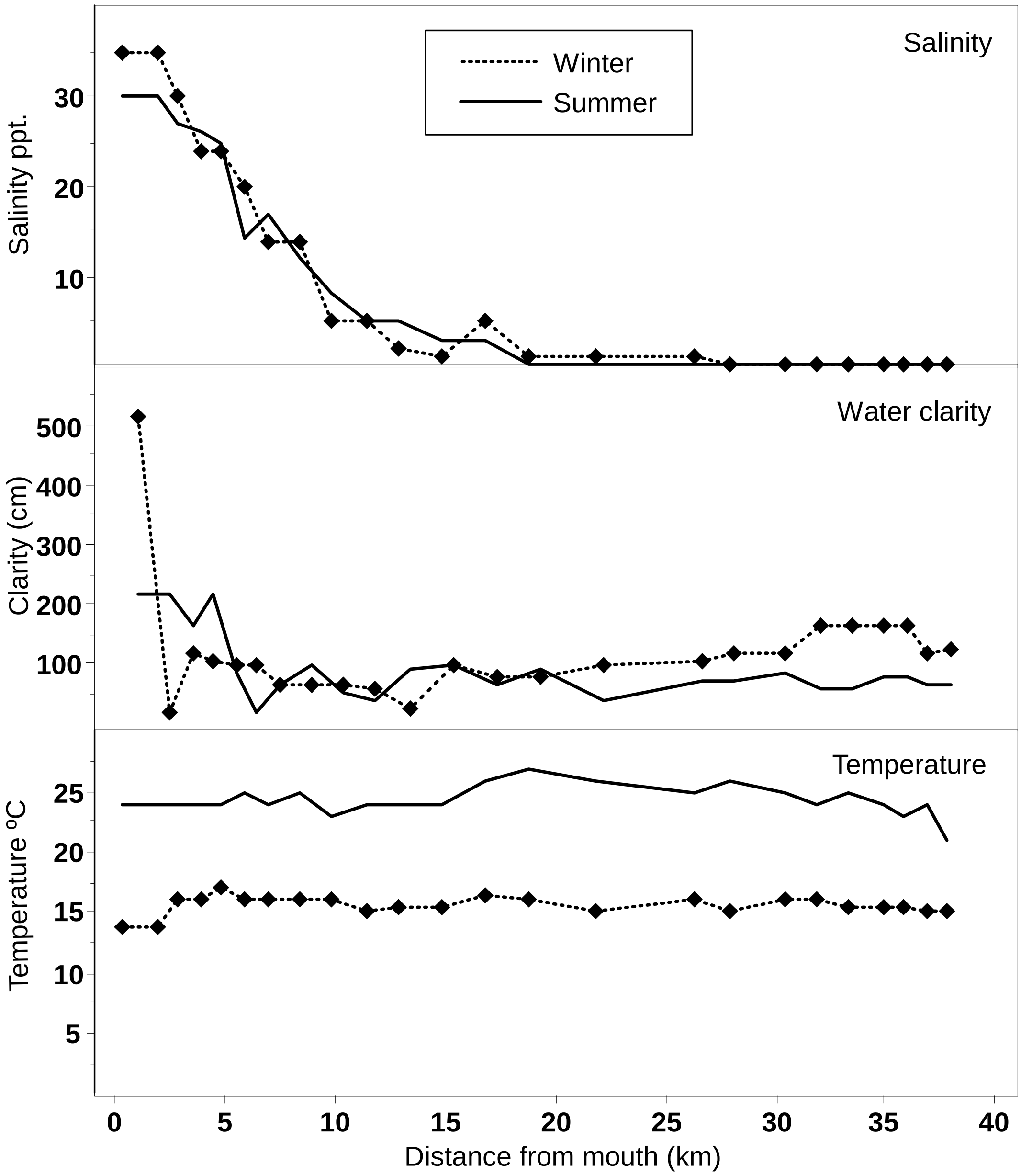

Fig 3. Salinity, water clarity and temperature measured at each sampling site during winter (August) and summer (February) 2000 on the Breede River Estuary.

Partially estuarine dependent species (II b & IIc), such as *Liza richardsonii*, *Liza dumerilii* and *Solea bleekeri* were spread throughout the estuary during summer but concentrated in the lower 10 km during winter (Figures 4 b & c). *Liza richardsonii* was interesting in that it had two peaks of abundance during summer, one in the lower 5 km and one 30-40 km upstream, the latter which disappeared in the winter months. With the exception of *Pomadasys olivaceum*, which was found 15 km upstream in salinities of less than 10 ppt non-estuarine dependent marine species were confined to the lower 5 km and salinities above 20 ppt. The facultative catadromous *Myxus capensis* was found above 20 km in 0 ppt during both seasons and has also been recorded 100 km upstream shoaling with *Mugil cephalus* (Figure 4 b & c, Lamberth 2001).

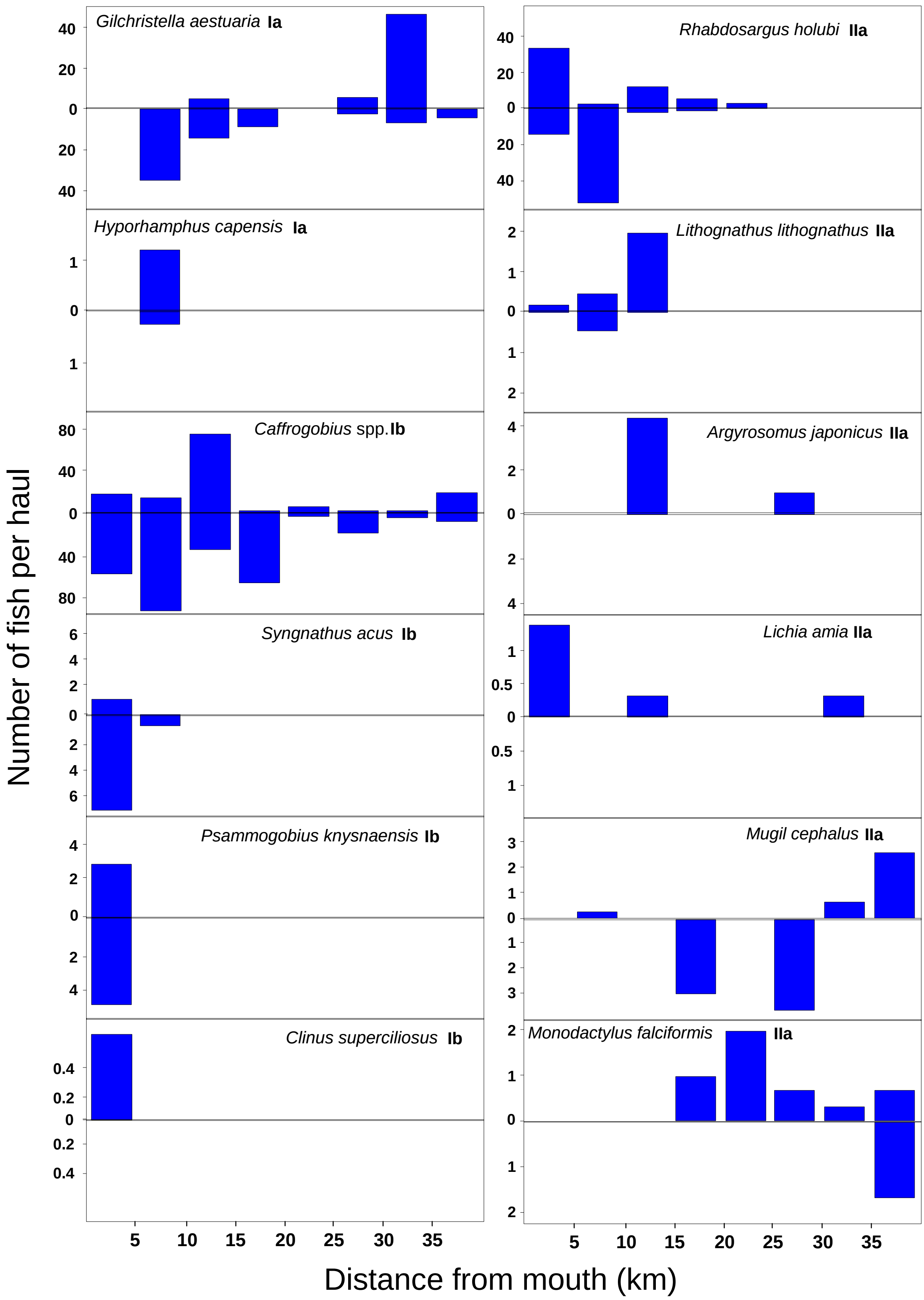

Fig. 4a. Catch per seine haul from the mouth of the Breede Estuary to 40 km upstream during summer (Feb) and winter (Aug) 2000. Summer catches are shown above, and winter catches below, each axis. Species arranged in order of their estuarine dependence category (Table 1)

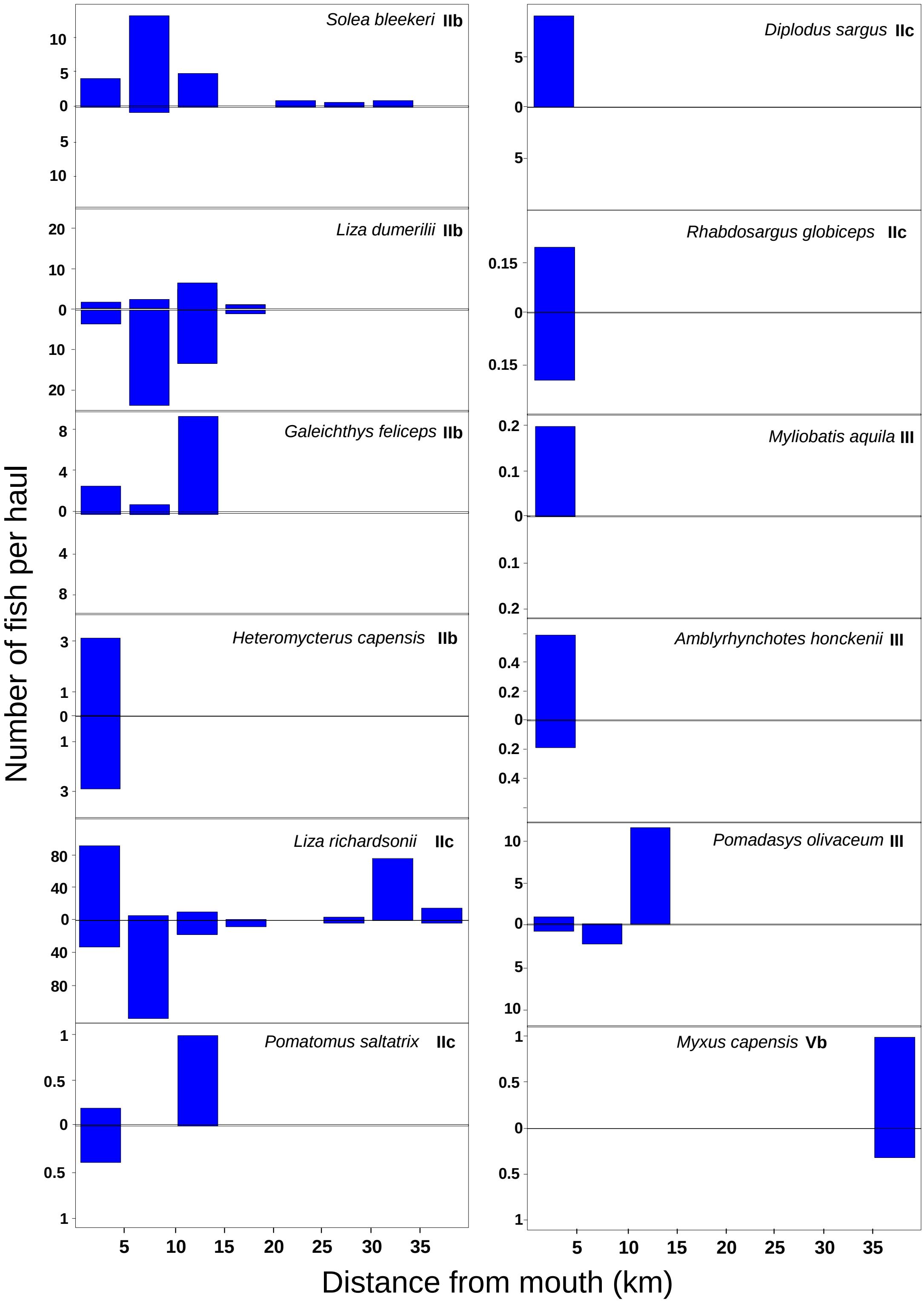

Fig. 4b. Catch per seine haul from the mouth of the Breede Estuary to 40 km upstream during summer (Feb) and winter (Aug) 2000. Summer catches are shown above, and winter catches below, each axis. Species arranged in order of their estuarine dependence category (Table 1)

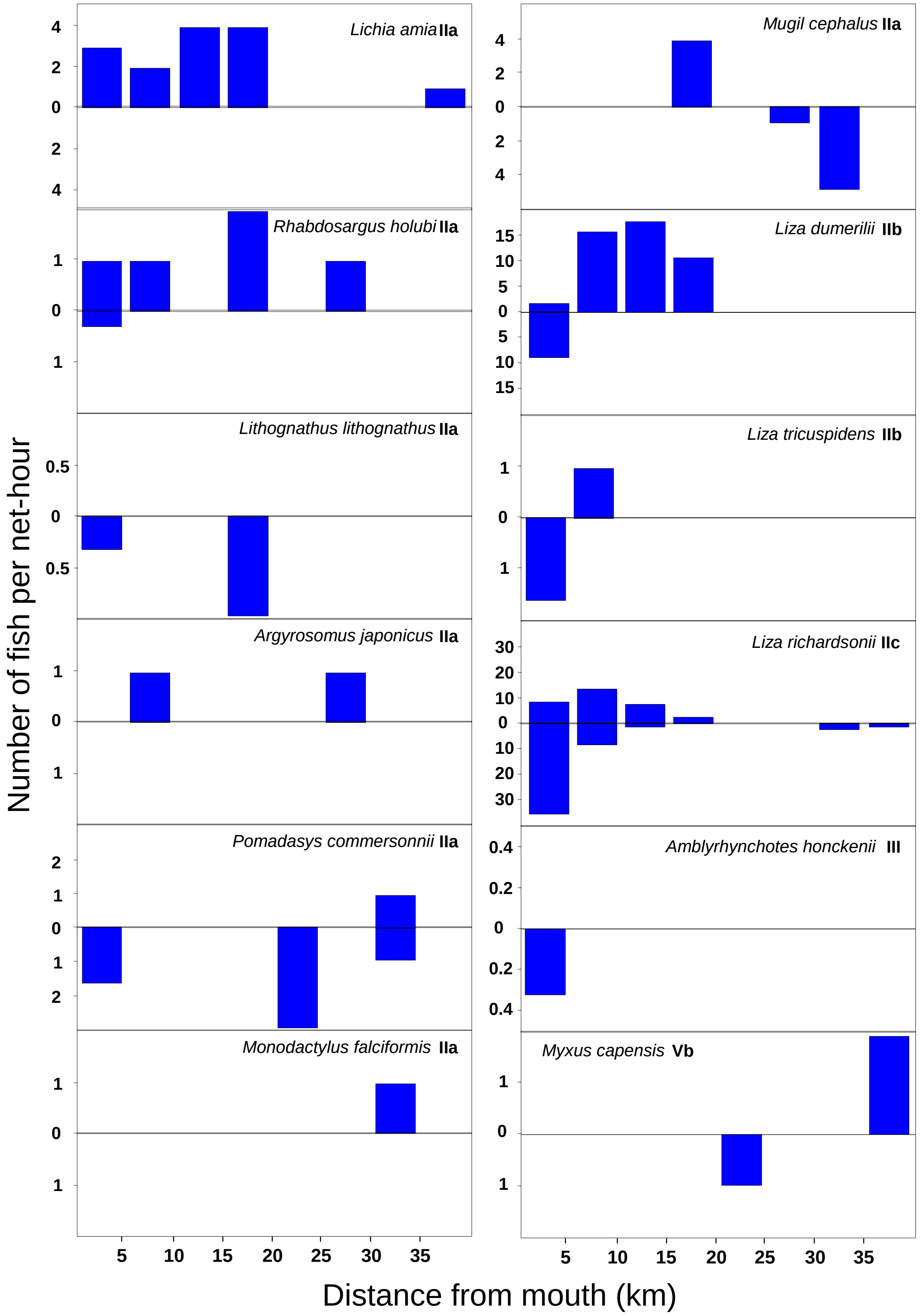

Fig. 4c. Catch per gillnet hour from the mouth of the Breede Estuary to 40 km upstream during summer (Feb) and winter (Aug) 2000. Summer catches are shown above, and winter catches below, each axis. Species arranged in order of their estuarine dependence category (Table 1)

On the whole, the majority of completely and partially estuarine dependent species were most abundant from 5-20 km from the mouth in salinities ranging from 0-20 ppt and water clarity less than 100 cm. Non estuarine dependent marine species were most often in the lower 5 km at salinities higher than 20 ppt whereas most freshwater tolerant and catadromous species were further than 20 km from the mouth in salinities of 0-1 ppt. The along stream distribution of large species was similar to that recorded in a 1985-1987 gillnet survey in the Breede Estuary the exceptions being that *Argyrosomus japonicus* and *Lichia amia* were caught up to 44 km from the mouth during that study (Coetzee & Pool 1991).

Migration between adjacent estuaries and the sea

The Breede Estuary cannot be considered apart from other estuaries in the region as it comprises only one component of the complexities surrounding the interactions between estuaries and the sea. Besides larval or juvenile recruitment, many species migrate into and out of the estuary as adults, some on a daily basis. Three species, *Argyrosomus japonicus*, *Pomadsys commersonnii* and *Lichia amia* have been tagged, released and recaptured in enough numbers to get a fair idea of their movement patterns.

Juvenile *P. commersonnii* recruit into estuaries where they remain until at least 20 cm in length (Fennessy 2000). Interestingly enough, although adults are abundant, no juveniles of this species have been found in the Breede River or adjacent estuaries on the south coast (Lamberth unpublished data). In turn, there has been a gradual southwards range expansion over the last thirty years or so with catches changing from a rare to frequent occurrence in the Breede Estuary. The range expansion may be part of a long-term cycle and / or a response to climatic change. Information from tagged and recaptured fish indicates that most *P. commersonnii* remain resident within a particular estuary and

adjacent surfzone with many moving between the two habitats on a daily basis. The longest time at liberty for a fish tagged in the Breede is 5 years whereupon it was recaptured in the estuary (Fennessy 2000). There are exceptions to the rule, with one tagged *P.commersonnii* being recaptured in the Swartkops Estuary 563 km to the east.

Twenty-eight *A. japonicus* tagged at Lekkerwater and Koppie Alleen in the adjacent De Hoop Marine Reserve have been recaptured, five of these in the Breede Estuary (Attwood unpublished data). Time at liberty ranged from 1-5 years. One fish tagged in the Breede as a juvenile was caught seven years later as an adult off Struisbaai (Marc Griffiths unpublished data). In turn, one fish tagged at Stilbaai 50 km away was recaptured 1.5 years later in the Breede Estuary 4 km upstream (van der Elst & Bullen 1991). The fish recaptured in the estuary tend to be the larger individuals of 100 cm or more in length, which indicates a fair degree of adult movement from the adjacent surf-zone into the estuary.

Lichia amia recruit into estuaries as juveniles of 20-40 mm in length and large adults are present in both permanently open and temporarily closed systems. One sub-adult tagged in the Breede was caught 5 years later 1 200 km away on the KwaZulu-Natal coast. On the whole, tagging studies indicate a strong link between the Breede and adjacent estuaries and surf-zones and emphasize its importance as a juvenile as well as an adult habitat on a regional and national basis.

IMPORTANCE OF THE ESTUARY TO FISHERS

Although recreational angling is the dominant fishing method, cast-netting and a moderate level of illegal seine and gillnetting take place within the Breede Estuary. Under the Marine Living Resources Act of 1998, no commercial linefishing is permitted within estuaries.

The estuarine line fishery

The estuarine line-fishery comprises recreational shore-angling and recreational boat fishing. The boats used range from small dinghies to ski-boats of 6 m in length. Based on angler densities on the adjacent shorelines and angler and boat counts in the Breede, Klein, Bot and Heuningnes estuaries, there are an estimated 66 258 angler-days of effort expended per annum in estuaries on the south coast. This represents the effort of approximately 2 209 fishers. These effort estimates are thought to be extremely conservative as the Overberg District Council issues 1 200 boat permits per year, mostly for the Breede River. . The gear used ranges from handlines to fishing rods of various shapes and sizes including fly-fishing. All the effort is currently recreational although approximately 14 % of these anglers admit to selling part of their catch. In addition, current confusion over estuarine regulations and commercial line-fish permits has seen commercial line-fishers moving into estuaries from where they were previously excluded.

An estimated 102 t of line-fish are caught annually from estuaries on the south coast. Forty percent of this total is from the Breede Estuary. In terms of numbers, the catches are dominated by spotted grunter *Pomadasys commersonnii* (43 %) and to a lesser extent by white steenbras *Lithognathus lithognathus* (23 %), leervis *Lichia amia* (8 %) and dusky kob *Argyrosomus japonicus* (5 %). With the exception of spotted grunter, the catches of all the other species comprise almost entirely juvenile, sub-adult and/or undersize fish. *Cpue* is estimated at 2.4 fish per angler-day. However, 51 % of the catch is either small juveniles and/or undersize. Therefore, catch rates of retainable edible fish above the minimum legal size are only 1.2 fish per angler-day. Of the four main species, the stocks of *L. lithognathus* and *A. japonicus* are collapsed, *L. amia* are maximally exploited whereas the status of *P. commersonnii* is unknown. Estuarine fish stocks cannot be considered as discrete and in isolation from the marine environment. The current status of estuarine stocks is largely a reflection of the nationwide decline that has occurred for most line-fish species. In all, the associated yields are not sustainable with the current levels of effort.

Enforcement of the line-fish regulations is virtually absent in this region with the average angler having his catch inspected approximately once every 25 years. Voluntary compliance is also low. Of 1 700 anglers interviewed in a regional survey, 70 % kept undersize fish, 90 % exceeded the bag limits and 70 % ignored closed seasons when the opportunity arose. Compliance will only improve with visible policing by the responsible authorities and by government support for the establishment of estuarine conservancies comprised of local residents.

Seine, gill, & cast netting

There are currently no commercial gill or seine-net permits issued for estuaries on the south coast and all current activity is illegal. There were in the past 35 seine permits issued in the Breede Estuary for catching "baitfish". Cape Nature Conservation, due to problems with excessive bycatch and the illegal targeting of linefish species, specifically dusky kob *Argyrosomus japonicus* and spotted grunter *Pomadasys commersonni,* withdrew the permits. Illegal seine netting occurs in the Breede Estuary where approximately two tons are netted annually. Most of this catch comprises *P. commersonnii*. An estuarine seine fishery would not be sustainable.

There are up to 10 illegal gillnets used intermittently in the Breede Estuary, mostly by riparian landowners or holiday homeowners with easy access to the water. There are also reported incidents of west coast gill-netters who travel to these estuaries specifically to net spotted grunter *Pomadasys commersonni* and large flathead mullet *Mugil cephalus*. Due to strong tidal currents the gill-nets are often used as seines rather than left stationary. Boats used range from dinghies to skiboats, all of which are motorised. Nets used in these estuaries are usually of west coast in origin, 70 to 100 m in length with mesh sizes ranging from 48 to 145 mm stretched. Approximately three tons are caught annually.

Cast nets are confined to purely recreational activity on the south coast. These nets are used by approximately 300 shore anglers on a regular basis with a total effort value of approximately 8 972 angler-days per annum. This accounts for 1.2 % of angler effort. Most of the effort is directed towards harders *Liza richardsonii*. Total annual catch is approximately 10.2 t of which 1 t is caught in the Breede Estuary. *Liza richardsonii* are the dominant species providing 99 % of the total catch. Occasionally, flathead mullet *Mugil cephalus*, striped mullet *Liza tricuspidens* and strepie *Sarpa salpa* are targeted. Catch per unit effort is approximately 1.1 kg per angler-day. Most of the catch is used as live-bait for catching linefish.

POSSIBLE EFFECTS OF ALTERED FRESHWATER FLOWS

In order to predict the response of the fish community to future changes in flow, samples were grouped into five salinity ranges. Fish densities (fish.m^{-2}) were then multiplied by the total area covered by each salinity range. For each scenario, "absolute abundance" was the sum of the total number of fish within each salinity range. The predicted changes are based on the assumption that all being equal, overall fish abundance will correspond with the shrinking or expansion of their preferred salinities under present day conditions. In reality, many of the species are tolerant of a wide range of salinities and will also respond to changes in, amongst others, habitat availability, prey availability, turbidity and temperature.

Reference condition

Under reference conditions the estuary was more river dominated than present during which State 1 & 2 conditions with average flows greater than 10 m^3s^{-1}, persisted for at least nine months (Apr-Dec) every year (Table 5 a & b). Under these conditions the REI zone of < 10 ppt begins 2-10 km from the mouth during a spring tidal cycle and extends 40-50 km upstream (Taljaard *et al*. 2001). State 3 conditions (3-10 m^3s^{-1}) would have dominated during the summer months of Jan-Mar and State 4 & 5 would seldom have occurred. Under drought conditions the REI zone would have persisted from 32 km upstream and been approximately 20 km in extent.

The extensive REI zone suggests that turbidity would have been higher over a greater stretch of the estuary. This would have favoured species such as *A. japonicus*, which prefers turbid waters, and *G. aestuaria*, which adapts easily to either turbid or clear conditions. High turbidity would have excluded *Atherina breviceps*, which is a visual feeder that prefers clear water. Low salinity conditions throughout much of the estuary would have favoured catadromous species or freshwater tolerant species such as *M. capensis*, *M. cephalus* and *M. falciformis*.

Table 5 a. Summary of five possible abiotic states of the Breede estuary (from Taljaard *et al.* 2001).

	State 1	State 2	State 3	State 4	State 5
General description	Strongly fw dominated	Fw dominated with significant saline intrusion in lower reaches	Balanced marine and fw influence	Marine dominated	Strongly marine dominated
Typical flow	>20m3/s, usually in winter	10-20m3/s, common in autumn & winter	3-10m3/s	0.5-3m3/s	<0.5m3/s, only occurs in summer (Nov-Apr)
Mouth condition	Wide Open	Wide open	Open	Open	Open
Tidal amplitude	0.9-1.5m	0.9-1.5m	0.9-1.5m	0.9-1.5m	0.9-1.5m
REI zone begins (spring tides)	2-10 km	12-18 km	18-32 km	32-50 km	> 50km
REI width (maximum)	50 km	40km	34 km	18 km	(effectively no REI)

Table 5b. Monthly occurrence of the abiotic states under the different flow scenarios

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Reference	3	3	3	2	1	1	1	1	1	1	1	2
Present	4	4	3	3	2	1	1	1	1	1	2	3
Limited	4	4	3	3	3	2	1	1	1	1	2	3
Moderate	4	4	4	3	3	2	1	1	1	1	2	3
Bromberg	4	4	4	4	3	3	2	1	1	1	2	3
Le Chasseur	4	4	4	4	4	3	2	1	1	2	3	3

Low phytoplankton, benthic diatom and zooplankton production would have suited *G. aestuaria*, which can switch feeding behaviour from filter to selective feeding over a short time period. However, an abundant supply of detritus from the *Phragmites* beds would have been ideal for partial detritivores such as the mullet species *M. cephalus*, *M. capensis* and *L. richardsonii*. Benthic burrowers *Upogebia* and *Callianassa* would have been restricted to the lower reaches if there was suitable habitat present but densities and productivity would have been lower due to the lower salinities. Consequently, adult benthic feeders such as *L. lithognathus* and *P. commersonnii* would probably have occurred further downstream and in lower densities. Larger *Zostera* beds in the lower reaches would have facilitated a much higher abundance of fish such as pipefish *Syngnathus acus* and gobies *Caffrogobius* spp.

In all, the fish community would have been dominated by estuarine resident or dependent species that are tolerant of, or prefer, lower salinities. These would have been the estuarine resident *G. aestuaria*, the detritiverous *M. capensis*, *M. cephalus* and *L. richardsonii* and the omnivorous Cape moony *M. falciformis*. These small species would have been preyed on by adults and juveniles of the large picivorous *A. japonicus* and *L. amia* which are likely to have been abundant, and the dominant predators in the system. Juveniles of most estuarine dependent benthic feeders such as *L. lithognathus* and *R. holubi* are likely to have been present but the adults are likely to have had a shorter residence time within the system. Non estuarine-dependent marine species are likely to have been rare and confined almost entirely to the lower reaches of the estuary. Overall, the estuarine fish community would have been characterised by "low" diversity and "high" abundance typical of a freshwater dominated system.

Present day conditions and future scenarios

Under present day conditions the estuary is less river dominated than under natural conditions but state State 1 & 2 conditions with average flows greater than 10 m^3s^{-1} still persist for at least seven months (May-Nov) every year (Table 5 a & b). Under these conditions the REI zone of < 10 ppt begins 12-18 km from the mouth during a spring tidal cycle and extends approximately 40 km upstream (Taljaard *et al*. 2001). State 3 conditions (3-10 m^3s^{-1}) are confined to mostly autumn and December whereas State 4 conditions dominate the summer months of Jan-Feb. Present day conditions represent a 42 % reduction in MAR. The future scenarios represent a further reduction in MAR from 47 % under limited development to 64 % under the Le Chasseur scenario.

The reductions in MAR result in the Breede Estuary gradually changing from a river to marine dominated system. The REI zone shrinks and may even become non-existent under drought conditions. In turn, depending on their salinity preferences, the ranges of different species of fish may either shrink or expand. Depending on the persistence of the different states and the life-history characteristics and movement patterns of the species concerned, changes in species composition and abundance may be either short-term or permanent.

Species that breed only in estuaries (Ia) have undergone a 15 % reduction in numbers from the reference to present day condition whereas those that have estuarine and marine breeding populations (Ib) have increased by 9 % (Table 6). Estuarine breeders continue to decline to 81 % and 63 % of reference abundance under limited development and the Le Chasseur scenario respectively. Their decline corresponds with the shrinking of the REI zone and their preferred salinity range of 0-10 ppt. Category Ib species increase due to their being equally at home in the estuarine or marine environment, mostly confined to the middle and lower reaches of the estuary and preference or tolerance of low turbidity. The response of category Ia species to lower flows is largely due to the decline in estuarine round-herring *Gilchristella aestuaria* whereas the increase in category Ib species is due to Cape silverside *Atherina breviceps* (Table 7). *G. aestuaria* is responding to a loss of habitat or preferred salinity in the upper reaches of the estuary whereas *A. breviceps*, a visual feeder, is responding to a decrease in turbidity and increase in area covered by their preferred salinity range in the middle and lower reaches.

Category II completely and partially estuarine dependent fish, are 3-7 % more abundant under present day as opposed to reference conditions (Table 6). Under the future scenarios they experience a 9-16 % increase from reference conditions. However, this is not entirely true for all species within this category (Table 7). Four of the seven completely estuarine dependent (IIa) species experience a drastic decline from reference conditions to the Le Chasseur scenario. These, and their corresponding declines are Cape moony *Monodactylus falciformis* (62 %), flathead mullet *Mugil cephalus* (54 %), dusky kob *Argyrosomus japonicus* (49 %) and spotted grunter *Pomadasys commersonnii* (34 %). The decline in numbers of *A. japonicus* is a point of concern as the stock of this species is already at 4 % of pristine and has collapsed. In turn, *A. japonicus* and *P. commersonnii* are the most important species in terms of catch in the Breede and other south and east coast estuaries.

Table 6. Estuarine dependence categories in terms of "absolute" abundance in each salinity range during reference and present day conditions and for each of the four future scenarios. Percentage reference is abundance expressed as a percentage of that under reference conditions

Dependence category	Salinity ppt 30-35	20-30	10-20	0-10	0	Total	% Composition	% Reference
REFERENCE 100 % MAR								
Ia	0	14238	52668	193116	158383	418405	3.948	
Ib	1516496	1645313	445665	622632	158383	4388489	49.654	
IIa	174310	291094	143845	170641	39596	819486	9.579	
IIb	453206	87012	107601	137345	6092	791255	7.833	
IIc	784395	592471	433801	540225	283263	2634153	28.424	
III	41834	7910	1699	5827	0	57270	0.537	
IV	0	0	0	0	160	160	0.001	
V	0	0	0	0	3046	3046	0.024	
PRESENT 58 % MAR: 6 % INCREASE IN ABUNDANCE								
Ia	0	16918	58881	161772	119404	356974	3.701	85
Ib	1683926	1954965	498238	521574	119404	4778107	49.536	109
IIa	193555	345878	160814	142945	29851	873043	9.051	107
IIb	503242	103388	120294	115053	4592	846569	8.777	107
IIc	870996	703975	484974	452542	213549	2726037	28.261	103
III	46453	9399	1899	4881	0	62632	0.649	109
IV	0	0	0	0	121	121	0.001	75
V	0	0	0	0	2296	2296	0.024	75
LIMITED 53 % MAR: 8 % INCREASE IN ABUNDANCE								
Ia	0	17641	62465	158497	99914	338517	3.435	81
Ib	1735695	2038472	528568	511016	99914	4913666	49.867	112
IIa	199505	360653	170603	140051	24979	895791	9.091	109
IIb	518714	107804	127617	112724	3843	870701	8.836	110
IIc	897773	734046	514497	443382	178693	2768391	28.095	105
III	47881	9800	2015	4782	0	64479	0.654	113
IV	0	0	0	0	101	101	0.001	63
V	0	0	0	0	1921	1921	0.019	63
MODERATE 48 % MAR: 9-15 % INCREASE IN ABUNDANCE								
Ia	0	18258	61987	146100	99914	326259	3.291	78
Ib	1767641	2109792	524524	471045	99914	4972916	50.168	113
IIa	203177	373271	169298	129097	24979	899821	9.078	110
IIb	528260	111576	126640	103907	3843	874226	8.819	110
IIc	914297	759728	510560	408701	178693	2771979	27.964	105
III	48763	10143	2000	4408	0	65313	0.659	114
IV	0	0	0	0	101	101	0.001	63
V	0	0	0	0	1921	1921	0.019	63
BROMBERG 43 % MAR: 12 % INCREASE IN ABUNDANCE								
Ia	0	19598	65094	130428	80425	295543	2.903	71
Ib	1851355	2264618	550810	420516	80425	5167725	50.767	118
IIa	212799	400663	177782	115248	20106	926600	9.103	113
IIb	553279	119763	132987	92761	3093	901883	8.860	114
IIc	957598	815480	536147	364860	143836	2817921	27.683	107
III	51072	10888	2100	3935	0	67995	0.668	119
IV	0	0	0	0	81	81	0.001	51
V	0	0	0	0	1547	1547	0.015	51
LE CHASSEUR 36 % MAR: 15 % INCREASE IN ABUNDANCE								
Ia	0	20938	68200	114755	60935	264828	2.535	63
Ib	1935070	2419444	577097	369987	60935	5362534	51.336	122
IIa	222422	428056	186267	101400	15234	953378	9.127	116
IIb	578297	127951	139333	81615	2344	929540	8.898	117
IIc	1000898	871233	561733	321018	108980	2863863	27.416	109
III	53381	11632	2200	3462	0	70676	0.677	123
IV	0	0	0	0	62	62	0.001	38
V	0	0	0	0	1172	1172	0.011	38

Table 7. Species change in abundance from reference to present day conditions and the four future scenarios.

	Dependence category	Percentage of abundance under reference conditions				
		Present	Limited	Moderate	Bromberg	Le Chasseur
Gilchristella aestuaria	Ia	84	80	77	69	61
Omobranchus woodi	Ia	118	123	127	136	145
Caffrogobius spp.	Ib	102	104	103	104	105
Psammogobius knysnaensis	Ib	110	113	114	119	124
Atherina breviceps	Ib	115	119	122	130	137
Syngnathus acus	Ib	116	122	125	133	141
Clinus superciliosus	Ib	119	124	128	138	147
Monodactylus falciformis	IIa	75	63	63	51	38
Mugil cephalus	IIa	78	70	67	57	46
Argyrosomus japonicus	IIa	81	75	71	61	51
Pomadasys commersonnii	IIa	87	79	80	73	66
Lithognathus lithognathus	IIa	108	111	112	116	120
Rhabdosargus holubi	IIa	109	112	113	117	121
Lichia amia	IIa	110	113	115	120	125
Galeichthyes feliceps	IIb	95	95	92	89	87
Solea bleekeri	IIb	100	102	100	101	101
Liza dumerilii	IIb	104	107	105	107	109
Heteromycterus capensis	IIb	111	115	117	122	128
Hyporhamphus capensis	IIc	96	98	95	93	91
Liza richardsonii	IIc	103	104	104	106	107
Pomatomus saltatrix	IIc	108	111	112	115	119
Rhabdosargus globiceps	IIc	112	115	117	123	129
Diplodus sargus	IIc	116	120	123	131	139
Pomadasys olivaceum	III	90	89	85	80	74
Lithognathus mormyrus	III	104	107	107	109	111
Amblyrhynchotes honckenii	III	109	112	113	118	122
Myliobatis aquila	III	112	115	118	124	130
Spondyliosoma emarginatum	III	118	123	127	136	144
Cyprinus carpio	IV	75	63	63	51	38
Myxus capensis	Vb	75	63	63	51	38

Three category IIa species, white steenbras *Lithognathus lithognathus*, Cape stumpnose *Rhabdosargus holubi* and leervis *Lichia amia* experience increases in abundance of 20-25 % with decreasing flows (Table 7). Interestingly, these increases are approximately half the magnitude of the declines experienced by *A. japonicus* and other category IIa species. The benthic feeding *L. lithognathus* is likely to respond positively to an upstream expansion of the mudflats and an increase in the burrowing mudprawn *Upogebia africana* whereas *L. amia*, a visual piscivorous predator, will respond positively to reduced turbidity.

With the exception of barbel *Galeichthys feliceps* and Cape halfbeak *Hyporhamphus capensis*, category IIb & IIc fish increase in abundance with declining flows but not as markedly as those of Ia (Tables 6 & 7). Species such as harder *Liza richardsonii* and black-hand sole *Solea bleekeri*, which show no strong preference for any salinity range and are found throughout the estuary, show very little change in abundance with decreasing flows with an overall increase of 7 % and 1% for the Le Chasseur scenario respectively. Elf *Pomatomus saltatrix*, white stumpnose *Rhabdosargus globiceps* and dassie *Diplodus sargus*, all category IIc species that prefer higher salinities and less turbid waters show the greatest increase in abundance in response to reduced flows (Table 7).

Non estuarine-dependent marine species (category III) undergo the greatest increase in abundance with decreasing flows (Table 6). At present they are 9 % greater in numbers than during reference conditions and will increase by 23 % if the Le Chasseur scenario ever occurs. Category IV freshwater species are likely to decline by 62 % but as they are solely represented by introduced fish such as carp *Cyprinus carpio,* this can be regarded as a positive consequence of reduced flows. The facultative catadromous freshwater mullet *Myxus capensis* has decreased by 25 % from reference to present day conditions and is likely to be only 38 % of reference under the Le Chasseur scenario. This species is regarded as vulnerable and in decline throughout its range, largely due to water abstraction and weirs and other obstacles impeding its migration into the freshwater reaches of rivers.

In summary, reduced freshwater flows are likely to see an overall reduction in abundance of species that breed only in estuaries, those that are entirely estuarine dependent and catadromous species. Numbers may decline to such an extent that some of these species may completely disappear from the Breede Estuary. Partially estuarine dependent and marine species are likely to increase with the encroachment of higher salinity further upstream and expansion of available habitat. Overall, the fish community will experience a gradual change from relatively high diversity low abundance under present conditions to low diversity high abundance with future reductions in flow.

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APPENDIX H

Specialist Report:

Avifauna

This report was compiled by:

Jane Turpie

July 2001

1. INTRODUCTION

In response to increasing demands for water, Resource Directed Measures (RDM) are being carried out for the Breede River catchment in order to make allocation decisions. This study forms part of an estuarine reserve determination for the Breede River Estuary, in which specialist studies will contribute towards the setting of the Ecological Management Class (desired future state of health) of the estuary.

The RDM process is being carried out at an intermediate level, the methods for which are described in detail in Taljaard, Turpie & Adams (1999). Runoff scenarios for the natural and present situation are used to evaluate the present ecological status of the estuary and to determine the ecological reserve category (ERC). These runoff scenarios, together with a series of four possible future run-off scenarios are then evaluated to derive the Reserve and Resource Quality Objectives for the particular estuary.

Based on the abiotic study (hydrology and water quality), five possible states of the Breede estuary have been identified, and their prevalence under the 6 different runoff scenarios are summarised in Tables 1 and 2 (Taljaard *et al.* 2001).

Table 1. Summary of five possible states of the Breede estuary (from Taljaard *et al.* 2001).

	State 1	State 2	State 3	State 4	State 5
General description	Strongly fw dominated	Fw dominated with sign saline intrusion in lower reaches	Balanced marine and fw influence	Marine dominated	Strongly marine dominated
Typical flow	>20m3/s, usu in winter	10-20m3/s, common in autumn & winter	3-10m3/s	0.5-3m3/s	<0.5m3/s, only occurs in summer (Nov-Apr)
Mouth	Wide Open	Wide open	Open	Open	Open
Tidal amplitude	0.9-1.5m	0.9-1.5m	0.9-1.5m	0.9-1.5m	0.9-1.5m
REI zone begins	0-12 km	12 – 18 km	17 – 32 km	32 – 50 km	> 50 km (effectively no REI)
Suspended solids	No major change between states				
Nutrients	Generally low throughout (estimated to be <10mg/litre)				

Table 2. Summary of the predominant states in each month for the reference condition, present condition and four possible future scenarios (based on Taljaard *et al.* 2001)

	J	F	M	A	M	J	J	A	S	O	N	D
Reference	3	3	3	2	1	1	1	1	1	1	1	2
Present	4	4	3	3	2	1	1	1	1	1	2	3
Limited Dev	4	4	3	3	3	2	1	1	1	1	2	3
Moderate Dev	4	4	4	3	3	2	1	1	1	1	2	3
Bromberg Dam	4	4	4	4	3	3	2	1	1	1	2	3
Le Chasseur Dam	4	4	4	4	4	3	2	1	1	2	3	3

The terms of reference for the specialist bird study are as follows:

1. Describe the avifaunal community based on site visits (one summer and one winter count) as well as existing information;
2. Determine the importance of the estuary for birds;
3. Identify the key abiotic or biotic parameters which influence the avifauna;
4. Define the present status of the avifaunal community;

Predict the reference condition for birds, using the above information, as well as the reference conditions estimated by other specialists for the abiotic and other biotic components;

5. Predict the effect of each of the 4 future scenarios on birds; and
6. Complete the Intermediate RDM specialist templates.

2. STUDY APPROACH AND METHODS

Two counts were conducted on the estuary, one towards the end of summer, when bird numbers usually peak, on 17-18 March 2000, and one in winter, when bird numbers are usually close to their minimum, on 17-18 June 2000. Birds were counted between the estuary mouth and the settlement at approximately 30km upstream. This study also draws upon data collected for an honours project carried out by Charles Pemberton under my supervision (Pemberton 2000). The latter project aimed to further examine the factors influencing the distribution of shorebirds in the lower estuary, and involved seven counts of waders of the lower estuary during both the immediate pre-migration period (late March 2000) and during early spring (September 2000). All count data were separated into sections of the estuary, and the latter study also collected samples of invertebrate fauna from 11 sites in the lower estuary. The invertebrate samples of 25x25cm and 10cm depth were sieved through a 1mm mesh. In addition, current count data are compared with published count data from past counts.

Having described the avifaunal community and identified the factors which influence it, the study then draws upon specialist studies on microalgae, macrophytes, invertebrates and fish to predict the impacts of different scenarios on the estuary's birds.

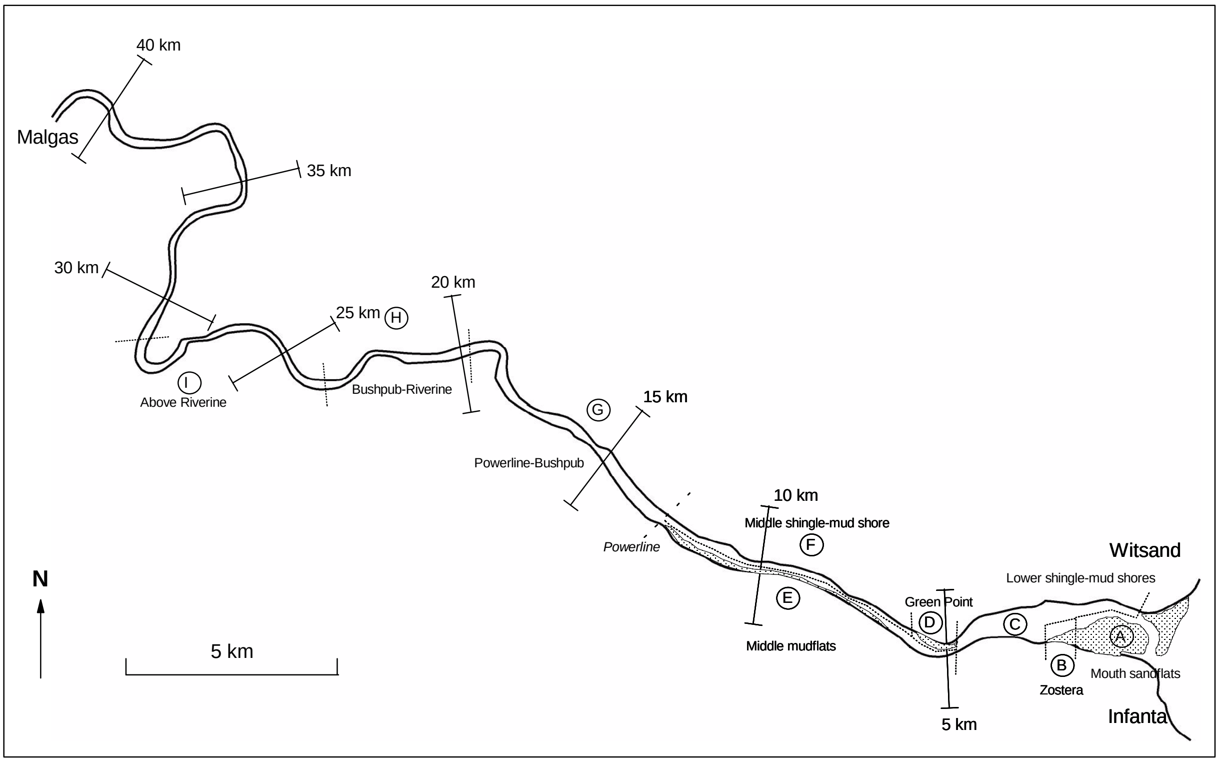

Figure 1. Map of the Breede River estuary showing the divisions between main counting areas (dotted lines). A more detailed study of waders divides regions A-F into 11 counting sections: 2 areas in A; B; 3 areas in C; D; and 4 areas in E.

3. IMPORTANCE OF THE BREEDE RIVER ESTUARY FOR BIRDS

Species richness and abundance

A total of 48 waterbird species were counted during the summer and winter counts of 2000 (Table 3). In addition the estuary supports several additional passerine waterbird species such as African Reed Warbler, African Sedge Warbler Red Bishop, Cape Weaver, and several terrestrial species were seen flying along the estuary, such as Jackal Buzzard, Blue Crane and Cape Vulture.

No monthly counts have been carried out at the Breede estuary, but bird numbers are expected to be maximal in March before summer migrants return to their breeding grounds, and minimal in mid-winter. A maximum of 1762 waterbirds were counted on any one day in March 2000, with a total of 1900 birds being counted over 8 counts (sum of maximum counts of each species). In comparison, a total of only 379 waterbirds were counted in a single count in June.

National and regional importance

The Breede River estuary is fairly important for birds on a national level. It ranks 22nd out of South African estuaries in terms of total numbers of waterbirds, and between 20th and 30th in terms of other importance criteria (diversity, rarity and conservation status) (Turpie 1995). The score is calculated using the 1980 summer bird count, which is the most comparable (in terms of year and timing of count) to the existing data for all estuaries. Nevertheless, the 1980 count data (1915 birds of 30 species) is very similar to the 2000 data (see section 5). This ranking does not make the Breede a very high priority estuary for birds, but it is certainly highly significant at a regional level. However, when all biotic components are taken into consideration, the estuary ranks within the country's top 20 estuaries in terms of conservation importance, although it does not achieve desired protected area status (Turpie *et al.* in review).

The estuary has a fairly unusual composition of birds compared with other South African estuaries. It is one of relatively few estuaries that support good numbers of Grey Plover, Ringed Plover and Terek Sandpiper and Knot. However, non-wader species are not particularly well represented. Two Red Data species – African Black Oystercatcher and Caspian Tern - have been recorded on the estuary, and Cape Vulture breeds in the vicinity.

Using the importance score for birds as outlined in the draft RDM documentation (Taljaard *et al.* 1999), the Breede estuary has a bird importance score of 90. This means that it falls within the second 10% percentile of South African estuaries in terms of its importance for birds.

Table 3. Waterbird species recorded on the Breede estuary during 2000, giving maximum numbers counted during late summer (17-29 Mar) and winter (17-18 June). Counts are given separately for the lower and upper estuary, separated at the point where the powerline crosses the estuary.

	Summer			Winter		
	Lower	Upper	TOTAL	Lower	Upper	TOTAL
Dabchick	0	0	0	0	1	1
Whitebreasted Cormorant	2	2	4	13	2	15
Cape Cormorant	7	0	7	0	0	0
Reed Cormorant	9	2	11	8	31	39
Darter	1	6	7	6	7	13
Grey Heron	8	0	8	1	0	1
Purple Heron	0	1	1	0	0	0
Little Egret	12	3	15	9	1	10
Sacred Ibis	3	1	4	11	10	21
African Spoonbill	8	0	8	3	0	3
Redknobbed Coot	0	1	1	1	2	3
Purple Gallinule	0	0	0	0	1	1
Egyptian Goose	141	17	158	7	26	33
Yellowbilled Duck	235	27	262	13	65	78
Cape Teal	1	0	1	0	0	0
Cape Shoveller	0	0	0	2	7	9
African black duck	0	1	1	0	0	0
Spurwinged Goose	0	0	0	1	4	5
African Fish Eagle	0	1	1	0	0	0
Osprey	0	0	0	1	0	1
African Black Oystercatcher	1	0	1	0	0	0
Kittlitz Plover	2	0	2	4	0	4
Whitefronted Plover	29	0	29	18	0	18
Ringed Plover	303	0	303	0	0	0
Greater Sand Plover	2	0	2	0	0	0
Grey Plover	186	0	186	76	0	76
Blacksmith Plover	4	2	6	25	13	38
Common Sandpiper	1	0	1	0	0	0
Greenshank	33	3	36	2	0	2
Knot	21	0	21	6	0	6
Curlew Sandpiper	296	0	296	0	0	0
Sanderling	1	0	1	0	0	0
Ruff	4	0	4	0	0	0
Terek Sandpiper	16	0	16	2	0	2
Turnstone	4	0	4	0	0	0
Bartailed Godwit	7	0	7	8	0	8
Curlew	1	0	1	0	0	0
Whimbrel	78	6	84	14	0	14
Blackwinged Stilt	0	3	3	0	0	0
Water Dikkop	0	0	0	7	0	7
Kelp Gull	330	3	333	119	7	126
Caspian Tern	0	0	0	2	0	2
Swift Tern	8	0	8	3	0	3
Common Term	49	1	50	8	0	8
Little Tern	5	0	5	3	0	3
Giant Kingfisher	0	0	0	1	0	1
Pied Kingfisher	2	6	8	2	4	6
Cape Wagtail	4	0	4	4	0	4
TOTAL	1813	87	1900	379	181	560

4. FACTORS INFLUENCING AVIFAUNAL COMMUNITY STRUCTURE & ABUNDANCE

Identification of key factors influencing birds

It is notoriously difficult to accurately predict the impact of changes in estuarine characteristics on bird assemblages (Hockey & Turpie 1999), and predictions often have to be made on the basis of qualitative ("gut-feel") assessments of the relationships between the main variables that influence bird community structure and abundance in estuaries (Fig. 2). These relationships may vary seasonally, from estuary to estuary, or between biogeographical zones, and difficulties in prediction are also compounded by variability due to external factors such as breeding success on distant breeding grounds. To date, no comprehensive, quantitative studies have been made of the influence of abiotic and biotic factors on bird community structure and abundance in South African estuaries.

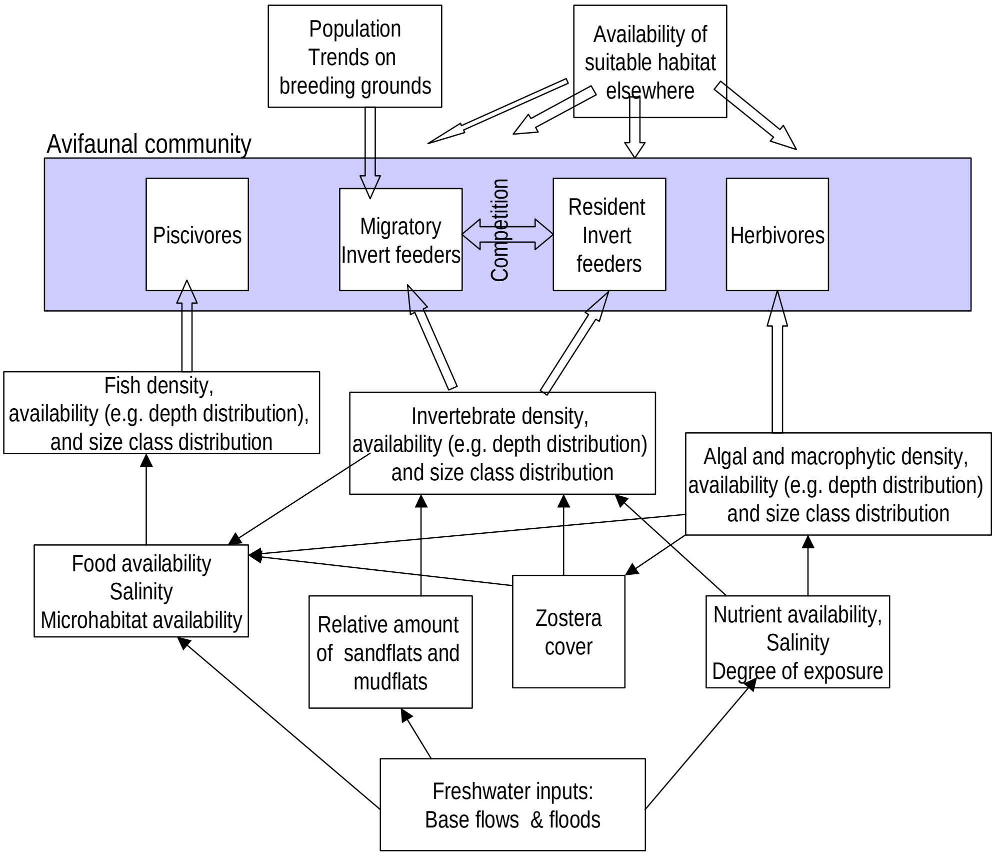

Figure 2. A simplified example of the types of relationships used in predicting the structure of an estuarine avifaunal community. Assumptions are made about the nature of relationships for each of the arrows depicted.

A complex array of variables is expected to influence the bird community (Fig. 2). Apart from external influences, different trophic groups of birds are probably influenced primarily by the availability (or catchability) of food (plants, invertebrates or fish), in turn influenced by its abundance and size class distribution. In addition to the relationship between food groups, the availability of food is in turn expected to be influenced by salinity, nutrients and relative availability of different habitat types (e.g. mudflats, sandflats, vegetated habitats). The latter variables are influenced by freshwater inputs to the estuary. Certain groups or species are liable to be more responsive to changes in system variables than others, depending on their ability to adapt to a range of circumstances (e.g. Turpie & Hockey 1995). Of

course, other variables, such as availability of roosting, perching or breeding sites, may feature strongly in determining the presence of certain species.
For example, some of the basic assumptions made in predicting differences in the bird community under different scenarios are as follows:

- The numbers of any one trophic group are positively correlated with the area of suitable habitat and the biomass of available food
- The composition of that trophic group is related to the composition of the food group, particularly the mean size of the individuals in that food group

Where the composition and productivity of the food group is determined by abiotic factors such as salinity or sediment particle size, these variables may indirectly determine the nature of the avifaunal community. For example, a broad assumption applied to invertebrate feeding waders could be:

- Wader densities are negatively correlated with sediment sand fraction, because the latter is negatively correlated with invertebrate density/availability.

The remainder of this section examines the composition of the avifaunal composition of the Breede estuary in more detail so as to demonstrate some of the relationships to the abiotic and biotic variables considered in the RDM process. This includes a more in-depth examination of the factors that influence the distribution of one group, the waders, within the lower estuary (using data collected by Pemberton 2000).

Overall community structure

The avifauna is dominated by waders (plovers, sandpipers, dikkops, etc - 49%), waterfowl (ducks, rails, grebes - 24%) and Kelp Gulls (19%) in summer (Fig. 3), but these three groups number much less in winter, leaving a more even representation of different groups on the estuary in winter. Numbers of wading birds (herons, ibises, spoonbills etc) remain constant from summer to winter, and numbers of cormorants (including darters) increase on the estuary in winter (Fig. 3).

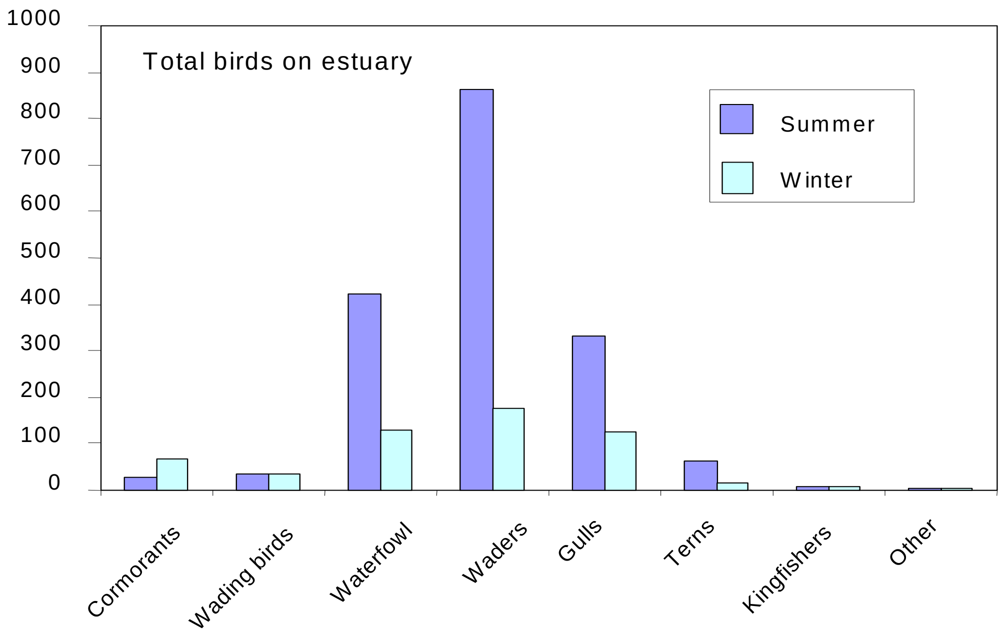

Figure 3. Avifaunal community composition in summer and winter in terms of (a) taxonomic groups and (b) broad trophic groups.

In terms of trophic groups, the avifauna is dominated by migrant invertebrate feeders (migratory waders) in summer (50%), with resident herbivores (mostly waterfowl species) making up 22% and generalist Kelp Gulls making up 18% (Fig. 4). Resident invertebrate feeders (some waders and waterfowl species) make up only 3% of the avifauna in summer. There is a more even distribution of trophic groups in winter, when migrant and resident invertebrate feeders contribute almost equally to make up 42% of birds, and resident piscivores, herbivores and generalists each make up about one fifth of the numbers. Only migratory piscivores (certain terns) consistently make up a small proportion of the avifauna (3%).

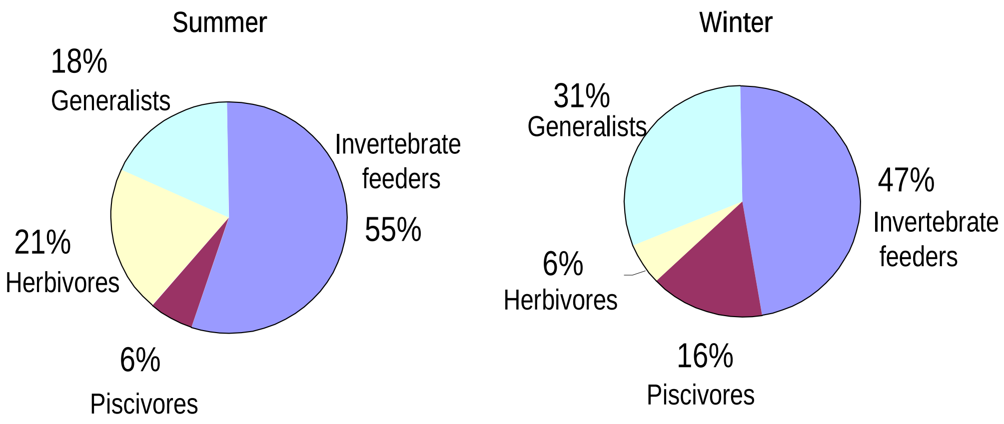

Figure 4. Trophic composition of the Breede estuary avifauna in summer and winter

The large number of invertebrate feeders is due to the relatively large intertidal area of the estuary, although the area where estuarine muds predominate is the main influence, not the extensive sandy areas near the mouth. The sandy areas do provide an important gathering site prior to the tidal exposure of the mudflats (pers. obs). Note that over a third of the resident herbivores are Egyptian Geese which do not feed within the estuary, but in surrounding agricultural fields. However, these birds are dependent on waterbodies for loafing, roosting, and breeding.

The relatively low proportion of piscivorous birds in the estuary is consistent with the finding that the estuary is currently characterised by a high diversity but low biomass of fish (Lamberth 2001). The piscivorous species tend to feed on estuarine fish species. Cormorants and egrets in lower estuary feed on gobies; Grey Herons probably eat gobies, mullets and Cape stumpnose; Reed cormorants probably feed on *Gilchristella*, gobies, freshwater mullet and Cape stumpnose, Kingfishers probably rely mostly on *Gilchristella*, and Fish eagles on mullets and grunter (based on discussion with S. Lamberth). Although individuals of most species were observed feeding in the estuary, many of the gulls and terns counted in the estuary may not feed there, and the mouth area appears to be important mainly as a roosting area for these species. The sandbanks at the mouth form a particularly attractive roost site, as much of the area is surrounded by channels during part of the low tide period, thus forming safe islands for roosting.

Distribution of birds along the estuary

As for the plant and invertebrate communities of the estuary (Adams & Bornman 2001, Wooldridge 2001), the avifaunal community differs markedly in composition between the lower and upper reaches of the estuary, the natural split occurring in the region of the powerline. The lower estuary is characterised by large areas of intertidal sand- and mudflats fringed with rocky (shale) banks or saltmarsh, whereas intertidal banks in the upper estuary are small and bordered by rocky banks or reeds. The upper estuary is fringed for the most part with reedbeds, predominantly *Phragmites australis*, and becomes increasingly river-like upstream of the powerline.

In summer, 95% of the birds counted were in the lower estuary, with only 87 birds being counted in the upper estuary (Table 1). The avifaunal community of the lower estuary in summer is thus very similar to that described above for the estuary as a whole. The upper estuary is dominated by resident herbivores (53% - mainly Egyptian Goose and Yellowbilled Duck), with most of the remainder being made up of resident piscivores (23% - cormorants, darters, egrets and kingfishers). Small numbers of migrant and resident waders (invertebrate feeders) also use the mudflats in the upper estuary.

Birds are slightly more evenly distributed in winter, when 68% of birds were counted in the lower estuary, and the number of birds in the upper estuary more than doubled to 181. In winter, the lower estuary is dominated by Kelp Gulls, migratory waders (overwintering juveniles, predominantly Grey Plovers and Whimbrels) and resident waders (mainly Blacksmith Plovers and Whitefronted Plovers). The winter composition of birds in the upper estuary is very similar to that in summer (herbivores and piscivores), except for a complete absence of migratory species.

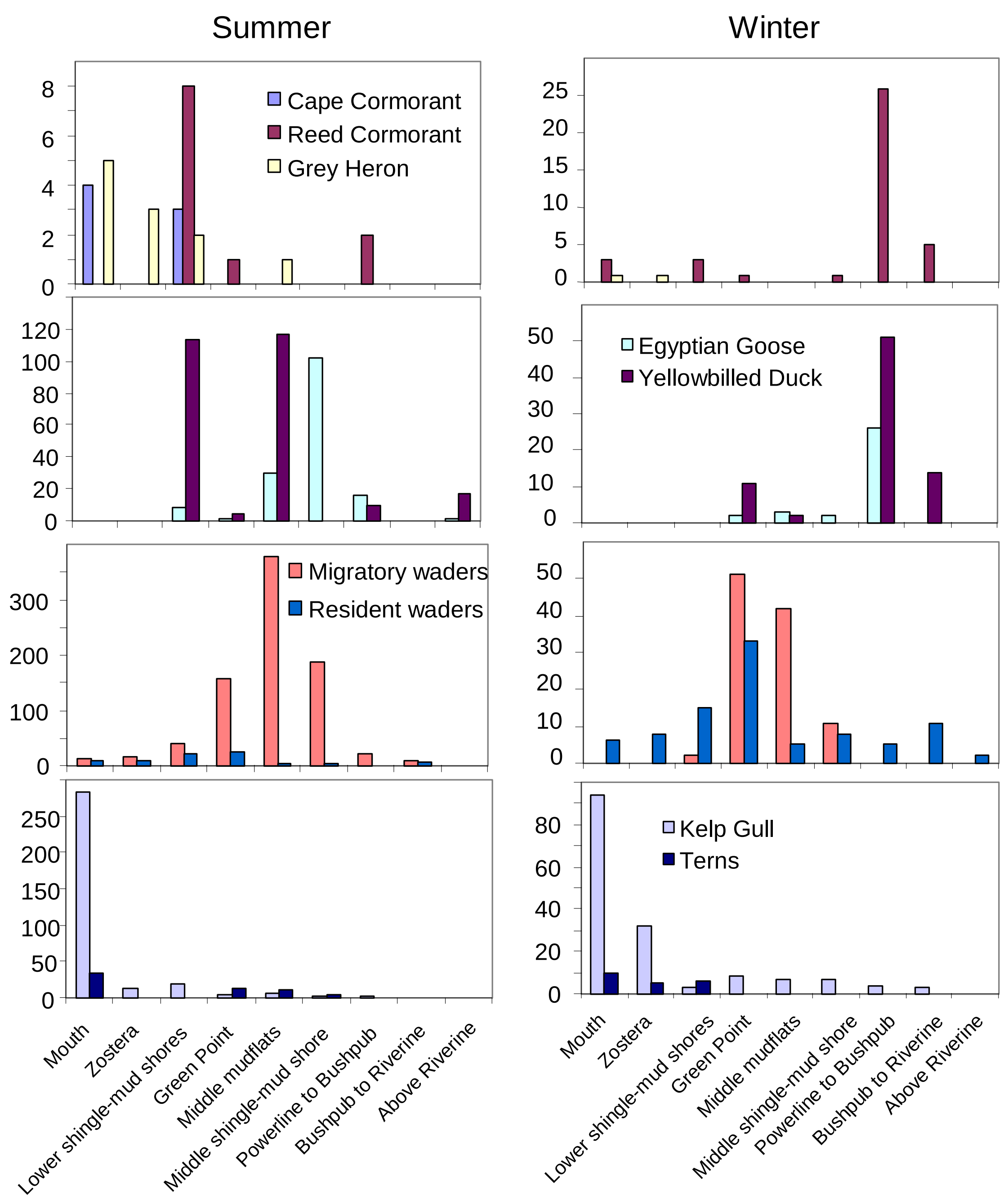

Figure 5. Distribution of selected species and groups of species along the estuary from 0-29 km.

The distribution of certain species and groups along the estuary is shown in more detail in Fig. 5.

- Cape Cormorants and Grey Herons have a strong marine-oriented distribution, whereas Reed Cormorants move between the upper and lower parts of the estuary, in particular immigrating to the upper estuary during winter.
- Egyptian Goose and Yellowbilled Duck are most common in the undisturbed parts of the upper estuary during the winter. During summer, numbers in the upper estuary remain similar, and additional birds move into the lower estuary, where they occupy the marsh and mudflat areas.
- Migratory waders concentrate almost entirely in the estuarine mud part of the estuary, restricting their distribution even further to Green Point and the middle mudflats in winter. Remaining migrant waders tend to occupy the most preferred mudflats during winter when competition for space is minimal. The distribution of resident waders stays much the same throughout the year.
- Kelp Gulls venture up the estuary in small, decreasing numbers in both summer and winter. In addition, large aggregations, probably of marine-feeding individuals, gather in the mouth area in summer. Terns tend to concentrate in the lower estuary (only marine tern species were recorded).

The distribution of waders was studied in more detail within the lower estuary, where multiple counts were carried out in March and September (Pemberton 2000).

Factors influencing the numbers and composition of waders (intertidal invertebrate foragers)

a. Variability in wader numbers due to tidal amplitude and mudflat area

The count data highlight the variability in numbers of birds counted on the estuary during different phases of the tides. Numbers in summer were significantly negatively correlated with the water level at low tide (Fig. 6). This is not expected to be a linear relationship, as the area exposed (mudflat area or mudflat area-hours) will not change linearly with change in low tide height. In other words, highest numbers of birds are present on the estuary during spring tides when the greatest area of mudflats is exposed, and lowest numbers are recorded on neap tides. At the Breede estuary, the mudflat area exposed at neap tides is very small (quantitative data are not available). Of interest is the fact that this trend applies to migratory waders and not resident species, and thus may be an artefact of birds departing on migration, since spring to neap counts were done on progressively later days in March. However, since most departures are usually in early April, and since the birds usually depart *en masse* in large flocks, this is not consistent with the observed trend.

We do not properly understand the relationship of birds to estuarine feeding areas in terms of the carrying capacity of these areas. But when feeding areas are reduced, the increase in interference competition usually forces some birds to leave the area in search of alternative foraging areas. Indeed the trend was strong among visual foragers, but weak or non-existent among purely tactile foragers (Knot and Bartailed Godwit). There is no doubt that a reduction in tidal amplitude, or more accurately, a reduction in exposed mudflat area, at the Breede would affect bird numbers negatively during summer when bird numbers are high.

In contrast, bird numbers show no relation to tidal height in spring. There is substantially less variation in numbers (coefficient of variation) in spring for Grey Plover and Whimbrel than in summer, suggesting that numbers in spring were more constant. This further supports the notion that the variability that occurs in summer is driven by competition for foraging space whereas birds are not forced to move off when mudflat areas are reduced at times when bird numbers are low: both Whimbrels and Grey Plovers are visual foragers that require a large foraging area, frequently defended as a static territory.

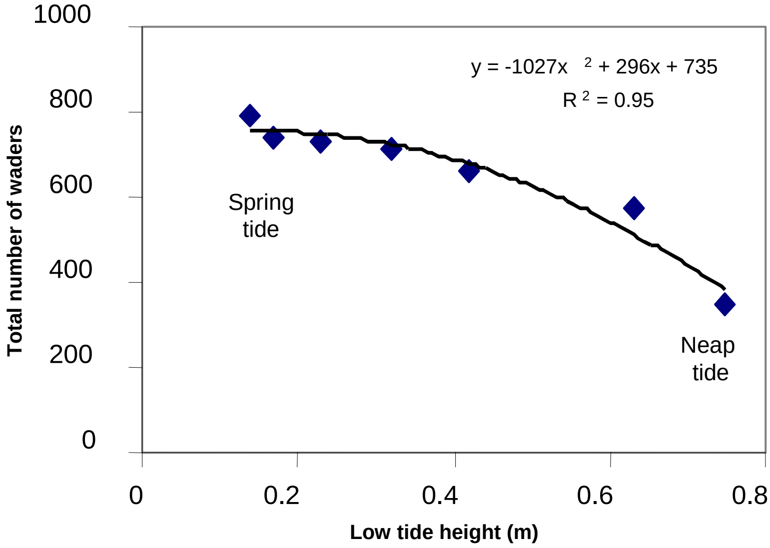

Figure 6. Relationship between wader numbers and water height at low tide at the Breede estuary in March 2000

b. Influence of overall prey biomass on overall wader numbers

There is a significant positive relationship between biomass of waders and biomass of invertebrate prey on the lower estuary in spring (Fig. 7), when numbers of waders are at intermediate levels. Thus in the absence of excessive competition, waders probably follow an 'ideal free distribution', in which they distribute themselves in such a way that individuals achieve similar rates of energy intake at all sites. This relationship was not as apparent in summer (Fig. 7), when territorial behaviour of visual foragers probably complicates the relationship between birds and prey. Nevertheless it is reasonable to assume that an overall increase in invertebrate biomass will have a positive impact on wader numbers, and vice versa.

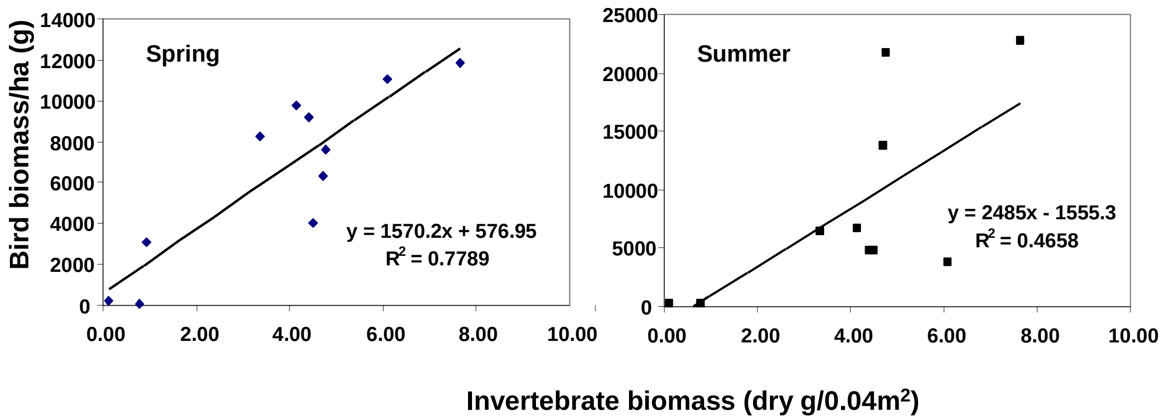

Figure 7. Relationships between wader biomass/ha and invertebrate biomass on different mudflats of the lower Breede Estuary in spring and summer 2000. The summer plot excludes the *Zostera* site, which had a high bird biomass but low prey biomass.

c. Influence of sediments and invertebrate community structure on wader community structure

An analysis of invertebrate fauna from 11 sites in the lower estuary reveals three main groupings (Fig. 8): those associated with the sandy mouth area (dominated by *Caliannassa* and bivalves), those in and around the Zostera beds at the boundary between the extreme sandy area and the estuarine mud zone (sites 1 and 2, dominated by bivalves and crabs), and those associated with the estuarine mud zone (sites 4-11, dominated by *Upogebia* and polychaete worms). Within the latter group, site 11 is slightly distinct, being the most dominated by *Upogebia*, and having a higher proportion of larvae in the samples. These three groupings are consistent with Wooldridge's (2001) findings using a smaller sieve mesh size.

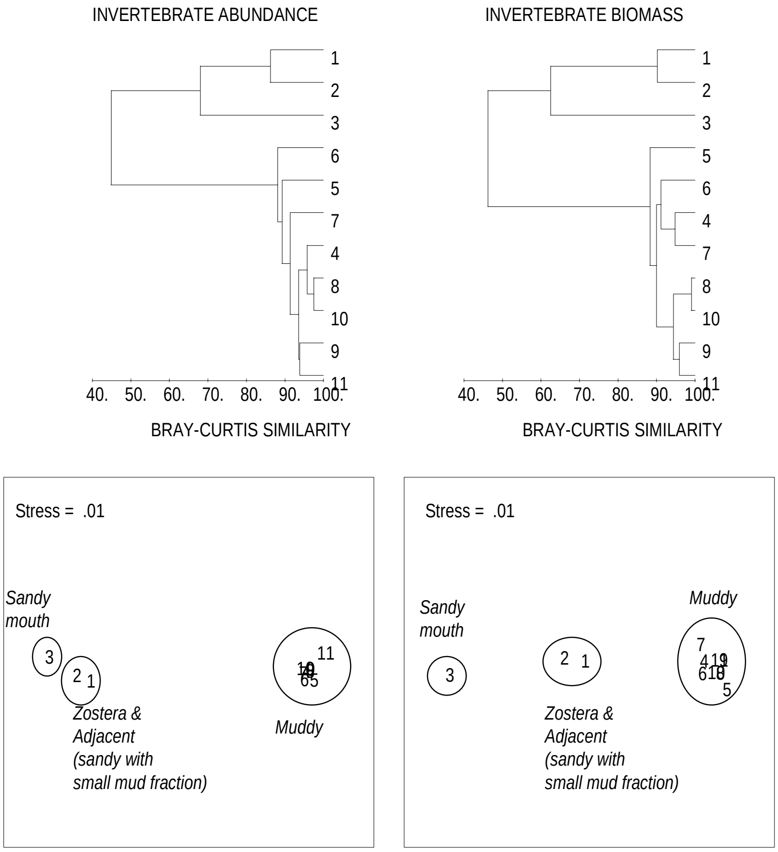

Figure 8. Dendrograms and multi-dimensional scaling plots for invertebrate abundance and biomass at 11 sites.

An analysis of wader count data from the same 11 sites reveal related groupings, but a finer differentiation of community structure (Fig. 9). The sandy mouth (site 3), Zostera (site 1), and next to Zostera (slightly muddier site 2) are markedly different from the rest, but also from one another. In spring, they contained less than 5 birds each. Sites 2 and 3 contained Whitefronted Plover, which tends to occur on sandy substrates, Grey Plover and Whimbrel, which are attracted by large prey such as crabs and *Calianassa*, and the *Zostera* site 3 was dominated by Ringed Plover, which eats smaller invertebrates. The differences in community structure at these low numbers may not be reliable or biologically meaningful. The muddy sites 4-11 were split into two groupings in spring and three in summer (Fig. 9). In spring, sites 4-9 were characterised by a relatively even diversity of birds, but with Curlew Sandpipers usually being most numerous. Within this grouping, there was a slightly greater predominance of Grey Plovers and Whimbrels at sites 7 and 8. Sites 10 and 11 were almost entirely dominated by Curlew Sandpipers. The latter sites are the mudflats closest to the powerline and have finer sediments which may be preferred by tactile foragers. In summer, Curlew sandpipers dominated all sites except sites 6 and 7, which were dominated by Grey Plovers and other large waders, and site 11, which was strongly dominated by Ringed Plovers. Ringed Plovers probably forced Curlew Sandpipers off site 11 in summer.

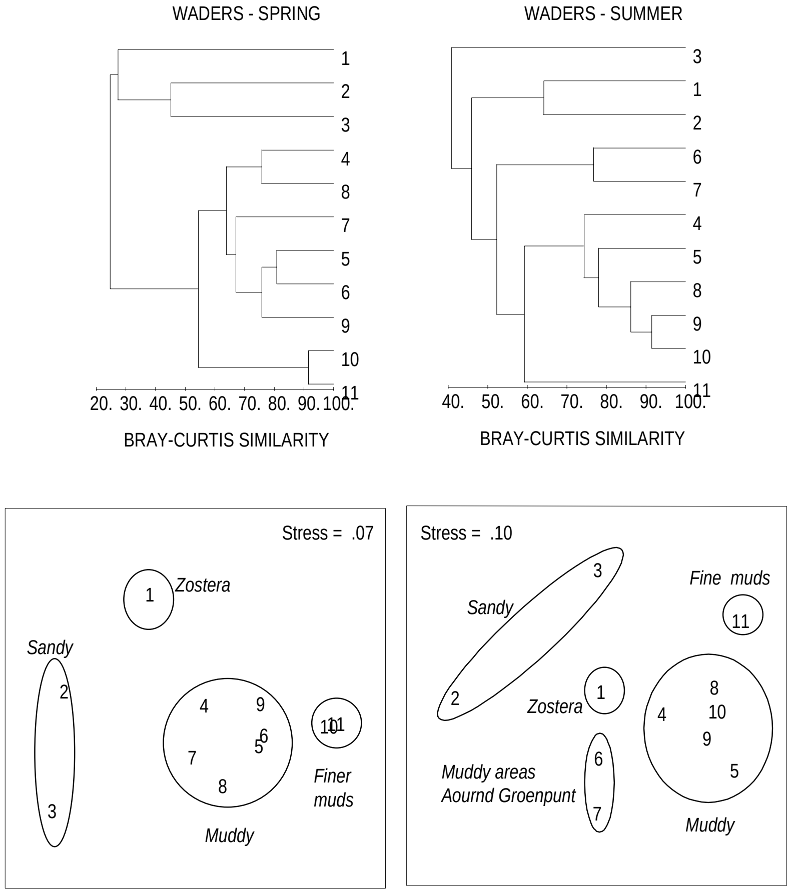

Figure 9. Dendrograms and MDS plots for waders at 11 sites in spring and summer.

Site 7 (Groenpunt) had the highest biomass of both Upogebia and polychaetes. Its avifauna was consistently dominated by large wader species such as Grey Plover, Whimbrel and Bartailed Godwit: large waders require larger prey and can displace many of the smaller birds which might also have been attracted to the high biomass of polychaetes. Site 11 had the highest biomass of prawns and polychaetes of the mudflats upstream of Groenpunt. However, this site was consistently populated by small waders going after small prey.

Thus, while both invertebrate and wader communities are broadly distinguished depending on sediment type, the avifaunal community is probably defined by a mixture of prey availability in different size ranges, sediment penetrability and competitor distribution. Thus, for example, it clearly cannot be predicted with certainty that a mudflat dominated *Upogebia* is going to be dominated by large wader species, as demonstrated by the different wader community on site 11. Further research is needed to understand the interaction of these variables on wader communities.

5. REFERENCE CONDITION AND PRESENT STATUS

The estuary's avifauna has not been well-studied in the past, with the earliest published counts having been carried out in the mid-1970s (Summers *et al.* 1977) and 1980 (Underhill & Cooper 1984). There will probably have been some change in the prevalence of type 1 conditions over this period, but the estuary will not have resembled the reference condition. For example, the *Zostera* beds were already greatly reduced by 1981.

A comparison of the Underhill & Cooper (1984) counts with present-day counts suggests that there have been some small changes in the avifaunal assemblage (Table 4). The total numbers recorded in March 2000 (1900) were almost identical to those in 1980, but the maximum count on any one day in March was 1762, possibly significantly less than the 1915 birds counted in a single count in midsummer 20 years ago. This difference may be seasonal, however.

The original counts also show an overwhelming predominance of migrant waders vs resident species, as is still the case today. Notable differences are highlighted in Table 4. The present count reflects the fact that there has been an influx of ibises an spoonbills into the Western Cape in the last 20 years. These species were rare in the area at the time of the previous count. Numerous Shelduck were recorded on the estuary 20 years ago. This is an important species in the western Cape. However, it is still numerous in the vicinity of the estuary (pers obs), and its absence during the present study may have been due to the temporary availability of suitable waterbodies elsewhere at the time. Although the numbers are small, it is interesting that summer counts in 1980 included Redbilled Teal and Cape Shoveller – species associated with freshwater, whereas the present counts included Cape Teal instead, which is more tolerant of brackwater conditions.

Table 4. A comparison of count data from summer 1980 (Underhill & Cooper 1984) and summer 2000 (this study), with noteworthy differences highlighted in bold.

Species	1980	2000	Species	1980	2000
Whitebreasted Cormorant		4	**Threebanded Plover**	**14**	
Cape Cormorant		7	Ringed Plover	118	303
Reed Cormorant	13	11	Greater Sand Plover	4	2
Darter	2	7	**Grey Plover**	**71**	**186**
Grey Heron	4	8	Blacksmith Plover	38	6
Purple Heron		1	Common Sandpiper	3	1
Little Egret	10	15	Marsh Sandpiper	3	
Sacred Ibis		**4**	Greenshank	21	21
Hadedah Ibis		**1**	**Knot**	**1**	**21**
African Spoonbill		**8**	Curlew Sandpiper	444	181
Redknobbed Coot	291	1	Sanderling		1
Egyptian Goose	5	158	Terek Sandpiper	10	16
Shelduck	**150**		Bartailed Godwit	4	7
Yellowbilled Duck	181	262	Whimbrel	54	84
Cape Teal		**1**	Blackwinged Stilt		3
Redbilled Teal	**4**		Kelp Gull	148	333
Cape Shoveller	**1**		Caspian Tern	1	
African Black Duck		1	Swift Tern		8
African Fish Eagle	1	1	Common Term	282	55
African Black Oystercatcher	**11**	**1**	Whiskered Tern	4	
Kittlitz Plover		2	Pied Kingfisher		8
Whitefronted Plover	22	29	Cape Wagtail		4
			Total	**1915**	**1762**
			Species	**30**	**38**

The population of African Black Oystercatcher, a Red Data species, appears to have been much higher 20 years ago. The difference, if real, is probably due to human disturbance, but possibly also indirectly through depletion of prey supplies such as *Solen*. The reason for the apparent loss of Threebanded Plovers, a resident wader species, is not clear. Finally, Grey Plovers and Knots appear to have increased substantially in number. The latter is likely to have been due to an overall increase in numbers visiting South Africa. The reference condition is probably not too dissimilar from the 1980 condition in terms of composition of avifauna, but numbers of invertebrate feeding waders is likely to have been slightly lower given the large loss in *Zostera* area which usually forms rich feeding grounds.

However, the above counts were carried out when the estuary was already altered from the reference condition. The Breede estuary used to be more river-dominated than at present, with state 1 (strongly freshwater dominated) persisting for more than half the year, and state 3 (balanced) occurring from January to March (Taljaard *et al.* 2001). Based on photographs and maps dating back to 1865, it is thought that there has been an increase in deposition of marine sediments in the estuary (Carter 1983). The flood tidal delta is probably larger now than in the reference condition, possibly due to a decrease in scouring by floods. The estuarine mud zone is estimated to have been smaller in the reference condition. In addition, the area of *Zostera* beds in the estuary has decreased considerably (Adams & Bornman 2001), having been reduced to about a third of its area within the flood tidal delta area from 1942 – 1981 (aerial photographs in Carter 1983). In addition, it appears that *Zostera* beds have been lost from further up the estuary. Day (1981) indicates that *Zostera* beds were well grown from Port Beaufort to above Karool's Kraal, whereas *Zostera* is very sparse in this part of the estuary now. It is difficult to predict exactly what has happened to the extent of *Zostera* in the estuary due to the natural changes that occur, but I assume there has been an overall decrease. Reeds and rushes became denser from Karool's Kraal to Malgas.

Under these conditions, it is thought that macroinvertebrates such as *Upogebia* and *Callianassa* might have been restricted to lower reaches than at present, if suitable habitat was present, and that their densities and productivity would have been lower due to the lower salinity (Wooldridge 2001). These assessments agree with anecdotal reports of long term residents in the area, who claim that the *Zostera* beds have shrunk markedly in the last 40 years, the sandflats have expanded and the secondary channels near the mouth are filling in, and the *Calliannassa*, *Solen* and *Arenicola* supplies have declined. The latter declines have probably been largely due to overfishing. Lamberth (2001) estimates that more fish (both large and small) would probably have been found in the estuary in the reference condition.

Thus, based on the assumption of a rather slight change in the estuarine avifauna from reference condition to the present, the present health score in terms of birds is estimated to be 85% (Table 5).

Table 5. Calculation of the biotic health score for birds. Note the calculation of the score is altered from Taljaard *et al.* 1999 based on changes made during the Nahoon RDM process in 2000.

Variable	Measurement	Score	Weight
1. Species richness	Estimated % of original species remaining *Scoring guideline: 100% = 100, 90% = 80; 80% = 65; 70% = 50, 60% = 35; 50% = 25; 40% = 17; 30% = 10; 20% = 5; 10% = 0*	90	25
2. Abundance	Estimated % of total biomass remaining	90	
3. Community composition	Estimated % resemblance to original composition. *Scoring guideline: No change = 100%* *Original community totally displaced by opportunistic spp = 0%*	85	
Bird community health score = minimum of the three scores		85%	

6. EFFECT OF FUTURE DEVELOPMENT SCENARIOS

Four future development scenarios were evaluated together with all the other specialists in a workshop setting. The following is a summary of the biotic changes expected, interpreted from specialists reports and workshop discussion, and concentrating on those changes of particular relevance to birds (affecting habitats and food supplies). The largest difference in the abiotic characteristics of the estuary is between the natural and present state. The differences between the remaining four scenarios and the present condition are not as large. The three last scenarios are not a continuum in terms of impacts on biota, as they differ in terms of the placement, size and flow releases of impoundments. For example, whereas the "moderate" scenario includes extreme low flows in the dry season, the last two scenarios have flow releases to prevent this situation.

Limited Development scenario

Abiotic: 46% reduction of natural MAR - 10% reduction from present; 26% reduction in flooding – compared to 22% reduction at present; State 1 exists for July to October (half the time as the reference condition), summer months are characterised by states 3 and 4 (balanced to marine dominated).

Microphytes: low/medium productivity due to low water retention period, most primary production exported from estuary to marine zone (nevertheless, productivity is higher than in present and reference state).

Macrophytes: little influence on macrophytes, some upstream retreat (dieback) of *Phragmites*. Slightly less *Potamogeton* in upper estuary.

Invertebrates: Intertidal invertebrates will be little affected, perhaps slightly more zooplankton.

Fish: Overall 8% increase in abundance of fish compared to reference condition (present day is 6% greater)

Birds: Effect on birds is expected to be minor. No impact on waders; probably no significant loss of reedbed species such as rails and passerines.

Moderate development scenario

Abiotic: 52% reduction in natural MAR – 20% decr from present; 29% reduction in flooding; Very similar to previous, except that state 4 (marine dominated) persists for a bit longer than state 3. The states are most intense in this scenario – for short periods. No expected change in mud: sand or intertidal area. REI is smallest.

Microphytes: medium productivity, most primary production exported from estuary to marine zone.

Macrophytes: significant upstream retreat (dieback) of *Phragmites;* loss of *Zostera* at mouth, increase in *Zostera* in middle reaches on estuarine muds (E bank); loss of *Potamageton* in upper estuary.

Invertebrates: Increase in zooplankton. Intertidal invertebrates: expect more *Upogebia* in the middle reaches on the W mudbanks towards powerline, would expect more crabs and fewer *Upogebia* in areas colonised by *Zostera*; overall increase in availability of large invertebrates relative to small ones.

Fish: A change in community composition towards marine, and a 9-15% increase in the abundance of fishes, predominantly small-bodied species.

Birds: Species richness: no major change. Community composition: expect a decrease in numbers of herbivorous and reedbed species. A few more invertebrate-eating waterfowl in upper estuary (small numbers). An increase in piscivorous birds, particularly marine. In waders, possibly a slight shift in proportion of larger relative to smaller species, and overall slight increase in abundance due to increased productivity of the estuary. Overall abundance: possibly a slight increase.

Bromberg Dam development scenario

Abiotic: 57% reduction in natural MAR; 33% reduction in flooding; State 1 reduced to three months (Aug - Oct), while state 4 dominates from January to April. No expected change in mud:sand or intertidal area. REI is slightly bigger than Moderate scenario but smaller than present.

Microphytes: relatively high productivity, exports to marine zone greatly reduced.

Macrophytes: Increase in water hyacinth, reeds flourish wherever fw available but overall decrease in biomass but not as much loss as in moderate scenario (and less deritutus produced); some loss of Potamogeton; *Zostera* increases in the middle reaches.

Invertebrates: Similar as for moderate scenario, Only real diff between this scenario and present, is duration of high salinity scenario is a bit longer. Little impact on intertidal invertebrates because macrophytes aren't changing much. Intertidal inverts depend on epiphytic algae and detritus.

Fish: Loss of estuarine species, increase in marine species such as harders, overall 12% increase in abundance.

Birds: Effect on birds is expected to be noticeable. No major changes in waders; increase in marine cormorants, terns and gulls; decrease in estuarine-freshwater wading bird species (e.g. herons, egrets); possibly a small reduction in herbivorous species (Yellowbilled Duck), further loss of reedbed species such as rails and passerines.

Le Chasseur Dam development scenario

Abiotic: 64% reduction in natural MAR ; 35% reduction in flooding; State 1 reduced to two months (Aug - Sep), and state 4 further dominates from January to May. It's a big dam, so may have a significant effect on sedimentation (captures much of the sediment). Dam doesn't affect suspended solids which flocculate out to form estuarine muds. Significant floods are still coming through, though a bit smaller, and early winter floods disappear. Overall increase in sandiness in lower estuary. May or may not have sedimentation in upper reaches.

Microphytes: relatively high productivity, exports to marine zone greatly reduced.

Microphytes: Community composition and abundance change. Ab is quite low under nat conds and gets progressively higher as the estuary stays longer in the marine state. Comm composition remains fairly constant. Shifts slithgly towards marine, 10% max overall, but productivity goes quite high.

Macrophytes: Increase in water hyacinth, reeds flourish wherever fw available but overall decrease in biomass, *Zostera* unchanged

Invertebrates: No change in species richness but there is a major change in community composition relative to the reference condition. Now have more plankton, much fewer *Palaemon*, and slight increase in intertidal inverts due to increase in salinity. Community changes by 45% from original. Incr in biomass of plankton and int invertebrates but this is balanced in terms of biomass of all invertebrates by the decrease in Palaemon, with an overall slight decrease (10%).

Fish: Lose the winter and spring peaks in numbers. Significant loss of species richness, and huge change in community composition (55 of natural). Abundance increases by about 15%. Now dominated by marine species.

Birds: Species richness: no major change. Community composition: expect a decrease in numbers of herbivores (and passerines) due to loss of *Potamageton* and reedbed habitat. A few more invertebrate-eating waterfowl, but small numbers. In waders, expect more larger species, perhaps a loss of smaller species, with a small increase in overall abundance, but no huge changes, as waders very adaptable and site-faithful. An increase in the numbers of piscivorous bird species (which seem to respond more readily to food increases), with a change in composition favouring marine species. Overall community structure about 80% similar to natural. Overall abundance: increases a little – perhaps 15% (85% similar to natural).

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APPENDIX I

Comments report on "Intermediate Determination of Resource Directed Measures for the Breede River Estuary"

by
Colin Carter

(including reply from specialists)

Before making comments that may create a wrong impression, I want to say that this document is a highly impressive and valuable piece of work. It is clear that protection of the estuary must be a major consideration in any proposal for further development of the water resources of the Breede River, and even for the operation of existing facilities.

1. The report notes that its scope is limited to the aquatic ecosystem. Presumably other needs and impacts such as human health, economic and recreational needs as well as the impact of expanding settlements along the estuary and adjacent coastline will be considered elsewhere, since these could also affect water requirements and protective measures.

Reply from Specialists:

We agree, however, our brief was to determine Resource Directed Measures for the estuarine aquatic ecosystem only.

2. The estuary system is highly complex, affected by the varying flows of the tidal cycle, the erratic daily inflows of river water, the buffering effect of the pool of fresh water at the upstream end, effect of wind on water movement etc.

Reply from Specialists:

Agree.

3. The crucial factors are salinity and the variation in salinity. It seems unlikely that a one-dimensional model, with little data available for calibration, could predict salinity conditions accurately in these complex conditions. My subjective [and lay] impression is that upstream salinity at low river flows may be overestimated. This could be significant for the aquatic system [and also for the social impact].

Reply from Specialists:

The character of the Breede River Estuary is that it is reasonably well mixed vertically and this makes the system suitable for the application of a one-dimensional numerical model.

We agree that there might be an over-estimation (possible underestimation) of the upstream salinity penetration at low river inflows. This uncertainty is as a result of not having calibration data during low flow periods in the estuary. This uncertainty can only be addressed through monitoring of the system during the low flow period. However, as stated in the report, we are fairly confident of the predictions.

4. The increased extent of the River-Estuary-Interface zone arising from the reduction in river flow, seems to increase the productivity of the microalgae, the bottom of the food chain, and hence upward through the chain, accompanied by reduced productivity in the adjacent sea. One wonders whether there is an overall net benefit, taking into account the sheltered nature of the estuary. [Is it sacrilege to suggest that nature could be improved upon?]

Reply from Specialists:

From the Reference Condition to Present State there was actually a net decrease in the REI zone rather than an increase. In our opinion, the increase in the micro algae productivity was mainly attributed to longer retention times of water under the Present State compared to the Reference Condition.

Referring to your comment 'could nature be improved upon'…

It is important, in RDM determinations, to relate change in abiotic and biotic components in an estuary to its reference condition, which represents its 'natural optimum'.

In this instance, although the alteration in flow is seen to 'improve' primary productivity by modifying habitat to benefit micro algae, this could be to the disadvantage of other biotic components of the food chain (e.g. fish and invertebrates) as they 'loose' habitat. A second concern is that we do not actually fully comprehend the ripple effect of this 'improvement' in primary productivity on the higher levels of the food web.

5. Because the eastern part of the Breede River catchment receives an appreciable part of its rainfall in summer, low flows are often interrupted by days of much higher flows. In those years when this is not the case and salinity rises in the upstream reach, it may be possible to overcome this by releasing flushes from upstream dams [as is already done to reduce the salinity of river water used for irrigation]. This would probably ameliorate critical conditions in the estuary. On this basis it may be possible to abstract an increased quantity of river water, compared with the "limited development" scenario [which was found to be acceptable], without endangering the estuary.

Reply from Specialists:

Due to the complex interactions between river inflow and hydrodynamic processes in estuaries, our protocol follows a scenario-based approach. Of the scenarios provided to the estuarine team, the 'Limited Development Scenario' met the criteria for the preliminary or recommended Reserve for Water Quantity. However, this does not exclude the possibility of refinement, to a scenario somewhere between the 'Limited' and 'Moderate', e.g. inclusion of flow releases to alleviate high salinities during the low flow period. This scenario could typically be included for assessment as part of the Comprehensive determination of RDM for the Breede River Estuary.

6. It is clearly necessary to devise measures for the protection of the environment and ecology of the estuary. However, the report also recommends a Reserve for Water Quantity for the Breede River Estuary. This appears to be premature, considering the limited knowledge available and given the fact that such determinations tend to be rigidly applied. In this case the monthly quantities recommended are simply the quantities entering the estuary after implementation of the "limited development" scenario. This scenario was judged to represent the largest development that would not result in unacceptable conditions in the estuary, based on the possibly unreliable predictions of the salinity model. Different and more attractive scenarios, providing different flows into the estuary, could conceivably also avoid creating unacceptable conditions. The desirable approach seems to be co-operation among all parties to produce the most favourable development, rather than laying down the Reserve in advance.

Reply from Specialists:

Our brief initially was to estimate the freshwater requirements of the Breede River Estuary, but was then modified into an Intermediate Determination of RDM. However, the available information was limited, which affects the confidence in the results of this investigation.

Agreed – refer to our reply to Comment 5. 'The desirable approach seems to be co-operation among all parties to produce the most favourable development…' *This should be the underlying philosophy in the determination of RDM.*

7. In regard to floods, it was assumed that development would not affect the magnitudes of larger floods, with the implication that this should be a requirement. The purpose of this is apparently to maintain scouring action. The report does not however provide any information regarding present conditions of sedimentation and scour, or regarding flows needed to create scouring velocities.

Reply from Specialists:

It has been assumed that Reserves set as part of an Intermediate RDM will NOT be used to issue water abstraction licenses that will affect the magnitudes of larger floods (e.g. 1:5 year and above). The Intermediate RDM methodology for estuaries, therefore, does not require extensive evaluation of changes in, for example, the magnitude and occurrence of floods.

Although this study provides a preliminary assessment of potential changes in floods from one scenario to another, these were based on very limited data sets and are, by no means, sufficient to quantify specific specifications in terms of, for example the magnitude and occurrence of floods. Specific specifications in terms of the occurrence and magnitude of different flood regimes, therefore, can only be provided once more detailed analysis of floods under the Reference Condition, Present State and Future Development Scenario have been conducted.

8. The recommendations under Resource Monitoring Programme appear to be directed mainly towards improved understanding of the functioning of the Breede Estuary and of estuaries in general. While this research is no doubt highly desirable, much of it will not directly affect the planning of development of Breede River water resources. The one factor that is evidently of crucial importance is the variation in salinity. I suggest that this be measured continuously at two points, possibly Diepkloof [29km] and Malgas [42km]. This would give warning of unusual conditions. The effect of this on biota could then be investigated when necessary. Apart from changes in river flow, and consequently salinity, other abiotic factors do not seem likely to change significantly, and changes in biota not resulting from salinity changes seem likely to arise mostly from natural cycles. The average volume of water in the upper 20km of the estuary is only about 7Mm^3. A warning that salinity in this section was reaching an undesirably high level should enable arrangements to be made to release a slug of water from upstream dams sufficient to restore normal salinity. [10m^3/s for 8 days would supply 7Mm^3]. Such an inflow of water is a naturally occurring event even in the dry season, and should not therefore result in abnormal conditions in the estuary.

Reply from Specialists:

This comment somehow contradicts earlier ones, such as comments that it is difficult to give accurate estimates on freshwater requirements of estuaries because of the limited knowledge available. An effective monitoring programme is essential for confirmation and refinement of the results of this RDM study.

The abiotic and biotic components in an estuary are strongly interdependent, i.e. physical dynamics and water quality largely drives the responses observed in biota. Historically, monitoring in estuaries was discipline-based and did not provide much understanding on cross discipline dependence. To be able to predict the <u>flow component</u>, i.e. that required for the planning of the development of the Breede River Water Resource, we need to be able to better quantify and predict the ripple effect of flow, firstly through physical dynamics and water quality and, ultimately, through to the biotic components.

We agree that variations in salinity are of crucial importance as a driver of biotic response in this system and that it can be used as a 'warning' indicator of potential shift in estuarine conditions (i.e. monitored at a higher frequency). However, as stated above our knowledge on the cross discipline dependence also need to be better defined to improve confidence for the Reserve.

We agree that water releases could be considered to mitigate undesirable high levels of salinities in the upper reaches. However, experience in the Kromme Estuary in 1998 showed that it would probably require more than the 7 mM^3 replacement volume to reduce salinities substantially, due to the more complex hydrodynamic responses of estuaries, compared with rivers and loss of water on route.